An Engineering Study for:

Newfoundland & Labrador Hydro
Holyrood Generating Station

For:

PHASE I - Investigation of Methods to Improve Emissions on Units 1, 2 and 3

October 21, 2002 ***Study Number 40233000***

ALSTOM

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MHI-NALCOR-110

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1. INTRODUCTION

1.1. EXECUTIVE SUMMARY

ALSTOM Canada Inc. has completed this Phase I Report of an Engineering Study for Newfoundland and Labrador Hydro to evaluate alternative low emissions technologies for the three (3) units at Holyrood Generating Station.

In preparing this report ALSTOM considered a wide range of technologies, involving both the boilers, and potential backend equipment which were relevant to Newfoundland & Labrador Hydro's Holyrood Generating Station. These various technologies also cover a wide band of cost options to consider.

ALSTOM has experience with, and confidence in all of the technologies discussed in the body of this report. The report it separated into three (3) technical sections, specifically 1) fuel changes, 2) firing system technologies for the boiler, and 3) capture technologies through back end equipment. Each technology is discussed technically, followed by presentation of the predicted performance of the system, and then finally a scope description of the recommended equipment arrangement selected to achieve this performance.

Specifically, impacts on emissions for reduced sulfur and asphaltine oils have been included. Firing Systems modifications to reduce NOx emissions including, burner tuning, low NOx burners, low NOx burners with Overfire Air, and urea-based Selective Non-Catalytic Reduction (SNCR) have been evaluated. Particulate capture technologies including Mechanical Collectors, Electrostatic Precipitators (ESP's), as well as Dry & Wet Flue Gas Desulfurization have been evaluated. The feasibility of applying each technology to the Holyrood site has been investigated, and in most cases, the physical limitations are presented.

Finally order of magnitude pricing and equipment delivery spans are presented for each of the equipment options, as well as a very general presentation on the impact these technologies would have on operating and maintenance costs at the station.

The study concentrates primarily on the impacts to NOx, SOx and Particulate, but the capture technologies also impact the removal efficiency of other emissions as shown in the following table, although these are not investigated in detail within this report.

Removal Efficiencies:	SOx	NOx	Particulate	CO	Metals	Acid Aerosols
Mechanical Collector	None	None	50%	None	Some	None
ESP	None	None	92.30%	None	Some	None
DFGD	95%	None	0.1 lbs/mmbtu (max)	None	Some	Good
WFGD	98%	None	30 - 50% (max)	None	Some	Poor

In recent years ALSTOM and Newfoundland & Labrador Hydro have reviewed in detail the operation of the 3 units at this site, and these reviews have confirmed that the units are operating very efficiently. Over the past few years improvements have been made to maintenance and outage work, equipment has been upgraded (such as the modifications to Unit 3 reheater surface in 2001), and engineering studies, completed and ongoing, continue to investigate opportunities to further improve the operation of the plant.

Some technologies have not been addressed in this report such as sea water scrubbers, or particulate screens. With respect to sea water scrubbers, it is our opinion that this is not a technology well suited to the Holyrood site due to its high price and due to permitting difficulties with the technology. To date, no one has been successful in obtaining a permit for the sea water scrubber in North America. With respect to particulate screens, which had been discussed in the past between, although the capital costs may not be significant, the reduction in particulate, although measurable, would not likely be visible out of the stacks. It is very difficult to predict the reduction efficiency of this type of solution, and it could be investigated further if a low cost, invisible but measurable particulate reduction is still attractive.

Some solutions such as converting the units to natural gas, or orimulsion fuels, or larger stacks for better dispersal of the emissions are not practical and so were not considered or discussed.

1.2. UNIT DESCRIPTION

1.2.1. Holyrood Units 1 and 2

Newfoundland & Labrador Hydro (N&L Hydro) Units #1 & #2 at Holyrood Generation Station are duplicate, 1970 vintage 150 MW, oil-fired boilers originally designed and built by Combustion Engineering (now ALSTOM). The boiler was designed to generate an MCR main steam flow of 1,050,000 lb/hr at an outlet temperature of 1005°F and a pressure of 1900 psig, with a feed-water inlet temperature of 468°F. The MCR design condition for the reheater was a flow of 921,000 lb/hr at an inlet temperature of 690°F and a pressure of 518 psig, with an outlet temperature of 1005°F. These two units were modified in approximately 1987 by ALSTOM to achieve an increased output of approximately 175 MW. The resulting revised steam conditions are an MCR main steam flow of 1,167,000 lb/hr at an outlet temperature of 1005°F and a pressure of 1955 psig, with a feed-water inlet temperature of 464°F, with a reheater flow of 1,045,000 lb/hr at an inlet temperature of 667°F and a pressure of 493 psig, with an outlet temperature of 1005°F.

1.2.2. Holyrood Unit 3

Unit #3 at Holyrood Generation Station is a 1980 vintage 150 MW, oil fired boiler originally designed and built by Babcock and Wilcox. Unit #3 was designed to generate an MCR main steam flow of 960,600 lb/hr at an outlet temperature of 1,005°F and a pressure of 1890 psig, with a feed-water inlet temperature of 464°F. The MCR design condition for the reheater was a flow of 865,700 lb/hr at an inlet temperature of 683°F and a pressure of 487 psig, with an outlet temperature of 1,005°F. ALSTOM has modified the reheater of unit #3 in 2001, but this modification has been done with the intent of achieving the originally intended boiler performance while providing improved reheater material protection.

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2. FUEL CHANGES

2.1. FUEL VARIATIONS AND SPECIFICATIONS

This section investigates the effect that sulphur and asphaltine content in the fuel has on the flue gas emissions from the Holyrood units. No general fuel oil sourcing (pricing) information or contacts were provided by N&L Hydro, therefore the discussion is not able to comment or recommend the effects of N&L Hydro purchasing better fuel to improve emissions. For example, evaluating the costs and effects of changing from a current fuel oil containing approximately 2.2 % Sulphur to one containing approximately 1.6 or 1.2 % Sulphur.

2.1.1. Fuel Oil Variations

The fuel specification used by Newfoundland and Labrador Hydro can have a significant impact on flue gas emissions from the Holyrood Units. The fuel sulfur level directly impacts flue gas SO_2 emissions. The oil ash level as well as oil asphaltine content directly impacts flue gas particulate emissions levels leaving the boiler. This boiler exit particulate level will then directly impact both the design and operations of any flue gas particulate removal equipment.

Shown below are actual current and predicted sulfur emissions for several differing levels of fuel oil sulfur contents.

Holyrood Sulfur Emissions									
	Oil HHV	Oil sulfur %	Asphaltines %	Average Economizer Outlet O_2	Predicted SO_2 Emissions Lb/10^6 Btu	Predicted SO_2 Emissions mg/DSm^3 @3% O_2	Predicted SO_2 Emissions ppm @ 3% O_2	Unit No. 1 Actual Average SO_2 Emissions ppm @ 3% O_2	Unit No. 2 Actual Average SO_2 Emissions ppm @ 3% O_2
Unit #1	17,824	2.184	3.7	0.7	2.4506	3,770.7	1,318.4	1,274.4	1,264.5
Alternate Oil 1	17,824	1.8	3.7		2.0197	3,107.7	1,086.6		
Alternate Oil 2	17,824	1.2	3.7		1.3465	2,071.8	724.4		

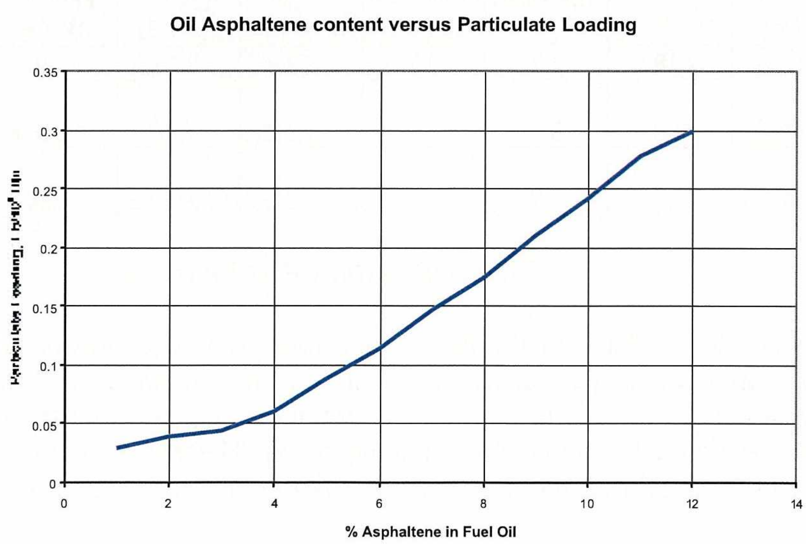
Predicted Sulfur (SO_2) Emissions

Predicted particulate vary related to the fuel composition as well as to operating conditions. Low NOx operations can increase particulate emissions due to the processes required for low NOx combustion. These effects include low excess air operation, staged combustion, control of fuel and air mixing as well as Flue Gas recirculation if so equipped. The effects of low NOx combustion on particulate emissions is reported on elsewhere in this report. This section describes the effects on particulates that changes in fuel composition and/or fuel specification can have on particulate emissions. Next is a table showing actual particulate emissions data from the Holyrood Units as well as predicted changes to particulate levels for a change in fuel asphaltine content.

		Holyrood Particulate Loading Oct. & Nov. 2001 test results						
		Baseline "As Found"						
		Asphaltines %	Average Economizer Outlet O_2	Average gr/DScf	Average gr/DScf @3% O_2	Average mg/DSm^3	Average Lb/10^6 Btu	Average mg/DSm^3 @3% O_2
Actual	Unit #1	3.7	0.7	0.0593	0.0608	135.63	0.088295	138.96
Actual	Unit #2	3.7	1.2	0.0636	0.0666	145.57	0.094766	152.44
Actual	Unit #3	3.7	0.4-0.7	0.1129	0.1172	258.38	0.168205	268.3
Predicted Baseline	Unit #1	11	0.7		0.1781	373.73	0.24	385.63
Predicted Baseline	Unit #2	11	1.2		0.1951	409.38	0.27	422.42
Predicted Baseline	Unit #3	11	0.4-0.7		0.3434	720.42	0.47	743.35

Predicted Particulate Emissions from Boiler with Varying Asphaltine Content

The figure below shows the predicted impact and/or change in particulate loading due to fuel oil Ashpaltene content.



For the purposes of sizing the Electrostatic Precipitator, an asphaltine content of approximately 8% was used since there was a concern over the relatively low actual asphaltine % measured (3.7%), compared to the contract limit in the current fuel spec (11%). As an example of the impact that asphaltine content has on equipment selection, if the sizing of the Electrostatic Precipitator selected in this report assumed an asphaltine content of 3.7% (instead of 8%), the ESP size would reduce to a size of 3*30M-152-135-A2 (compared to the size noted in section 4.2.3 of this report). This would be a reduction of 26.7% and would reduce the ESP capital cost quoted in section 5.1.1 of this report by approximately 10% (or $600,000.00 CDN per unit). Therefore in order to efficiently and cost effectively select final equipment sizes, it may be necessary to tighten up the fuel purchasing specification first to ensure equipment can handle the worst case scenario, but at the same time not result in overly conservative sizing of this equipment.

With respect to the Flue Gas Desulfurization equipment, a more indepth study would have to be conducted to determine the size variation due to ashphaltines. This investigation is outside the scope of this study phase.

3. FIRING SYSTEM TECHNOLOGIES

3.1. LOW NOx TANGENTIAL FIRING SYSTEM OPTIONS FOR UNITS 1 AND 2

3.1.1. Technical Discussion

3.1.1.1. Introduction

HOLYROOD Units No. 1 & 2 are tangentially fired unit designed with three (3) oil elevations. ALSTOM Power discusses below two (2) potential optional Low NOx configurations: an in-windbox Low NOx firing system and a Separated Overfire Air (SOFA) based LNBFS Level II system to address Newfoundland and Labrador Hydro's request for assessing potential low NOx emissions on its units. Refer to Appendix C for an experience list of Tangentially-fired Low NOx retrofits supplied on oil and gas boilers.

3.1.1.2. Low NOx Tuning of Existing System

Based on a review of existing data and tests conducted at Holyrood #1 & #2, a reduction in NOx emissions to about 0.25-0.26 Lb/10^6 Btu (385-400 mg/Nm^3), or about 12%, may be possible with tests/tuning efforts from a base current emissions level of 0.27-0.30 Lb/10^6 Btu (415-460 mg/Nm^3) NOx. The goals of these tuning efforts would be to maximize the amount of airflow to the upper portions of the existing windboxes and to minimize the amount of air near the fuel. This can be accomplished by increasing the boiler windbox pressure, to the extent possible without approaching fan limitations, while operating with the top end air compartments full open and the lower windbox compartments pinched closed. In addition, an assessment of decreasing the air near the oil fuel could be done by closing the secondary air dampers in the fuel compartments (reducing fuel air). Decreasing total unit excess oxygen levels is a typical method employed to reduce NOx emissions. At Holyrood Units #1 and #2 further reductions in unit excess oxygen and/or NOx emissions with this method would be slight if at all because the units currently operate at about 1% excess O_2.

To accomplish the above, a parametric tuning effort should be conducted with the following variables to be analyzed, to determine optimum NOx emissions with the existing equipment.

- Air bias to top (2 or 3 compartments) of windbox via opening upper compartment(s) dampers and closing lower compartment(s) dampers.
- Selectively closing Fuel Oil compartment dampers forcing additional air to upper compartments.
- Operate with the whole top tier of burners out (BOOS).
- Increase windbox-furnace pressure differential (up to FD fan limits) for the above conditions to force additional air to upper windbox.

Note that as part of a previous study (Ref ALSTOM Study No. 40133001), some boiler optimization tuning was performed on Units 1 and 2 in April of 2001. This tuning exercise did investigate, among other things, the effect of increased windbox delta-P, and burner tilt on opacity and efficiency, but it did specifically address the redistribution of air vertically in the windbox, as discussed above.

3.1.1.3. In-Windbox Low NOx Option

The main windbox modifications will be limited to resizing the nozzle tips only. The top end air tips will be converted to operate as a CCOFA elevation with a single, straight air nozzle tip. All three (3) oil compartments will be downsized with new oil and bulbous straight air nozzle tips. Each oil nozzle tip will come with a new extension cone. The auxiliary air and bottom end air compartments will also have the new bulbous style air nozzle tips. All nozzle tips will be fabricated from 309 stainless steel.

The existing oil guns, ignitors, and scanners will be reused.

Another important component of the LNBFS Low NOx Burner System is the Vaned Close-Coupled Overfire Air System (VCCOFA), which is installed in the top most air compartment of the main windbox (top end air compartment). The existing air nozzle tips are removed and a set of fixed vanes are installed into this compartment to optimize the amount and injection angle of the close-coupled air. An illustration of the new Vaned Close-Coupled Overfire Air (VCCOFA) arrangement is shown in Figure 1.

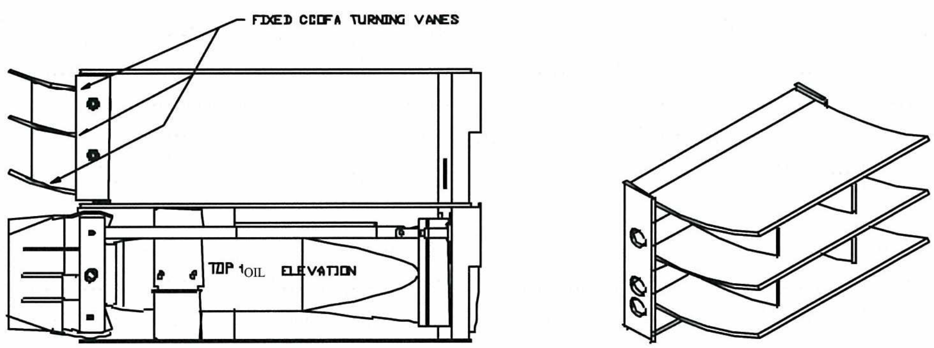


Figure 1 – Vaned Close Coupled Overfire Air (VCCOFA™)

Notes: There must be an independent damper drive installed to all of the VCCOFA compartments in order to for the P2 system to function as intended. That is, the VCCOFA compartment damper drive typically operates as a function of boiler load instead of windbox-furnace differential.

NOx reductions of about 15-20%, to approximately 0.23-0.25 Lb/10^6 Btu (355-385 mg/Nm^3) NOx, may be possible with the above In-Windbox NOx reduction option.

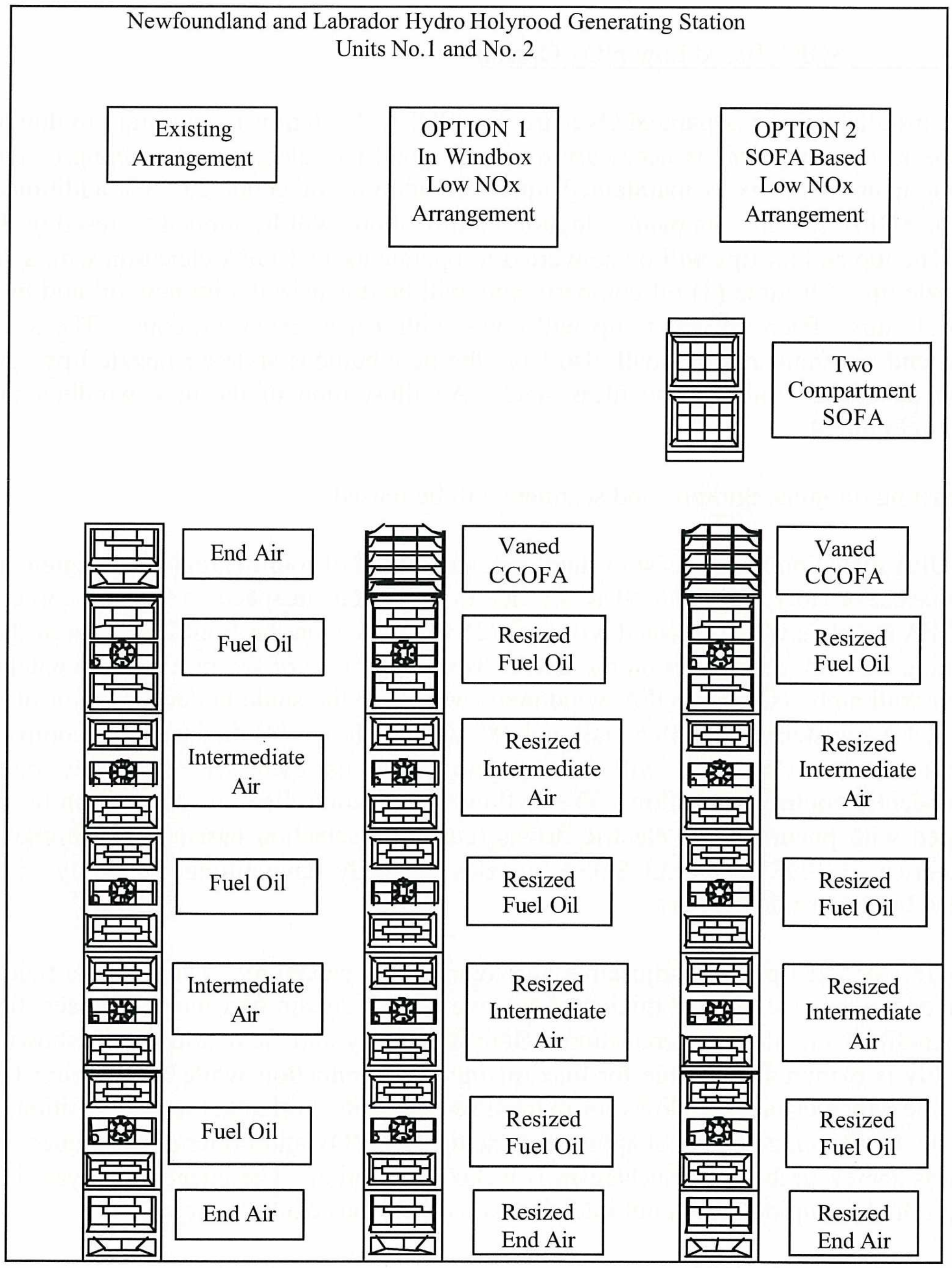


Figure 2 Schematics of Low NOx Options

3.1.1.4. SOFA Based Low NOx Option

For the installation of a Separated Overfire Air (SOFA) System it is important to downsize the main windbox nozzle tips. This is necessary to ensure good jet velocities and mixing of the fuel and air from the main windbox is maintained upon the addition of about 20-25% additional nozzle area from the SOFA system. The main windbox modifications will be limited to resizing the nozzle tips only. The top end air tips will be converted to operate as a CCOFA elevation with a single, straight air nozzle tip. All three (3) oil compartments will be downsized with new oil and bulbous straight air nozzle tips. Each oil nozzle tip will come with a new extension cone. The auxiliary air and bottom end air compartments will also have the new bulbous style air nozzle tips. All nozzle tips will be fabricated from 309 stainless steel. An illustration of the new windbox arrangement is shown in Figure 4.

The existing oil guns, ignitors, and scanners will be reused.

The SOFA elevation will consist of ductwork and a total of four (4) registers located above the main windboxes. For Holyrood Units #1 & #2, due to limitations in space on the rear corners of the units, the SOFA registers will be located with two (2) windboxes on the front 2 corners of the unit and the remaining 2 SOFA windboxes on the sidewalls near the rear of the unit approximately half way up the rear wall arch. These 4 SOFA windboxes will be at the same boiler elevation of about 65 feet. Each SOFA register will be 38.5" tall and 18" wide with two (2) distinct OFA compartments. Each compartment (or elevation) will be equipped with its own set of airflow control dampers independently controlling airflow. The airflow will be controlled on an elevation basis via dampers equipped with pneumatic or electric drives (customer selection based on preference versus cost). The fabricated 309SS material SOFA nozzles normally have tilting capability via a tilt system actuated by independent drives.

The SOFA nozzle tips have adjustable horizontal (yaw) capability. This permits field setting of the nozzle tips to achieve the best mixing of the overfire air stream and furnace gasses, thus getting the best benefit of the staged combustion. Both laboratory and field testing has shown that the yaw capability is extremely valuable for maximizing NOx reduction while minimizing CO and carbon loss. The yaw mechanism allows for manual setting of the horizontal nozzle position, while the unit is online, to customize the most appropriate setting for NOx and boiler performance. Once the best setting is achieved, the yaw mechanism is locked in position. The intent of the yaw is that it is used during initial set-up only; it is not intended as a continuous control mechanism.

NOx reductions of about 40-45% to approximately 0.15-0.19 Lb/10^6 Btu (230-292 mg/Nm^3) NOx may be possible with the above SOFA based Low NOx option.

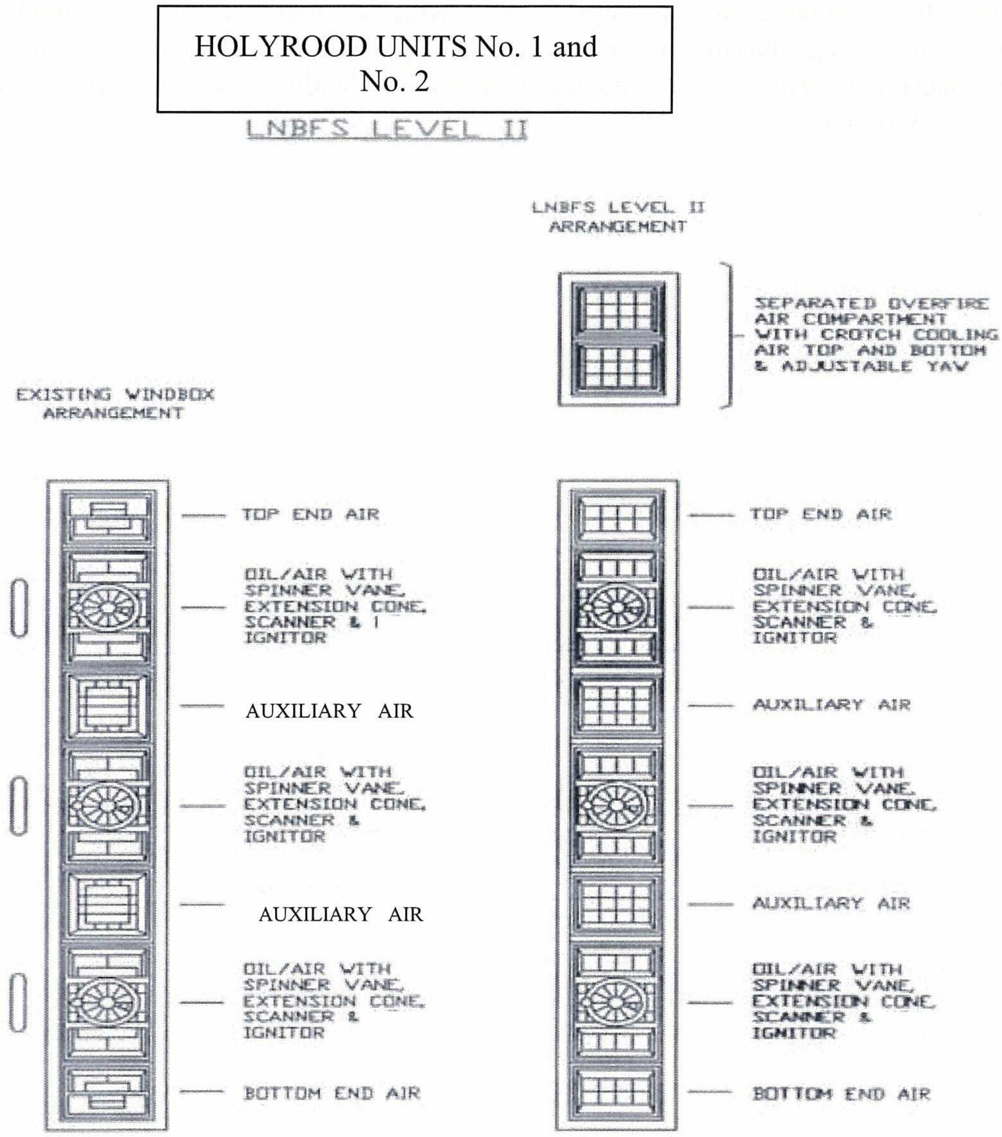


Figure 4 – Windbox Arrangement (Holyrood Units 1 and 2)

The SOFA windboxes are connected to the existing secondary air system through the new ductwork arrangement. The overfire air connecting ductwork will be constructed of 3/16" A-36 carbon steel, externally stiffened. All duct bracing, hangers, and hardware is usually provided within the scope of SOFA system.

3.1.2. Performance

3.1.2.1. Performance Predictions

Following the completion of the installation of the equipment for the selected tangentially fired low NOx options ALSTOM Power predicts the following:

	Existing NOx			Predicted NOx w/ Tuning			Predicted NOx Option 1: In-windbox Nox control (VCCOFA)			Predicted NOx Option 2: OFA & Burner Nox control		
	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3
Unit No.1	215	0.276	**424**	202.8	0.26	**400**	187.2	0.24	**370**	132.6	0.17	**262**
Unit No.2	236	0.303	**466**	202.8	0.26	**400**	187.2	0.24	**370**	132.6	0.17	**262**

Predicted NOx Emissions

		Holyrood Particulate Loading Oct. & Nov. 2001 test results							Predictions			
		Baseline "As Found"							NOx Control *Option 1* In-Windbox		NOx Control *Option 2* SOFA	
		Asphaltines %	Average Economizer Outlet O_2	Average gr/DScf	Average gr/DScf @3% O_2	Average mg/DSm^3	Average Lb/10^6 Btu	Average mg/DSm^3 @3% O_2	Predicted Average mg/DSm^3 @3% O_2	Predicted Average gr/DScf @3% O_2	Predicted Average mg/DSm^3 @3% O_2	Predicted Average gr/DScf @3% O_2
Actual	Unit #1	3.7	0.7	0.0593	0.0608	135.63	0.088295	138.96	152.86	0.0669	173.70	0.0760
Actual	Unit #2	3.7	1.2	0.0636	0.0666	145.57	0.094766	152.44	167.68	0.0733	190.55	0.0833
Predicted Baseline	Unit #1	11	0.7		0.1781	373.73	0.24	385.63	424.19	0.1959	482.04	0.2227
Predicted Baseline	Unit #2	11	1.2		0.1951	409.38	0.27	422.42	464.66	0.2146	528.02	0.2439

Predicted Particulate Emissions Leaving Boiler (Prior to any Flue Gas Cleanup Equipment)

Comments:

Unit No. 2, operating at a slightly higher excess oxygen level, and higher baseline existing NOx level served as the basis for the predicted NOx levels for both units No. 1 and No. 2.
Unit No. 3, Actual Particulate Emissions from Unit No. 3 appear abnormally high. (Twice as high as either Units No. 1 or No. 2.) This may be due to bad data, poor atomization, or firing a fuel with an analysis other than that provided. Lacking further information, this high particulate level for Unit No. 3 served as the basis for the low NOx and high Asphaltine predictions. With further information these predictions may be revised lower. It is recommended that testing be conducted on Unit #3 to assess the cause of the high particulate loading. It may be necessary to modify the existing atomizers and/or balance the burner-burner air flow distribution to reduce particulate emissions.

3.1.3. Materials and Services

The following is a listing of the major equipment included within the scope of the Low NOx Firing for the Holyrood Units #1 & #2. *Note:* Quantities are for one (1) unit.

3.1.3.1. In-Windbox Low NOx Modifications – OPTION 1

Item	Quantity	Description
1.	Twelve (12)	Single piece oil nozzle tip with extension cone fabricated from 309 stainless steel.
2.	Twenty-four (24)	Single piece oil compartment straight air nozzle tip fabricated from 309 stainless steel.
3.	Sixteen (16)	Single piece auxiliary air nozzle tip fabricated from 309 stainless steel, complete with horizontal links and pivot pins and bearings.
4.	Four (4)	Single piece bottom end air nozzle tip fabricated from 309 stainless steel, complete with horizontal links and pivot pins and bearings.
5.	Four (4)	Single piece VCCOFA nozzle tip (former top end air) fabricated from 309 stainless steel.
6.	N/A	Drawings and instruction manuals to incorporate the above equipment.

3.1.3.2. SOFA Based Low NOx Modifications – OPTION 2

Item	Quantity	Description
1.	Twelve (12)	Single piece oil nozzle tip with extension cone fabricated from 309 stainless steel
2.	Twenty-four (24)	Single piece oil compartment straight air nozzle tip fabricated from 309 stainless steel
3.	Sixteen (16)	Single piece auxiliary air nozzle tip fabricated from 309 stainless steel, complete with horizontal links and pivot pins and bearings.
4.	Four (4)	Single piece bottom end air nozzle tip fabricated from 309 stainless steel, complete with horizontal links and pivot pins and bearings.
5.	Four (4)	Single piece VCCOFA nozzle tip (former top end air) fabricated from 309 stainless steel
6.	Four (4)	16" wide SOFA windboxes complete with tilt and damper components
7.	Eight (8)	Single piece SOFA horizontal adjustable offset nozzle tips fabricated from 309 stainless steel
8.	Eight (8)	Hagan 2 ½" x 5" SOFA damper drives
9.	Four (4)	SOFA tilt drive
10.	Four (4)	SOFA waterwall tube panels with casing
11.	Four (4)	SOFA ductwork including expansion joints and hanger rods to connect from secondary air duct
12.	N/A	Drawings and instruction manuals to incorporate the above equipment

3.1.4. Work Not Typically Included

Material Scope Not Included

1. Main windbox restoration materials including tilt mechanisms and drives, dampers and drives, etc.
2. Scanner or ignitor repair or upgrades
3. Gas or oil system repair or upgrade
4. Balance of Plant materials
5. Control system modifications
6. Airflow monitoring devices
7. Asbestos Abatement
8. Insulation and Lagging

3.2. LOW NOx WALL FIRED SYSTEM OPTIONS FOR UNIT 3

3.2.1. Technical Discussion

3.2.1.1. Introduction

Two (2) Low NOx modification options have been included in this study in addition to NOx reductions via tuning of existing equipment. For the first Low NOx equipment option, ALSTOM Power would supply nine (9) new Radially Stratified Flame Core (RSFC™) burners per unit for Holyrood Unit No.3. For the second Low NOx equipment option ALSTOM Power would supply the above RSFC™ burners and in addition a Separated Overfire Air (SOFA) system would also be supplied in conjunction with the burners. Refer to Appendix C for an experience list of Wall-fired Low NOx retrofits we have supplied..

In reviewing the new burner selection, it appears the burners will fit into the existing windbox and waterwall openings, based on the advised 41-inch minimum pressure part opening. There also appears to be no interference internally in the windbox, such as buckstays, truss work, etc. that would inhibit the burner installation.

Existing scanners and ignitors will be reused. Material will be included to allow mounting of these components on the new burners.

3.2.1.2. Low NOx Tuning of Existing System

Holyrood Unit No. 3 has 9 existing B&W burners arrayed in a 3x3 matrix on the front wall. Based on current particulate and NOx emissions levels of 743 mg/DSm^3 particulate and 0.5 Lb/10^6 Btu (768 mg/Nm^3) NOx, it is predicted that parametric tuning and atomizer replacement could reduce NOx emissions to about 0.45 Lb/10^6 Btu (695 mg/Nm^3). For wall fired boilers, the burner-to-burner mixing is significantly less than for tangential firing. Thus, the matching and balancing of burner fuel and air flow distributions is more important for minimum particulate and NOx emissions as well as operating with minimum excess air. Also, as discussed in the previous sections on Units No 1 and No. 2, NOx can be reduced by biasing fuel to lower burners in the furnace while biasing the air to the top of the windboxes.

- To accomplish the above a parametric tuning effort should be conducted with the following variables to be analyzed to determine optimum NOx emissions with the existing equipment.
- Burner-to-burner Air Balance Assessment
- Air bias to top burner row of windbox via opening upper burner row dampers and closing lower burner rows dampers.

- Selectively closing Primary Air (inner swirl) dampers forcing additional air to Secondary Air (outer swirl).
- Operate with the whole top tier of burners out (BOOS).
- Increase windbox-furnace pressure differential (up to FD fan limits) for the above conditions to force additional air to upper burner row.

3.2.1.3. Wall Fired Burner Low NOx Option

The RSFC™ burner is an exciting new technology designed for low NOx emission and is proven successful in firing oil, gas, and coal on varying boiler designs around the world. The RSFC™ acronym stands for Radially Stratified Flame Core, which describes the unique flame structure that is at the heart of this burner design. The burner's three (3) air zones allows for a highly managed air/fuel mixing. The RSFC™ burner design allows it to be optimized to satisfy various drivers including emissions, efficiency, and turndown. Additionally, to reduce burner maintenance all movable linkage on the RSFC™ burner has been mounted externally, allowing operators to troubleshoot and maintain the burner while the unit is on line.

Description of the RSFC™ Burner Technology

The RSFC™ burner is designed primarily for low NOx emissions and also achieves reductions in CO and Opacity. Additionally, the RSFC™ burner design allows it to be optimized by the commissioning engineer to satisfy various other drivers including efficiency, flame stability, and turndown. To reduce burner maintenance, all movable linkage on the RSFC™ burner has been mounted externally, allowing operators to determine where problems exist while the unit is on line.

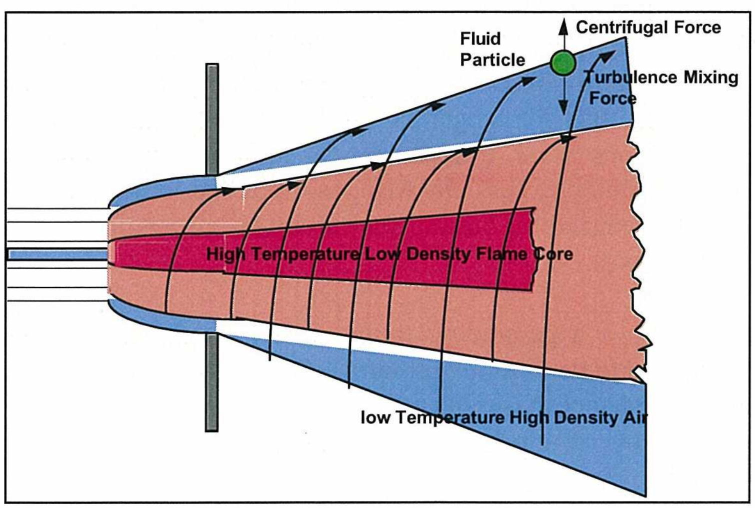


Figure 1 – RSFC™ Radial Stratification

Many wall-fired burners employ swirling flows to enhance mixing in the near-burner flow region. The RSFC™ burner is different in that swirling flow is used to create the opposite effect, namely the delay of mixing in the near-burner zone. It is this combination of a near burner, high-temperature, fuel-rich core followed by a downstream, fuel-lean combustion zone that creates the low NOx combustion conditions generated by the RSFC™ burner. The conceptual Low NOx RSFC™ burner flow field is depicted in Figure 1.

The RSFC™ achieves this flame pattern in a unique manner. The delay in mixing is achieved through stratification between the fuel jet and the surrounding, swirling combustion air. The stratification of the flame depends on turbulence and turbulent mixing dampening at the flame/air interface. The fuel enters along the centerline of the burner and is surrounded by three (3) separate air annuli of strongly swirling air as shown in Figure 1. The fuel jet penetrates into the central fuel-rich recirculation zone where the centrifugal forces of the swirling air pull the fuel jet apart and begin to mix the fuel with hot recirculated flue gas.

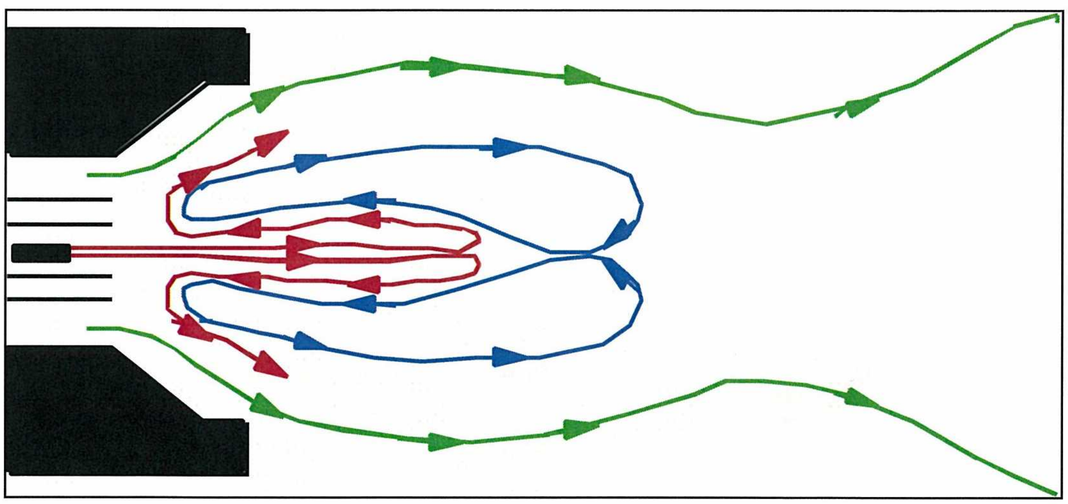


Figure 2 – RSFC™ Flame Flow Field

The first flame region, in the fuel-rich, high-temperature recirculation zone, allows a large portion of the fuel nitrogen to be released in a low stoichiometric zone where it is easily converted to molecular nitrogen. The internal recirculation zone also helps stabilize the flame by providing adequate energy to the root of the flame. This higher temperature zone along the centerline of the burner, surrounded by the cooler, swirling combustion air, creates the stratification that is characteristic of the RSFC™ burner flame structure. After passing through this initial stratified, low stoichiometric, combustion zone, the fuel quickly mixes with the remainder of the combustion air to complete the combustion processes. This has the effect of achieving a low NOx configuration in a shorter flame length when compared with a conventional low NOx burner. The actual RSFC™ flame flow field is shown in Figure 2.

The RSFC™ burner register has three (3) separate air swirl generators to supply three (3) different air zones at the burner front, depicted pictorially in Figure 3. The variable swirl in the primary and tertiary air streams is generated through the use of moveable vane swirlers. The axial, fixed vane swirler in the secondary provides a consistent swirl and pressure drop over most conditions tested. The register also has a cylindrical slide damper. This damper, which covers the primary and tertiary swirler inlets, can be used to shut-off air to an idle burner. It can also alter the air distribution burner-to-burner or bias the mass flow between the primary and tertiary air zones. The secondary air zone is left open to ensure that sufficient cooling air is supplied to an out of service burner. This arrangement will protect burners even on very highly rated furnaces.

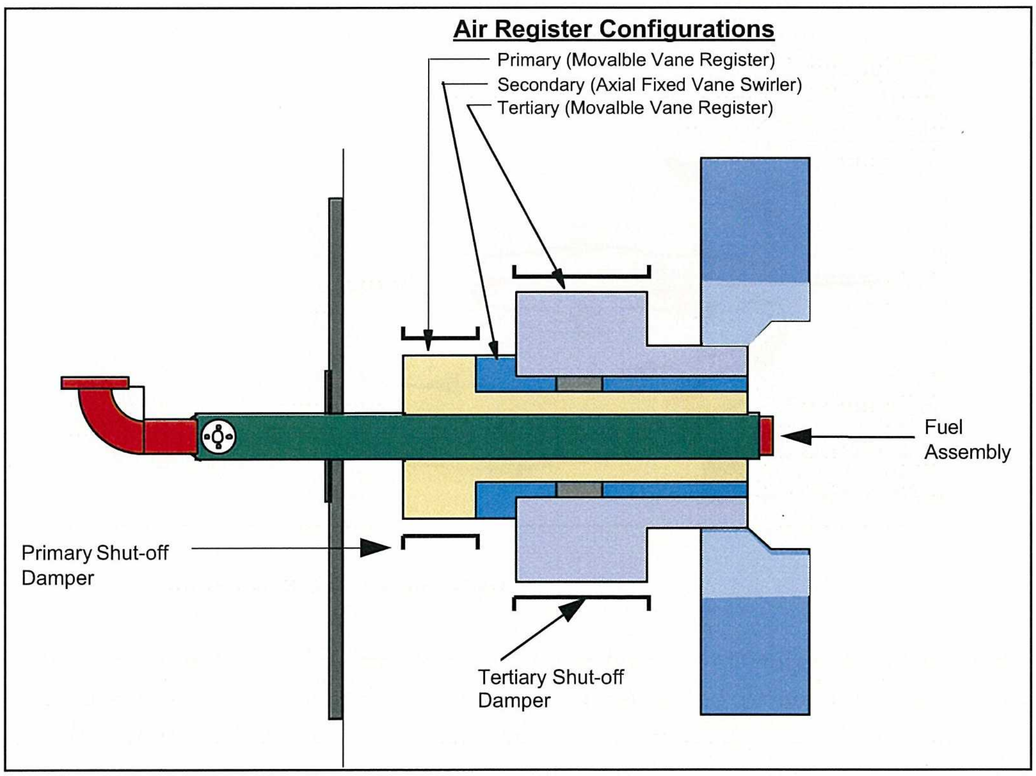


Figure 3 – Graphical Representation of the RSFC™ Burner

This air swirl is the basis for the RSFC™ burner's operational flexibility including its flame shaping ability and low NOx performance. All swirl vanes in the primary air zone are connected with linkage mounted on the external surface of the burner front plate and controlled with a single manual gear drive. The tertiary zone swirl vanes are connected and controlled in a similar way. The RSFC™ burner's independent air zone swirl adjustment and shut-off damper adjustment allow for individual burner swirl adjustment without effecting burner mass flow. This feature provides an effective tuning tool for the subject unit to control flame shape and length while preventing flame impingement on side wall or rear wall tubes. Air entering the secondary air zone in is not regulated with a shut-off damper. A fixed swirl vane assembly imparts a high axial on the secondary air as it enters the burner throat.

The workings of the moveable vane damper are all hidden in the shadow of the throat inlet to minimize binding, ash deposition, and overheating. The primary and tertiary air zones can be isolated when the burner is out of service. When the shut off damper is closed, air leakage is designed to be a nominal fifteen to twenty percent (15% to 20%). Most of this leakage will occur through the secondary air zone where it will cool both the primary and secondary throats. The tertiary shut-off damper is "wheel & track" mounted, motor driven, and controlled by a linear actuator capable of three position control. The primary shut-off damper is manually controlled. Movement of the register swirl vanes is accomplished through manual gear-driven linkage mechanisms. These mechanisms are used to adjust the amount of swirl in the primary and tertiary airflows. The linkage mechanisms are mounted externally to allow for easy visual inspection of burner positions and configurations. The external mounting also allows for ease of maintenance and operability. If there were a problem with a damper linkage assembly, the burner would not need to be removed to complete the repairs. The linkages can be serviced with pliers and pin punch even when the burner is in service.

For oil and gas-fired RSFC™ burner applications, there is no diffuser or swirler required. This reduces the historical problems of overheating and associated maintenance of this equipment.

Another feature is a burner throat configuration unique to the RSFC™ burner. This design allows for the optimization of low NOx flame shaping and reduced furnace gas recirculation on the burner wall. The potential for wall slagging and overheating of the burner components is greatly reduced as a result of the design.

The RSFC™ burner support system will consist of an attachment to the windbox plate and to the existing water wall tube throat seal box. The burner front plate will be bolted to a frame type windbox extension that is welded to the existing windbox front plate. This arrangement will allow for localized enlargement of the windbox for the new burners and for centering of the burner. The burner to waterwall throat seal box connection is a seated type that allows for movement between the burner, windbox, and waterwall seal box. A new mounting adapter will be installed on the existing seal box. This mounting adapter will incorporate the RSFC™ burners' seated connection.

The Company's RSFC™ burner was initially developed as a low NOx burner. The design objectives resulted in a product that is well suited to perform as a high efficiency burner. RSFC™ burners have successfully operated with O_2 levels of one-half to one and one-half percent (1/2 to 1-1/2%), while also achieving reduced emission levels. The commissioning engineer typically does selection of the oxygen level. The engineer will optimize the excess O_2 during burner tuning while taking into consideration various drivers such as emissions, efficiency, turndown and flame stability. The RSFC™ burner's multiple air zones allows the Company to highly manage the air/fuel mixing, which is the feature that provides the benefit of great mixing and therefore, complete combustion.

Reliability of the RSFC™ is achieved through the many unique features incorporated into its basic design. The modular construction of the swirl block makes the RSFC™ burner very strong and rigid. Each of the blocks used in the construction of the burner becomes a stiffener in the swirler geometry. In addition, many of the parts in the RSFC™ burner have been constructed out of stainless steel to ensure that the burner will be functional over the long term. The use of stainless steel protects the RSFC™ burner from heat, corrosion, and rust on the critical moving parts, resulting in a more reliable design.

The RSFC™ burner's stable flame front is established with its unique exit profile. The existing burner refractory will be removed with the installation of the RSFC™ burner. A new burner refractory profile will be installed within the existing pressure part opening. No pressure part modifications are anticipated for this burner's installation. A drawing of the desired refractory profile is furnished during contract execution as well as dimensions for a profile sweep.

Electric linear actuators with three-position capability have been included for tertiary shut-off damper control. Manual actuators have been included for the primary air side control. Manual gear drives for both primary and tertiary vane damper adjustments are included. The intended use for these dampers is to optimize flame shape during burner commissioning. The Company's experience is that these vane dampers will not require adjustment over the unit's load range, with the exception of any significant change in fuel properties.

Burner Design Features

- Burner components that are exposed to furnace radiation are constructed of high-temperature 310 stainless steel.
- Primary and tertiary air zones swirl independent and have infinitely adjustable swirl capability from full radial flow to straight.

- Closing of the RSFC™ burner primary and/or tertiary shut-off or biasing dampers can be done when a burner is out of service. The secondary air zone is always open for cooling of burner furnace side components when a burner is out of service.
- RSFC™ burner primary and/or tertiary shut-off or biasing dampers can be modulated to balance airflow between burners on units with a common windbox.
- All moving parts (swirler vanes and air sleeve) are shaded from direct radiation eliminating binding due to overheating. Primary and tertiary swirler linkage is external for simple on-line maintenance and adjustment.
- RSFC™ burner has multiple view port options for scanners, or direct viewing for either center or offset ignitor locations.
- RSFC™ multi-fuel capability – Typical combinations are oil and gas or coal and gas. Installations have been designed for up to five (5) fuels.

Modular construction provides for a strong, yet lightweight burner.

3.2.1.4. SOFA Based Low NOx Option

There will be three (3) SOFA registers – one above each centerline of each burner column. The approximate height of the SOFA register centerline above the top burner centerlines is 12 feet. Three (3) individual ducts are included to supply combustion air to the three (3) SOFA registers.

The SOFA will be separated into two (2) compartments, stacked vertically. They will be equal areas, and the total size should be 18 inches wide by 24 inches high. Each compartment will be supplied with one (1) damper. The damper "box" and compartment assembly will be supplied with a bolted flange to the supply ductwork in lieu of a welded flange.

The ducting should be a standard duct, vertical from the top of the windbox to the SOFA register, with a 90-degree turn to the damper box. Turning vanes may be used to assist in the airflow in the 90-degree turn.

All waterwall tubing is SA-210, 3-inch O.D 0.200 MWT on 3 3/4" spacing.

3.2.2. Performance

3.2.2.1. Performance Predictions

Following the completion of the installation of the equipment for the selected wall fired low NOx option ALSTOM Power predicts the following:

	Existing NOx			Predicted NOx w/ Tuning			Predicted NOx Option 1: RSFC Burners			Predicted NOx Option 2: RSFC Burners with SOFA		
	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3	ppm @ 3% O2	Lb/10^6btu	mg/Nm^3
Unit No.3	389	0.499	**768**	351	0.45	**693**	218.4	0.28	**431**	171.6	0.22	**339**

Predicted NOx Emissions

		Holyrood Particulate Loading Oct. & Nov. 2001 test results							Predictions			
		Baseline "As Found"							NOx Control *Option 1* In-Windbox		NOx Control *Option 2* SOFA	
		Asphaltines %	Average Economizer Outlet O_2	Average gr/DScf	Average gr/DScf @3% O_2	Average mg/DSm^3	Average Lb/10^6 Btu	Average mg/DSm^3 @3% O_2	Predicted Average mg/DSm^3 @3% O_2	Predicted Average gr/DScf @3% O_2	Predicted Average mg/DSm^3 @3% O_2	Predicted Average gr/DScf @3% O_2
Actual	Unit #3	3.7	0.4-0.7	0.1129	0.1172	258.38	0.168205	268.3	295.13	0.1289	335.38	0.1465
Predicted Baseline	Unit #3	11	0.4-0.7		0.3434	720.42	0.47	743.35	817.69	0.3777	929.19	0.4292

Predicted Particulate Emissions Leaving Boiler (Prior to any Flue Gas Cleanup Equipment)

Comments:

Unit No. 3, Actual Particulate Emissions from Unit No. 3 appear abnormally high. (Twice as high as either Units No. 1 or No. 2.) This may be due to bad data, poor atomization, or firing a fuel with an analysis other than that provided. Lacking further information, this high particulate level for Unit No. 3 served as the basis for the low NOx and high Asphaltine predictions. With further information these predictions may be revised lower.. It is recommended that testing be conducted on Unit #3 to assess the cause of the high particulate loading. It may be necessary to modify the existing atomizers and/or balance the burner-burner air flow distribution to reduce particulate emissions.

3.2.3. Materials and Services

The following is a listing of the major equipment included within the scope of the RSFC™ burner system for Holyrood Unit No.3. *Note:* Quantities are for one (1) unit.

3.2.3.1. Wall Fired Burner Low NOx Modifications – OPTION 1

Item	Quantity	Description
1.	Nine (9)	RSFC™ Low NOx venturi burners – nominally rated for approximately 165 MMBtu/hr equipped No. 6 fuel oil firing. Each burner will include two (2) view ports and one (1) scanner mount for the existing scanner. Each register will be shop assembled, including linkage and manual swirl damper actuators. The shut-off damper will be split with an electric linear actuator controlling the tertiary side, and the primary side controlled with a manual operator. The burner will also be equipped with an assembly to house the existing No. 2 fuel oil pilot assembly. Modifications to pressure parts are not required for burner installation (minimum 35-inch pressure part opening).
2.	Nine (9)	RSFC™ adapter flanges, to accept the new burner front plate into the existing windbox opening
3.	Eighteen (18)	Manual gearbox drives for operating the primary air and tertiary air swirl dampers
4.	Nine (9)	Electric linear actuators for control of tertiary air zone balance damper
5.	Nine (9)	Manual operators for control of primary air zone balance damper
6.	Ten (10)	WRHE steam atomized air-cooled oil gun for full load firing. Complete with guide pipe, stationary and removable union, spray plate and back plate, and oil and steam flex hose to interface with the existing supply piping - Includes one (1) spare. Note: Hose length provided is 6'.
7.	One (1)	Oil gun vise
8.	One lot	Material required to install the existing No. 2 fuel oil pilots onto the new RSFC™ burners
9.	One Lot	Material required to install the existing scanners onto the new RSFC™ burners

10.	Five (5)	Sets of the Company's standard instruction manuals and drawings

3.2.3.2. SOFA Based Low NOx Modifications – OPTION 2

Item	Quantity	Description
1.	Nine (9)	RSFC™ Low NOx venturi burners – nominally rated for approximately 165 MMBtu/hr equipped No. 6 fuel oil firing. Each burner will include two (2) view ports and one (1) scanner mount for the existing scanner. Each register will be shop assembled, including linkage and manual swirl damper actuators. The shut-off damper will be split with an electric linear actuator controlling the tertiary side, and the primary side controlled with a manual operator. The burner will also be equipped with an assembly to house the existing No. 2 fuel oil pilot assembly. Modifications to pressure parts are not required for burner installation (minimum 35-inch pressure part opening).
2.	Nine (9)	RSFC™ adapter flanges, to accept the new burner front plate into the existing windbox opening
3.	Eighteen (18)	Manual gearbox drives for operating the primary air and tertiary air swirl dampers
4.	Nine (9)	Electric linear actuators for control of tertiary air zone balance damper
5.	Nine (9)	Manual operators for control of primary air zone balance damper
6.	Ten (10)	WRHE steam atomized air-cooled oil gun for full load firing. Complete with guide pipe, stationary and removable union, spray plate and back plate, and oil and steam flex hose to interface with the existing supply piping - Includes one (1) spare. Note: Hose length provided is 6'.
7.	One (1)	Oil gun vise
8.	One lot	Material required to install the existing No. 2 fuel oil pilots onto the new RSFC™ burners
9.	One Lot	Material required to install the existing scanners onto the new RSFC™ burners
10.	Three (3)	Two-compartment SOFA registers; 18 inches wide by 24 inches high, arranged vertically; register equipped with required internal structural

		stiffeners, waterwall attachment flange (as required), expansion requirements, etc.
11.	Three (3)	Windbox to SOFA register connecting ducts; duct area to be 8.5 sq. ft The duct design shall incorporate expansion joints and hangers as required.
12.	Three (3)	Two-compartment damper box; each box is equipped with a damper designed for shutoff of its respective compartment; each damper will modulate independently.
13.	Three (3)	Damper drive support mounts
14.	Three (3)	Electric rotary actuators for control of the dampers – Each drive will be capable for full range modulation.
15.	Three (3)	Sets of waterwall offset tubes; to allow for new SOFA opening
16.	Three (3)	SOFA seal boxes for new offset tubes and compartments
17.	One Lot	Miscellaneous steel for buckstay and platform steel modifications
18.	Five (5)	Sets of the Company's standard instruction manuals and drawings

3.2.4. Work Not Typically Included

Material Scope Not Included

1. Main windbox restoration materials
2. Scanner or ignitor repair or upgrades
3. Oil system repair or upgrade
4. Balance of Plant materials.
5. Control system modifications
6. Airflow monitoring devices
7. Asbestos Abatement
8. Insulation and Lagging
9. Burner Throat Refractory

3.3. FUEL TECH NOXOUT SNCR PROCESS

In an effort to further reduce the NOx emissions from the Holyrood Units in addition to the burner and firing system modifications ALSTOM Power could, as an additional option supply engineering, material, start-up and optimization of the NOxOUT SNCR NOx Control Process to be supplied by Fuel Tech Inc.. This option is predicted to reduce NOx emissions an additional 25-30% NOx reduction from the full load predicted levels achieved with the burner/firing system modifications while maintaining ammonia slip to less than 10 ppm as measured at the stack.

If the Newfoundland and Labrador Hydro desires, this Option can be exercised at a later date, after the Low NOx Bulk Furnace Staging System (for Units #1 and #2) and/or the RSFC™ burners (Unit #3) have been installed and operated for a period of time.

For this option, the Company has requested and received a proposal from Fuel Tech Inc. to supply the SNCR System for each unit using one (1) 30,000-gallon reagent storage tank per unit, as well as specific components for this boiler.

A Typical SNCR system would include a common heated and insulated FRP Reagent Storage tank; a common Reagent Circulation Module enclosed in a heated building that is designed to supply reagent under constant pressure to the individual metering modules on the unit. Common dilution water pressure control modules will be utilized to feed and maintain dilution water to each of the metering modules.

Each boiler will have an Independent Zone Metering (IZM) module capable of automatically controlling the reagent and dilution water flow to various levels of injection, based on the demands of the system. The diluted reagent would be pumped to distribution modules on each level of injection where reagent and air flow is controlled to individual injectors.

The injectors for each unit will be a combination of wall injectors installed in the upper furnace and Multiple Nozzle Lances (MNL) installed through the side of the boiler in the superheat section. Both would come with automatic retract mechanisms. The MNLs would also require cooling water that is typically supplied from and returned to the hot well to retain heat in the cycle.

Continuous Furnace Temperature Monitors would also be supplied to provide additional control of the process. The control for Units would typically be through an Allen Bradley PLC with plant signal for load and furnace gas temperatures being used as a feed forward to determine which level of injection to use and the quantity of reagent feed. A NOx CEM measuring Unit stack emissions would be used as a feedback to fine-tune the process to maintain the target NOx level.

See Appendix B for a the Fuel Tech brochure further describing this technology.

4. CAPTURE TECHNOLOGIES

4.1. MECHANICAL COLLECTORS

4.1.1. Technical Discussion

Mechanical dust collectors use cyclonic designs to remove dust from the flue gas. Dust-laden gas is set in rotation by the guide vanes located in each cyclone. Fully inserted guide vanes impart maximum rotation, i.e. the whole of the gas flow is caused to rotate along the same helical path as that formed by the guide vanes. Fully withdrawn guide vanes impart less rotation; the part of the gas passing outside the guide vanes reduces the rotation. The guide vane device can be set at any intermediate position. During rotation, the solid particles in the gas are forced out wards towards the cyclone casing. The clean gas flows in towards the center of the cyclone, where additional separation takes place at the slots of the central tube, through which the gas must pass and be sharply deflected. The separation dust is drawn out through the bottom of the cyclone, from where it is transported through the bottom of the unit to a secondary collector for final separation.

The type MJCD multicylone is a controllable, dynamic dust collector designed for high-efficiency dust collection. The gas flow is uniformly distributed across the entire peripheral area, and the cyclone is therefore well-suited for both fine-grained and highly abrasive dust. To reach the desired efficiencies, multiple cyclones are connected in parallel and then multiple sections of cyclones are connected in series. The recommended arrangements includes the following:

4.1.2. Performance

4.1.2.1. Performance Predictions for Unit 1

Following the completion of the installation of the equipment for the recommended Mechanical Collector arrangement ALSTOM predicts the following:

Design Data		
Gas Flow Rate	Nm^3/hr	622,844
Flue Gas Temperature	°C	173
O2 Content, dry gas	(% vol.)	3.4
Dust Inlet	mg/Nm^3	559

Design Parameters and Expected Performance		Primary	Secondary	Tertiary
Flue Gas Flow	m^3/hr	1,021,000	74,880	9600
Flue Gas Temperature	°C	173	173	173
Differential Pressure	kPa	1.4	1.2	0.7
Expected Dust Emissions @ 3% O_2	mg/Nm^3, dry			282

4.1.2.2. Performance Predictions for Unit 2

Following the completion of the installation of the equipment for the recommended Mechanical Collector arrangement ALSTOM predicts the following:

Design Data		
Gas Flow Rate	Nm^3/hr	633,820
Flue Gas Temperature	°C	170
O2 Content, dry gas	(% vol.)	3.8
Dust Inlet	mg/Nm^3	612

Design Parameters and Expected Performance		Primary	Secondary	Tertiary
Flue Gas Flow	m^3/hr	1,032,000	74,880	9600
Flue Gas Temperature	°C	173	173	173
Differential Pressure	kPa	1.4	1.2	0.7
Expected Dust Emissions @ 3% O_2	mg/Nm^3, dry			282

4.1.2.3. Performance Predictions for Unit 3

Following the completion of the installation of the equipment for the recommended Mechanical Collector arrangement ALSTOM predicts the following:

Design Data		
Gas Flow Rate	Nm^3/hr	510,220
Flue Gas Temperature	°C	173
O2 Content, dry gas	(% vol.)	3.7
Dust Inlet	mg/Nm^3	1077

Design Parameters and Expected Performance		Primary	Secondary	Tertiary
Flue Gas Flow	m^3/hr	835,840	62,400	9600
Flue Gas Temperature	°C	173	173	173
Differential Pressure	kPa	1.3	1.2	0.8
Expected Dust Emissions @ 3% O_2	mg/Nm^3, dry			486

4.1.3. Materials and Services

To reach the desired efficiencies, multiple cyclones are connected in parallel and then multiple sections of cyclones are connected in series. The following is a listing of the major equipment included within the scope of the Mechanical Collecting system.

4.1.3.1. Recommended Equipment for Units 1 and 2

Item	Quantity	Description
1.0	Six (6)	Primary Collector MJCD Multicyclones consisting of 192 cyclones connected in parallel.
2.0	One (1)	Secondary Collector MJCD Multicyclones consisting of 96 unit cyclones connected in parallel.
3.0	Two (2)	Tertiary Collector MJCH high efficiency cyclones.
4.0	One (1)	Lot ductwork from air preheater to Collector inlet, from Collector outlet to gas fan, from gas fan outlet to exhaust stack.

4.1.3.2. Recommended Equipment for Unit 3

Item	Quantity	Description
1.0	Five (5)	Primary Collector MJCD Multicyclones consisting of 192 cyclones connected in parallel.
2.0	One (1)	Secondary Collector MJCD Multicyclones consisting of 96 unit cyclones connected in parallel.
3.0	Two (2)	Tertiary Collector MJCH high efficiency cyclones.
4.0	One (1)	Lot ductwork from air preheater to Collector inlet, from Collector outlet to gas fan, from gas fan outlet to exhaust stack.

Note that the Mechanical Collector Equipment layout is very similar in plan, to the recommended ESP equipment layout. For the ESP layout, the Holyrood Generating Station Master Site Plan Drawing B1-1403-121-C-003 Rev 8 was used to investigate the feasibility of locating the equipment arrangement at this site. Therefore for reference, the layout out sketch contained in Appendix A for the ESP, is representative of the location where the Mechanical Collectors would also be located.

4.1.4. Work Not Typically Included

Material Scope Not Included

1. Inlet and outlet ductwork access
2. Test ports and access thereto
3. Support for inlet and outlet ductwork
4. All foundations and anchor bolts
5. Gas Fans (if necessary)
6. Dust evacuation system

4.2. ELECTROSTATIC PRECIPITATORS

4.2.1. Technical Discussion

The following is a general description of APECS Electrostatic Precipitators; please note that certain portions may not be directly applicable to the equipment offered in the Scope of Supply.

APECS electrostatic precipitators are in use throughout the world in more than 1,200 installations. Refer to Appendix C for an experience list of ESP's supplied internationally on oil fired boilers.

The following describes the APECS Rigid Frame Precipitator, which is a steel casing design for collecting many different types of particulates, such as fly ash, cement, lime, sodium sulfate and dust containing iron metal oxides. The APECS electrostatic precipitator embodies many unique design features that ensure high collecting efficiencies over an extended lifetime with the minimum of preventative maintenance.

4.2.1.1. Casing

The precipitator casing is made up of all welded construction utilizing shop prefabricated plate panels, thereby assuring close tolerances and quality control. The casing is designed for pressures, seismic, wind, live loads, and dust loads as specified in the design section. The plate sections or panels are welded together for gas-tight construction with special care taken during welding to avoid porous welds which might invite corrosion. The roof of the precipitator casing supports both the internal discharge and collecting electrode systems. Loads are transmitted through columns to the support structures. The remainder of the precipitator internal components (drives, baffles, etc.) are supported by brackets welded to the precipitator casing.
Inspection door frames are welded to the precipitator casing. In order to accommodate the effects of thermal expansion, the casing rests on anti-friction assemblies arranged in radial form emanating from a single welded fixed point on the supporting structural steel.
Any external accessories, such as transformer-rectifiers, not permanently welded to the casing are equipped with permanent grounding lugs.

4.2.1.2. Gas Distribution Devices

It is essential that the precipitator be equipped with arrangements that will give an even gas distribution over the entire cross sectional area. This desirable gas distribution cannot be achieved solely through the design of the ducts, therefore, special gas distribution plates will be located in the inlet nozzles before the precipitator and at the outlet nozzle after the precipitator.
The gas velocity within the precipitator is approximately 1/10 of the velocity in the ducting before the precipitator In order to prevent area of high gas velocities in the precipitator, the precipitator is

equipped with a gas distribution arrangement which consists of three separate rows of perforated screens located in the inlet nozzles and one row of non perforated screens at the outlet of the casing.

The velocity distribution within the precipitator casing will be checked prior to start-up. During these gas distribution tests any necessary adjustments to the flow pattern will be made by the installation of deflector baffle plates attached to the perforated gas distribution screens.

For applications which are characterized by high inlet grain loadings and/or sticky particulates, rapping mechanisms, complete with geared motor, are provided for the two rows of inlet gas distribution screens located in the low velocity region of the inlet nozzles.

4.2.1.3. Collecting System

The APECS designed collecting system is based on the concept of dimensional stability. The upper edges of the collecting plates are bolted to suspension angles, which in turn are connected to support members welded to the roof structure. The lower edge of each plate is similarly bolted to an alignment bar which is guided laterally across the gas flow. This results in a dimensionally stable collecting system compatible with the discharge system. In order to maintain the collecting efficiency at the design level, it is essential that the discharge electrode and collecting systems be dimensionally stable.

The collecting plates are made of 18 GA A366 CS (or equal) plate shaped in one 500 mm piece by roll forming. Rigidity is the main purpose for the special design of the collecting plate edges. The collecting plates are provided with tabs at the top and bottom edges which are bolted to the top suspension iron and lower alignment bar, respectively.

A series of 500 mm collecting plates form a row, or curtain, for each field. The separated module design allows each panel to respond individually to the rapping forces and minimizes shipping damage common with unitized plate designs. At 1/3 and 2/3 of the plate height a tab type device is furnished between each adjacent panel to interlock adjacent panels to each other.

4.2.1.4. Collecting Plate Rappers

The design of rapping mechanisms for the collecting system is an important factor to consider in the design of precipitator internals. It is essential that the collecting plates are thoroughly cleaned during rapping. The acceleration of the plate which results from the rapping action is the most important determinant of ash removal and cleaning of the collector plates. In order to achieve efficient cleaning, the rapping system must be constructed so as to provide the required accelerations over all the plates.

Individual collecting plates in each row are bolted to and suspended from collector suspension angles. Each row of collector plates will receive a collector rapping anvil at the center field depth location attached to the suspension channel with tension control bolts. This arrangement ensures that the highest possible energy is transferred to the collecting plates when the tumbling hammer hits the corresponding rapping anvil.

The rapping system employs "tumbling hammers" that are mounted on a horizontal shaft in a staggered fashion with one hammer for each shock bar anvil. As a shaft rotates slowly, each of the hammers in turn overbalances and tumbles, hitting its associated shock bar anvil. The shock bar anvil transmits the blow simultaneously to all of the collecting plates in a row, because of their direct contact with the suspension channel and shock bar. A uniform rapping effect is, therefore, provided over the row of collecting plates.

It is of prime importance in any rapping system to avoid excessive reentrainment of the dust into the gas stream during the rapping procedure. With the APECS rapping mechanism the electrodes are given an acceleration that causes the collected dust to shear away from the collecting plates and fall down in large agglomerates. These large agglomerates, which result from the single shock shearing action, greatly reduce the possibility of dust re-entrainment during rapping.

The rapping frequency should be as low as possible in order to minimize dust re-entrainment from rapping. The frequency of the APECS rapping system is adjustable within wide limits. All internal parts of the rapping mechanism are accessible for inspection, being placed in wide access passages before, between and after the collecting fields.

All physical data essential for designing plate suspension and rapping intensity for this type of dust has been tested in APECS 's laboratories. This type of "tumbling hammer" rapping mechanism has been used by APECS for boiler plant precipitators for over 40 years as well as in all other APECS precipitator applications. The acceleration at any point on a collecting system similar to the one recommended has been determined from full scale tests carried out in
APECS 's laboratory.

When judging the effectiveness of the collecting and related rapping system, it is also essential to keep in mind the total collecting area being rapped at any one time. The higher the percentage of the total collecting area being rapped at any one time, the greater the re-entrainment of dust into the gas. With the APECS tumbling hammer rapping mechanism, a very small percentage of the collecting area for each precipitator is rapped at any one time. This improves the overall efficiency of the precipitator and avoids puffing at the stack outlet. The functional capabilities of the tumbling hammer system and its operational reliability have made it a APECS standard, utilized in all installations noted in the reference lists in Appendix C of this report.

4.2.1.5. High Voltage System

An essential part of the precipitator is the high voltage discharge system. In the APECS precipitator design, each individual discharge system is supported from four insulators. The discharge system is a frame structure that results in a stable configuration. The APECS design is such that the discharge framework is supported at each upper corner and at the top of the collecting system. The discharge framework extends beyond the top and bottom edges of the collecting plates.
These structural framework members consist of round or rectangular sections. The purpose of this design is to keep the field concentration at these points at a low level in order to avoid flashovers.
The discharge frames are thoroughly braced above and below the collector plate system. The APECS discharge system can be adjusted to its final position inside the casing which makes it possible to obtain and maintain highly accurate spacing, without the need for anti-sway or lower stabilizing insulators.

4.2.1.6. Discharge Electrodes

The APECS' rigid discharge electrodes consist of 1 ¼" diameter 16 gauge and 1 3/8" diameter 10 gauge mechanical tubing with 16 gauge emitting tips. The electrodes are installed in three (3) vertical levels within a rigid frame for proper alignment and to prevent electrode swaying.

4.2.1.7. Insulator Compartments

Each electrical bus section is supported on four insulators located in insulator compartments. These compartments are provided with hinged door covers to allow access to the insulators for inspection and service. There is a special arrangement in each insulator compartment that makes it possible to suspend the discharge electrode system by means of a temporary jacking hook if the insulator must be exchanged.

A screen tube is installed immediately below the support insulator. The screen tube decreases back draft of gases and assists in maintaining cleanliness of the support insulator.

4.2.1.8. Discharge Electrode Rappers

During electrostatic precipitation a fraction of the dust will be collected on the discharge electrodes; the corona will gradually be suppressed as the dust layer grows. Therefore, it is necessary to rap the discharge electrodes occasionally. This rapping is done with a rapping system consisting of tumbling hammers that are mounted on a horizontal shaft in a staggered fashion. These hammers hit specifically designed shock anvil beams that are attached at the top of the discharge frame. In this manner the vibrations generated by the hammers are transmitted to the discharge electrodes.

One such rapping mechanism will be provided per electrical bus section. The drive of the rapping mechanism is via an insulator shaft that is installed on the top of the precipitator casing. The operation of the gear motor for the rapping mechanism is controlled by an APECS EPIC-II, as described in Section 3.9.3, which is adjusted to optimum conditions at the time of commissioning. Subsequent adjustments can easily be carried out during operation, should operating conditions vary.

4.2.1.9. The Apecs Electrostatic Precipitator Control System

APECS has offered a line of proprietary microprocessor controls for its electrostatic precipitator since 1982. These controls were developed exclusively for electrostatic precipitators by APECS' R&D group in Vaxjo, Sweden. APECS now offers the next generation of electrostatic precipitator controllers EPIC-II (Electrostatic Precipitator Integrated Controller, Series II). This new microprocessor based automatic voltage controller provides the "state of the art" control for transformer - rectifiers and electrostatic precipitators.

EPIC-II

The EPIC-II main unit consists of a panel mounted control unit and a door mounted (RTU) display and terminal unit. The main unit contains one circuit board mounted in an enclosure. The one circuit board holds all the functions needed for the complete controller:

- One microprocessor for T/R control.
- One microprocessor for making computations and intelligence work such as communications and optimization routines.
- Data acquisition - analog and digital.
- Ignition circuits - for the SCR.
- Non-volatile memory - EEPROM for storing the system parameters.
- Real time clock - capacitor backed, no battery needed.
- Field bus communication (Flakt Bus) - for communication with RTU, Preview, host computer, and other EPIC-II units.

There will be one EPIC-II supplied for each transformer rectifier. Each EPIC-II does not require a RTU and therefore APECS will provide a recommended number of RTU's.

Transformer Rectifier Control

The primary function of the EPIC-II is to monitor and control the level of power inside the precipitator. The principle output of the EPIC-II is a signal which determines the phase angle of the SCR's, which in turn regulates the power supplied to the transformer rectifiers. By measuring secondary voltage and current in the precipitator, sensing sparks, and utilizing its operating program, the EPIC-II is able to provide the optimum level of precipitator power over a wide range of gas conditions.

The EPIC-II also monitors many conditions of the transformer rectifier and SCR's to provide complete protection for the system. The EPIC-II presents alarms via the Flakt Bus which allows them to be viewed on the RTU, on Preview, or via the host computer. Certain alarm conditions will cause the transformer rectifier to trip.

Rapper Control

With the EPIC-II, there is no need for a separate rapper controller. Each EPIC-II can control up to four rapper motors. The various time settings are easily made using the RTU. These operating parameters are stored in the non-volatile memory of the EPIC-II. Alarm conditions for the rapper motors are presented on the Flakt Bus for operator presentation.

Optimization Routines

Several energy saving and system operation optimization routines are available in EPIC-II. These routines include patented "EPOQ", semi-pulse optimization for performance and energy savings, opacity optimization for energy savings, and rapper operation optimization. Each EPIC-II includes an analog input (4-20mA) for use by the routines. The most common use of this input is for the opacity input. Note that this Information when input to one EPIC-II, can be shared with all other EPIC-II's via the Flakt Bus. These optimization routines offer best precipitator operation and energy savings for all operating conditions.

Remote Terminal Unit (RTU)

The RTU is a small operator interface with a keypad, for operator entry, and a display. The RTU is a general unit which collects its data and screen displays from the controller. The RTU's work over the Flakt Bus so that any RTU can access any EPIC-II on the Flakt Bus. The display provides easy to understand text display of information and alarms.

System Overview & TR Control

APECS will supply standard EPIC II controllers for each T/R set. In addition to controlling the T/R, each EPIC II is capable of controlling up to four rapper systems. The EPIC II controllers will be connected on a communications bus called Flakt Bus along with an EPIC II GATEWAY All T/R functions are available across the FlaktBus.

Local access to the control system is via Remote Terminal Units (RTU's) which are also connected to the communications bus. One per T/R control panel line-up is supplied.
There will be one EPIC II GATEWAY for the precipitator to allow communication to the preview system or the boiler DCS.

Connection To a DCS System

The Gateways are network ports that can communicate directly with the DCS system; in fact, this is the normal use of these devices. The Gateways utilize Modbus protocol and act as slave devices. The Gateways can easily be connected to a new DCS system as long as that system has a compatible Modbus port. Any additional pertinent alarm information required can be routed through auxiliary I/O on the EPIC II's.

4.2.1.10. Hopper Heaters

APECS will supply standard hopper heater control. A hopper heater control panel located under the hoppers and containing the fused power circuits for the heaters (one per hopper) will have individual H-O-A switches for each hopper power circuit. The automatic position allows a control thermostat to operate the heater as required to maintain the set point temperature. A second thermostat provides a low temperature alarm contact that illuminates an alarm light on the panel front. A common trouble alarm contact is provided. There is one hopper heater control panel per precipitator.

The hopper level switches are wired into the hopper heater panel and level alarm lights are located on the panel front. A common trouble alarm contact is provided. Please note that individual hopper information is not available at the control room. The philosophy is that any alarm from the hoppers needs to be investigated and individual hopper information is available at the local panel.

4.2.1.11. Insulator Heaters

To keep the insulators above the dew point of the gas during start up and operation, a special 1KW electrical resistance heater is provided for each insulator to supply heat to the insulators.

4.2.2. Performance

4.2.2.1. Performance Predictions

Following the completion of the installation of the equipment for the recommended Precipitator arrangement ALSTOM predicts the following:

ESP Predicted Performance				
		Unit 1	Unit 2	Unit 3
Fuel		Fuel Oil	Fuel Oil	Fuel Oil
Load		MCR	MCR	MCR
	MW	175	175	175
Btu Fired	MBtu/hr	1640	1640	1640
Gas Flow	Nm^3/hr (dry)	556,200	566,000	459,707
Gas Temp	°C	173	170	173
HHV	Btu/lb	17,857	17,857	17,857
Total Pressure @ ESP inlet	In.wg	-1.15	-1.15	-1.15
ESP Inlet Loading	mg/Nm^3 (dry) @ 3% O^2	559	612	1077
Removal efficiency	%	90	90	92.0
Maximum Particulate Emission	mg/Nm^3 (dry) @ 3% O^2	55.86	61.18	82.78

Flue Gas Analysis				
Fuel		Fuel Oil	Fuel Oil	Fuel Oil
Load		MCR	MCR	MCR
Moisture	% vol.	10.7	10.7	9.9
Operating O_2	% wet	3.4	3.8	3.7

4.2.3. Materials and Services

The following is a listing of the major equipment included within the scope of the Electrostatic Precipitator system.

4.2.3.1. Recommended Equipment for Units 1, 2 and 3

The recommended precipitator system per boiler is designated as:

1FTA 3*35.0M - 160 -150 - A2 - E131

The physical arrangement of each recommended precipitator for the boiler is summarized as follows:

Number of Precipitators	-	3
Number of Chambers / Precipitator	-	1
Number of Cells per Chamber	-	1
Number of Fields in Series	-	3
Field Height.	m	15.0
Field Depth, each.	m	3.5
Number Gas Passages/Precipitator	-	40
Plate to Plate spacing	mm	400
Number of Bus Sections/ Precipitator	-	3
Number of Transformer - Rectifiers	-	3
Gas Velocity through precipitator	m/s	1.09
Total gas treatment time	s	9.62
Aspect Ratio	-	0.70
SCA (Metric)	$m^2/m^3/s$	48
Total Installed Coll. Area/ Precipitator	m^2	12,600

Note that the Holyrood Generating Station Master Site Plan Drawing B1-1403-121-C-003 Rev 8 was used to investigate the feasibility of locating the above recommended equipment arrangement at this site. Although a more detailed investigation and discussion with site would have to take place, it appears as though it would be feasible. The equipment above has been superimposed onto a portion of this site plan, and for reference, this layout sketch is contained in Appendix A.

Mechanical Equipment

The following is a list of the major mechanical equipment (per boiler) typically supplied by ALSTOM:

Item	Quantity	Description
1.0	One (1)	Precipitator casings, consisting of inner roof (hot roof), side walls fabricated of 3/16 in A36, or equal, steel plate, adequately stiffened and braced to withstand differential pressures, stresses, and loads. The casing is complete with inspection doors in the side wall to allow access to internals.
2.0	One (1)	Outer roofs fabricated from 3/16 in A36, or equal, steel checkerplate, suitable for foot traffic.
3.0	Twelve (12)	Weathertight insulator compartments fabricated from 3/16 in A36, or equal, steel plate. The insulator compartments are provided with bolted doors for access to the supporting insulators.
4.0	One (1)	Set of inlet and outlet nozzles fabricated from 3/16 in A36, or equal, steel plate complete with flanges and bolts adequately stiffened and braced to withstand differential pressures.
5.0	Four (4)	24" X 24" hinged, interlocked, quick release access doors on the precipitator casing side wall, and inlet nozzle. Doors will be double wall, shop insulated construction.
6.0	One (1)	Set of stub columns and slide plate bearing assemblies for the precipitator casing support, welded fixed point, to allow unrestricted thermal expansion in all directions.
7.0	One (1)	Set of support steel fabricated from A36, or equal, steel providing 26 ft. of clearance below the hopper discharge flanges to grade.
8.0	Six (6)	Pyramidal hoppers fabricated from 3/16 in A36, or equal, steel plate with external stiffeners. The hoppers will have minimum valley angle to the horizontal of 60°. Each hopper will be supplied with the following accessories: 1 Set of heaters 2 Hopper heater thermostats (one for control and one for alarm) 1 Access door, 24" X 24". 2 StrikePlates 2 Poke Holes

		2 Hopper Vibrator Mounts 1 Level Probe (high level alarm)
9.0	One (1)	Set of access facilities for ESP, consisting of platforms, walkways, and caged ladders as shown on the arrangement drawings. The floor grating and stairtreads shall be galvanized . Handrail, posts, ladders and other access steel will be prime painted .
10.0	One (1)	Gas distribution system at the inlet consisting of three (2) separate rows of perforated roll formed channels fabricated from 16 GA A366, or equal, steel sheet and one (1) row of plain roll formed channels for the outlet fabricated from 16 GA A366,or equal, steel.
11.0	One (1)	Gas distribution rapping systems, heavy duty tumbling hammer type complete with drive.
12.0	861	Collecting plates, 500 mm wide, fabricated from roll-formed 18 GA A366, or equal, steel sheet
13.0	123	Shock bar anvils, fabricated from carbon steel bar stock and angle, mounted on the suspension iron at the top of each row of collecting plates.
14.0	Three (3)	Collector plate rapping systems, heavy duty tumbling hammer type complete with drive.
15.0	Three (3)	Frames for discharge electrodes comprised of suitable braced vertical and horizontal structural members, complete with four-point suspension arrangement to avoid warping and misalignment (rigid type construction).
16.0	Three (3)	Sets of rigid type discharge systems comprising of framework with four-point suspension arrangement to avoid warping and misalignment and rigid discharging electrodes (RDEs) arranged in three (3) vertical levels in order to maintain proper alignment and to minimize electrode swaying.
17.0	Sixty (60)	Shock anvils fabricated from MS. bar stock mounted at the top of the discharge electrode frames.
18.0	Three (3)	Discharge electrode system heavy duty tumbling hammer type complete with drive.
19.0	One (1)	Temporary high voltage support frame lifting “J” hooks and electrode replacement tool.
20.0	One (1)	Set of portable grounding rods and “High Voltage” warning signs.

21.0	Three (3)	Sets of insulators, each set consisting of:	
		4	Support insulators for supporting the discharge electrode system (four point suspension).
		1	Shaft insulator for isolating the discharge electrode rapping drive shaft.
		1	High Voltage feed isolation Insulator
		1	T/R removal system consisting of a portable trolley and monorail beam.

Electrical Equipment

The following is a list of the major electrical equipment (per boiler) typically supplied by ALSTOM:

Item	Quantity	Description
1.0	Three (3)	Transformer-rectifiers with silicon diode or the R/C compensated or avalanche type rectifiers, enclosed in a weatherproof tank with a NEMA 3R low voltage junction box. The insulating liquid shall be mineral oil. Each unit will have one negative polarity high voltage bushing. Transformer-rectifier sets are rated for 65 KVDC average, 1100 MADC at modified resistive load. Transformer-rectifier tanks, and radiators shall be manufactured from ASTM-A36 (or equal) steel. Each transformer rectifier set will have an oil drip pan.
2.0	Three (3)	Transformer-rectifier power supply control panels, free standing with louvers, front access only, individual 480V - two pole power contactor, SCR-Thyristor and controls and air cooling fans. The following meters are provided: Primary voltage and current, secondary kilovolts and milliamps. Circuit breakers shall be furnished for each panel.
3.0	Three (3)	EPIC II microprocessor based electrostatic precipitator controller with field energizing optimizing, integrated rapper controller and high speed field bus communication.

4.0	One (1)	Remote Terminal Unit (RTU) operator interface with keyboard and display. One RTU will be installed in T/R line-up and one additional RTU is supplied as a handheld carry around unit.
5.0	One (1)	Key interlock system (Kirk or equal) for access doors and transformer rectifier control panel breakers.
6.0	One (1)	Set of 1 kW Heaters for the lead through support insulators and discharge rapper insulators.
7.0	One (1)	Gateway to interface with Owner's DCS.

4.2.4. Work Not Typically Included

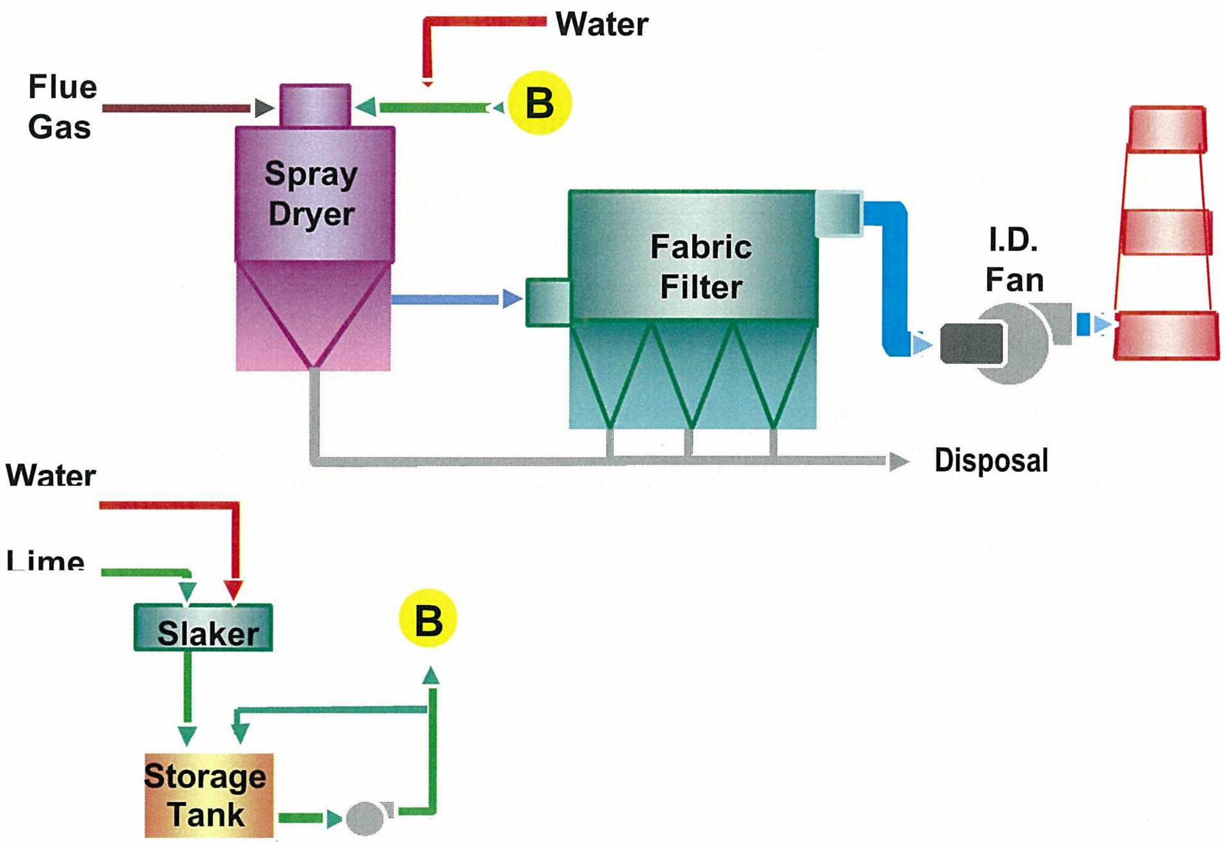
Material Scope Not Included

1. Inlet and outlet ductwork access
2. Test ports and access thereto
3. Support for inlet and outlet ductwork
4. All foundations and anchor bolts
5. Gas Fans (if necessary)
6. Motor Control Centers
7. Dust evacuation system
8. Control Building for ESP control system and MCC's (if required)

4.3. DRY FLUE GAS DESULFURIZATION

4.3.1. Technical Discussion

The Flue Gas Desulfurization System is designed to remove sulfur dioxide (SO_2) and particulate matter released from the coal fired steam generator. This is accomplished by intimately contacting a slurry of calcium hydroxide with the SO_2 laden gases while simultaneously allowing the hot flue gases to dry the reaction products. These dry reaction products are collected with the fly ash in the particulate collector.



Spray Dryer Absorber (SDA)

The flue gas enters the top of the spray dryer absorber and accelerates as it passes through the disperser. At the discharge of the disperser the finely atomized spray of dilute lime slurry is introduced and the gas velocity is abruptly reduced. This produces a highly turbulent flow assuring the slurry droplets are intimately and thoroughly mixed with the gas.

As the gas exits the disperser and travels down the SDA chamber, the SO_2 reacts with the calcium hydroxide to form calcium sulfite and calcium sulfate reaction products. At the same time, the sensible heat of the gas causes the water in the droplets to evaporate, leaving a dry particulate residue suspended in the gas stream. Some of the dry reaction products and fly ash fall out of the gas stream into the absorber bottom and are re-entrained in the exiting flue gases by a constant influx of air from the bottom of the absorber cone. The gas stream carries the remaining products and fly ash to the particulate collector.

4.3.1.1. Process Design Parameters

The following is a summary of the process design parameters for the proposed DFGD:

Fuel	HHV	Ash	C	H	N	O	S	H2O
#6 Fuel Oil	17857 BTU/lb	0.1% (by wt)	87.84%	9.64%	0.49%	0.19%	2.2%	0.1%

Removals & Emissions

The DFGD system is designed to achieve an SO_2 absorbers outlet emission of 0.37 lb/MMBtu while treating approximately 1,650,000 acfm @ 340 °F of boiler effluent flue gas containing a maximum absorbers inlet SO_2 loading of 12,120 lb/hr equivalent to 7.4 lb/MMBtu.

Flue Gas Reheat

Not provided.

Reagent

Lime containing 90% (dry basis) reactive calcium oxide.

By-Product

Disposable by-product

4.3.1.2. Atomization

The AP technology for slurry introduction into the hot flue gas is rotary centrifugal atomization. The atomizer feed slurry is fed to a rapidly rotating disk. The disk imparts centrifugal force to the slurry causing it to pass through openings in the circumference of the disk. As the slurry passes through these openings to leave the disk, it is sheered into very fine droplets. The disk is rotated (11,295 RPM) to achieve proper droplet size.

The absorption of SO_2 is enhanced because the small droplets, which are intimately mixed into the gas stream, have a large total surface area. This large interfacial area promotes the diffusion of gases into the liquid droplets. These gases (SO_2, SO_3, HCl, HF) then react with the calcium hydroxide to form the calcium sulfite/sulfate/chloride/fluoride reaction products.

Alstom Power takes care in the ensuring that the droplet dries neither too quickly, which can hinder and curtail the acid gas absorption reactions, nor too slowly, which can cause "wet bottom." The flue gas temperature at the spray dryer absorber outlet is maintained by controlling the dilution water addition rate to the atomizer.

The spray machine consists of an electric induction motor, a speed increaser gearbox, a flex shaft vibration absorber, and an atomizer wheel. The motor, flex shaft, and atomizer wheel are arranged in a vertical in-line assembly. The motor is coupled to the flex shaft with a spline coupling and the atomizer wheel is pressed onto the output of the flex shaft.

The speed increaser gearbox is conservatively designed to last the life of the plant. The gears are designed for 40,000 hours or more and comply with all applicable American Gear Manufacturers Association (AGMA) standards. Gear replacement is relatively easy and can be accomplished on site by the Customer's maintenance personnel following well-documented procedures. The gearbox is equipped with high-speed shaft bearings (tilting pad journal bearings). The low-speed and idler shaft bearings are rolling contact bearings. The journal bearings are designed for a three-year life at maximum load rating. Lube oil is supplied and cooled by the lubrication system.

4.3.1.3. Reagent Preparation

Lime is delivered pneumatically by self-unloading trucks that blow the lime through a four-inch line from grade to the top of the seven-day capacity lime silo. Pebble lime is fed from the lime bin at the desired rate by a bin activator and rotary or screw feeder to the lime slaker. The lime is mixed with a regulated amount of water to produce lime slurry of 20% solids. This slurry is passed through a vibrating screen to remove grit. The screened lime slurry flows directly to the lime slurry storage tank.

4.3.1.4. Transportation of Reagent

Centrifugal pumps transfer the lime slurry from the storage tank to the slurry control valves. Dilution water is delivered under line pressure to the water control valves.

The control valves are varied automatically, producing the correct flow rate to the atomizers for the desired degree of gas cooling and acid gas control.

4.3.1.5. Pulse Jet Fabric Filter

The fabric filter plant offered incorporates the OPTIPULSE bag pulse cleaning system. This design concept, which is unique to ALSTOM Power, was developed in the early nineteen seventies (1970s), and is well-proven and reliable and has been utilized in hundreds of filter plants.

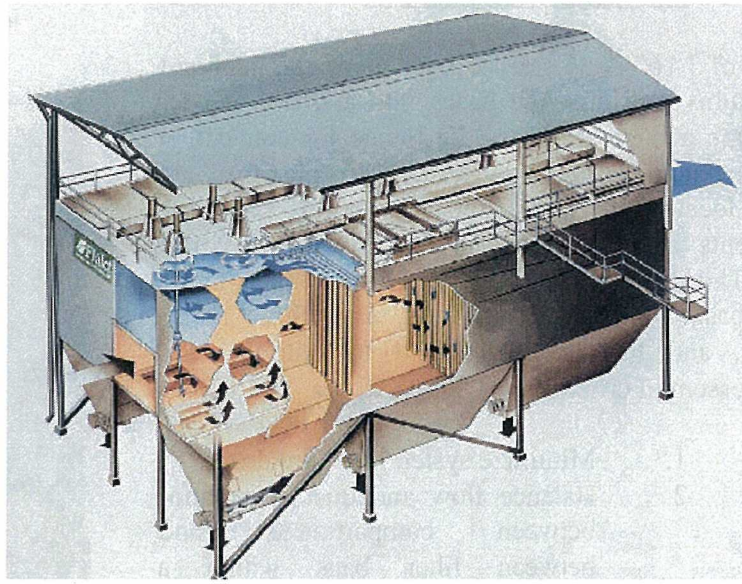
OPTIPULSE offers the following main exclusive features:

- Higher efficiency in converting medium pressure compressed air into pulse pressure in the filter bag than that of traditional high pressure (> 60 psi) designs. As a result, low-pressure oil free compressors can supply pulse air with consequential savings in capital cost, operating costs, and maintenance costs.

- Pulse air injected directly into the filter bags with only a limited amount of entrained secondary gas means less dispersion of the kinetic energy in the primary jet. This gives high propagation velocity of the pulse pressure along filter bags of up to 26 ½' in length. Importantly, the pulse overpressure over the length of the bag is higher than in high-pressure and low-pressure design baghouses.

- Cleaning energy consumption and specific air volume is low due to the fast mechanical action of the low pressure pulse valve which ALSTOM POWER has developed to provide the required fast opening and closing actions. The essential cleaning action takes place when expanding the filter bag from its filtering position with little benefit from further extending the pulse length after the filter bag has been inflated.

- The pulses are accurately directed into the center of each filter bag. This alignment is established during construction and due to the static nature of the pulse pipes remains accurate. Therefore, cleaning remains at peak efficiency over the entire lifetime of the plant.



Typical LKP Baghouse

4.3.1.6. Fabric Filter Compartments

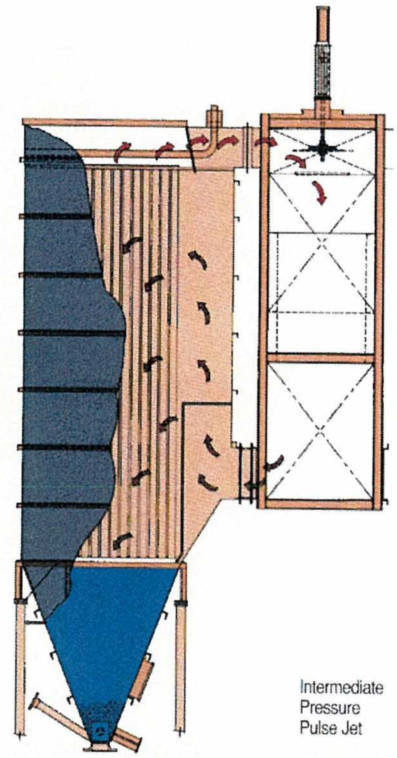
Each compartment casing is a gas-tight design to house the filter bags and their associated equipment. The fabric filter is designed to operate within guarantee limits at the design gas flow. The compartment casings are constructed of 3/16" A-36 steel or equivalent. Access to each compartment is achieved through top lift-off access doors. The doors are constructed of 3/16" A-36 or equivalent, and are sealed. The doors provide access to the nozzle tubes, bags and cages at the tubesheet level.

A penthouse-style enclosure frame with ventilation will be supplied.

4.3.1.6.1. Inlet and Outlet Plenums

Fabricated of 3/16" A-36 steel or equivalent, the inlet and outlet plenums distribute the gases into and out of each compartment, and provide a single flange for connecting to the inlet and outlet ductwork. The plenums are centrally located between the two (2) rows of compartments and connected to each by an isolation damper. The design of the plenums used in the fabric filter is based on years of field and flow model experience, and has been designed to optimize the following essential criteria:

1. Minimize system pressure drop.
2. Balance flow and dust distribution between compartments and between filter bags within a compartment.
3. Minimize the potential for dust dropout in the inlet plenum.



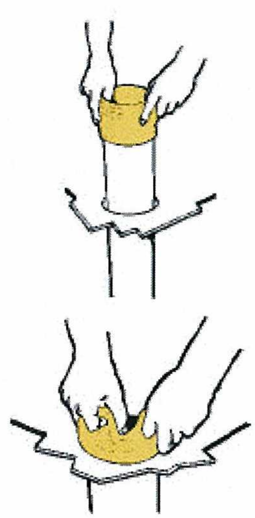
Typical LKP Plenum Arrangement

4.3.1.7. Tubesheet

The tubesheets are fabricated of 1/4" A-36 steel or equivalent with stiffening as necessary to support the imposed dead and live loads. Each tubesheet is seal welded to the housing and separates the clean and dirty sides of the compartment. It serves as a filter bag inspection platform inside the compartment. The filter bags are inserted through the tubesheet and held in place by a stainless steel snap band.

4.3.1.8. Filter Bags

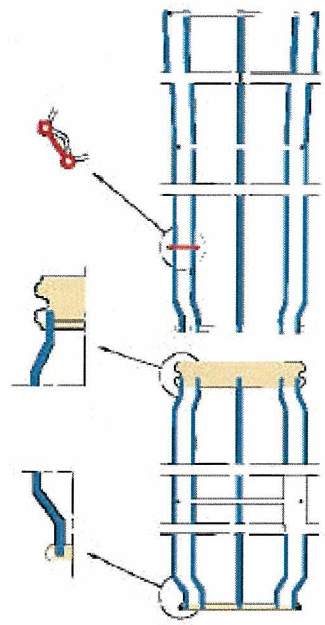
Each of the filter bags is 5 1/8" in diameter and nominally 26'-6" long. A four-inch (4") cuff is sewn at the bottom and top of the bags. Also, a metal snap band is sewn into the top cuff of the bag. This seals the bag to the tubesheet.



Snap-Band Installation of LKP Filter Bags

4.3.1.9. Bag Cages

All cage wires are 16 wire/ eight gauge to provide adequate cage strength for handling and transportation while also reducing the local internal stresses in the fabric along the fold lines. The cages incorporate a separate metal top-supporting ring to provide positive cage location, alignment, and support, and a separate metal bottom cap. These features of the ALSTOM Power filter bag cage accommodate thermal expansion of the cage / filter bag and tolerances on manufactured lengths of cage / filter bag. Cages are of a "split design" in two pieces each for ease of removal.



Typical LKP Filter Bag Cage (No Tools required for disassembly)

4.3.1.10. Pulse Air Cleaning System

The filter bags are cleaned by means of compressed air pulses that are directed down through the filter bag's opening. The compressed air expands the bag with such a strong acceleration that dust particles on the outside of the bag are loosened when the bag later contracts. The compressed air is directed down into the bags via a pulse pipe provided with nozzles. The nozzles are specifically designed to reduce flow losses to a minimum. The compressed air pulse is extremely short (approximately 0.1 s) and adjustable. The entire cleaning operation, which occurs while the filter bags are in full operation, consumes little energy.

Distribution of air in short pulses is done by means of a patented valve. The pulse repetition frequency can either be constant or controlled by the resistance over the filter bags. Resistance-controlled cleaning by means of a PLC is especially suitable for varying operational conditions. The practical solution to the problem of pulse regulation involved, among other elements, a unique ALSTOM POWER valve design OPTIPOW for which a patent has been applied for.

4.3.1.11. Pulse Air System Cleaning Cycle

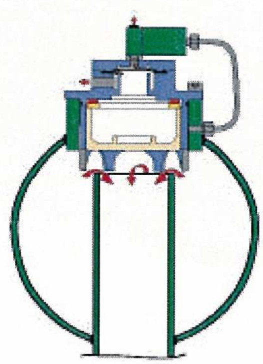
Filter bag cleaning is controlled by a set pressure differential across the filter. The bandwidth of the variation in filter pressure differential can be selected arbitrarily narrow corresponding to the number of filter bag rows that are pulse cleaned (down to one (1) row or module respectively) when cleaning is initiated. The fluctuation in the flue gas pressure at the source's outlet terminal point can thus be minimized.

If the pressure differential set point is not reached within a set period of time after the previous cleaning pulse, due to reduced load or for some other reason, the cleaning will be carried out at constant intervals. This will limit the amount of dust accumulated on the filter bags and limit the increase in differential pressure during a rapid load increase.

During the initial operating period and after commissioning, adjustment of the filter differential (or drag) set point as well as the pulse air pressure will take place. The settings are adjustable and each fabric filter installation should be set up for its own conditions. An optimum timing sequence should be determined by taking into account the minimum pressure loss vs. frequency of cleaning and filter bag life vs. outlet emissions.

4.3.1.12. OPTIPOW Pulse Valve

Proprietary valves have conventionally been used on most pulse jet filters. The maintenance requirements and lifetime of standard valves do not meet ALSTOM Power's requirements.



OPTIPOW Pulse Valve (open)

In 1975, ALSTOM Power, together with ASCO, developed an improved valve. This design has been extensively proven in the field on OPTIPULSE filters and refined in a number of ways to further extend the reliability. Following a thorough review of the development and operating history of the pulse valve, ALSTOM Power has continuously designed further improved versions, which incorporate state of the art plastic components specifically included to withstand corrosion, temperature, mechanical stresses, and shock loading. This design was subjected to extensive prototype testing and has been in service for several years.

4.3.1.13. Tanks and Nozzle Pipes

Pulse air for filter bag cleaning is evenly distributed by means of pipes arranged above each row of filter bags. These pipes have a nozzle for each filter bag, which is designed to direct the pulse air directly into the center of the filter bag.

Nozzle pipes are four inch (4") nominal mild steel plate assembled into fittings so that they may be easily lifted out and replaced during bag changing operation.

The pulse tanks with the pulse air solenoid valves integrally mounted are located on the outside of the compartment roof and pulse air is distributed to each filter bag via a distribution pipe which is an integrally welded part of the pulse tank assembly.

Typical LKP Nozzle Pipe Assembly

4.3.1.14. Dampers

All outlet and bleed-in dampers are pneumatically operated poppet type valves to ensure positive opening, closing, and sealing. The inlet damper is a manually operated butterfly damper.

4.3.2. Performance

4.3.2.1. Performance Predictions

Following the completion of the installation of the equipment for the DFGD system described ALSTOM predicts the following performance based upon the stated process design parameters:

Unit/Boiler Data			
No. Units:		3	
Gross Generation/Unit:	MW	175	
Fuel		Oil	
Sulfur Content	%	2.2	
		Per Boiler	Total Plant
Fuel Firing Rate	lb/hr	91,827	275,480
Flue Gas Generation	acfm	551,950	1,655,850
SO2 Production	lb/hr	4,040	12,121

FGD Performance Data			
SO2 Removal Efficiency	%	95	
Lime Purity	%	90	
		Per Boiler	Total Plant
Lime Consumption	lb/hr	7,322	21,966
	ton/hr	3.7	11.0
Make-Up Water Consumption	gpm	142	425
Total DFGD Power Consumption	kW	656	1,969
% of Gross Generation	%	0.38	

4.3.3. Materials and Services

The following is a listing of the major equipment included within the scope of the DFGD system.

Item	Quantity	Description
1.0	Two (2)	SDA towers
2.0	One (1)	Reagent handling/preparation (including two slaking systems)
3.0	One (1)	Fabric Filters (one LKPB type)
4.0	As Req'd	Ducts/dampers
5.0	As Req'd	Electrical (switchgear, MCCs, cable, raceway)
6.0	As Req'd	Piping and supports
7.0	As Req'd	Structural support/access steel
8.0	One (1)	DFGD building (control/electrical, pump, equipment)

Note that the Holyrood Generating Station Master Site Plan Drawing B1-1403-121-C-003 Rev 8 was used to investigate the feasibility of locating the above recommended equipment arrangement at this site. Although a more detailed investigation and discussion with site would have to take place, it appears as though it would be feasible. The equipment above has been superimposed onto a portion of this site plan, and for reference, this layout sketch is contained in Appendix A.

4.3.4. Work Not Typically Included

Material Scope Not Included

1. FD/ID Fans
2. Ash Handling System
3. BOP
4. Foundations / Civil Works
5. Reagents, Lubricants, and Precoats
6. Performance Testing
7. Fire Protection
8. Communication System
9. CEMs

4.4. WET FLUE GAS DESULFURIZATION

4.4.1. Technical Discussion

Wet flue gas desulfurization (WFGD) systems are employed to remove sulfur dioxide (SO_2) produced during the combustion of coal or oil in utility power stations. Sulfur dioxide is believed to cause adverse health effects as well as contributing to the destruction of structures and damage to wildlife and vegetation through acid rain. The following is a general description of ALSTOM Power's limestone, forced oxidation WFGD system. These systems remove up to 98% of the acid constituents present in flue gas by scrubbing with limestone. Gypsum, which may be sold or landfilled is produced as a byproduct.

4.4.1.1. Process Design Parameters

The following is a summary of the process design parameters for the proposed DFGD:

Fuel	HHV	Ash	C	H	N	O	S	H2O
#6 Fuel Oil	17857 BTU/lb	0.1% (by wt)	87.84%	9.64%	0.49%	0.19%	2.2%	0.1%

Removals & Emissions

The DFGD system is designed to achieve an SO_2 absorbers outlet emission of 0.37 lb/MMBtu while treating approximately 1,650,000 acfm @ 340 °F of boiler effluent flue gas containing a maximum absorbers inlet SO_2 loading of 12,120 lb/hr equivalent to 7.4 lb/MMBtu.

Flue Gas Reheat

Not provided.

Reagent

Limestone (100% < 18 mm) and ground limestone (90% < 44mm) containing 95% (dry basis) reactive calcium carbonate.

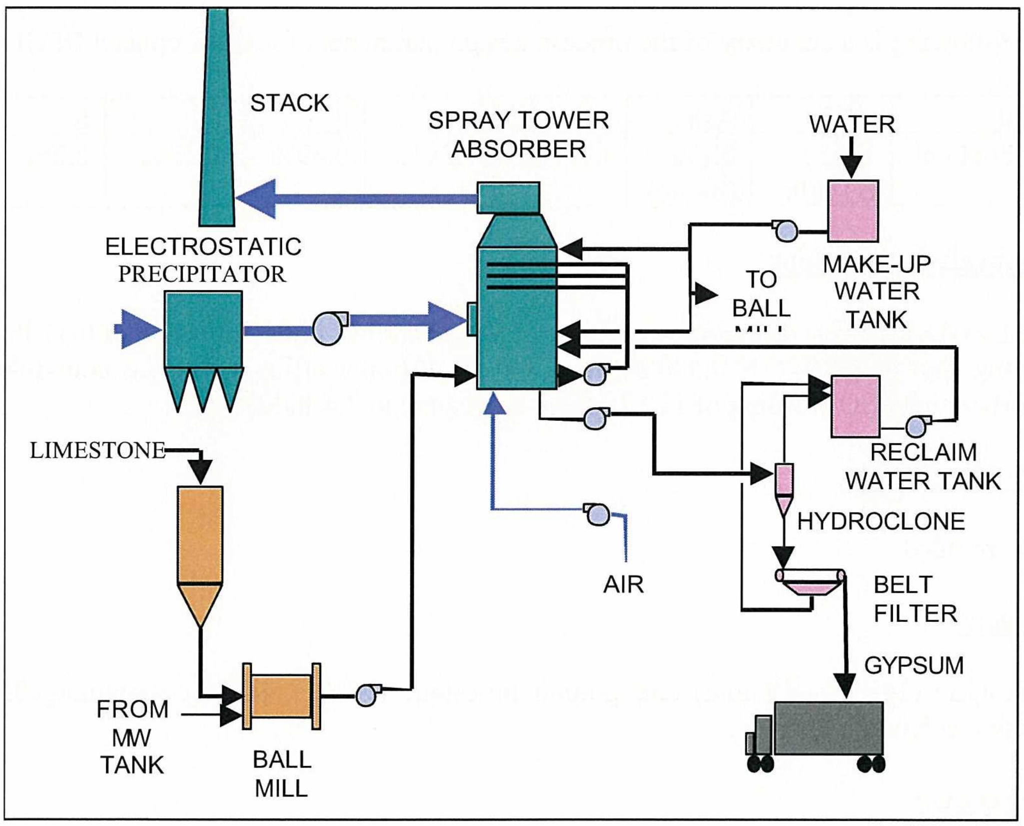
By-Product

The FGD system will produce commercial grade gypsum containing approximately 95% $CaSO_4 \cdot 2H_2O$ at 90% solids content.

4.4.1.2. WFGD Process Flow Diagram

Flue Gas Path

For boiler capacities less than approximately 1,000 MWe, a single absorber is fitted to each boiler unit. The flue gas is combined downstream of the boiler ID fans and taken directly to the WFGD system. After being treated in the absorber tower, the flue gas is discharged through a wet stack. The entire gas stream is treated in the absorber.
Induced draft (ID) fans provide the draft to overcome the pressure drop across the boiler, ESP, and FGD system. The absorber(s) discharge directly to the stack, without reheating. In most cases, absorber inlet or outlet dampers are not required unless a single absorber is coupled to multiple boilers. In that case, isolation dampers are generally provided to permit the boilers to operate independently of the WFGD system.



WFGD Process Flow Diagram

Flue Gas Path

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Alternatives

In the event that stack gas temperature requirements (e.g. 80 °C) are imposed by local regulations, reheat can be provided. Alternatives include gas-to-gas reheater (GGH), liquid couple heat exchangers, partial bypass, and heated air injection.

In a retrofit situation, booster fans may be furnished if the boiler ID fans are not able to provide the required draft. Typically, axial flow fans provide the optimum solution for this high-flow, low-head application.

Materials

The WFGD system flue gas ductwork is fabricated of carbon steel. The absorber inlet duct (between the absorber expansion joint and the vessel wall) will be lined with C-276 alloy to prevent corrosion. The ductwork between the absorber outlet flange and the chimney breeching flange will also be protected against corrosion by metallic or organic linings.

4.4.1.3. Absorber

Absorption

Open spray tower absorbers that range in size from 20 to 65 feet in diameter, are used to provide intimate contact between the flue gas and the scrubbing liquid. These absorbers are constructed with various types of alloys, stainless steels, and mild steel with various corrosion/erosion resistant linings.

The flue gas enters the spray tower near the bottom through an inlet transition. Once in the absorber, the hot flue gas is immediately quenched as it travels upward countercurrent through a continuous spray of process (recycle) slurry produced by a series of independent spray banks. The recycle slurry, which is a suspension of limestone and gypsum, extracts the majority of the sulfur dioxide (SO_2) from the flue gas. Once in the liquid phase, the sulfur dioxide reacts with the dissolved calcium carbonate (limestone) alkali to form dissolved calcium sulfite. In addition to removing sulfur dioxide, other acid gases present, such as hydrogen chloride (HCl) and hydrogen fluoride (HF), are removed as well.

The quantity of recycle slurry needed to effectively remove the specified amount of SO_2 is determined by a parameter known as the liquid-to-gas ratio (L/G). The choice of the L/G is based on the supplier's experience in design and operation of full scale units in conjunction with an ongoing research and development effort in such areas as oxidation, process effects of dissolved chloride ion and reagent particle size.

The absorbers generally have 2 to 4 installed spray banks (levels). Each spray level is fed through an individual riser by a dedicated recycle pump. The requirement for spare spray pumps/levels is decided on a case-by-case basis depending on regulatory, customer, and availability requirements.

Each spray level consists of tangential-inlet, hollow cone spray nozzles manufactured of nitride-bonded silicon carbide. This nozzle type provides the proper sized droplets for optimum SO_2 absorption, typically a $d_{50} < 2{,}000\ \mu m$.
When viewed from above, the pattern of spray cones produced by the spray nozzles appears as an array of overlapping circles. Great care is exercised in the layout of the nozzles to ensure overlap so that there are no voids through which flue gas can pass unscrubbed.

Reaction Tank

The recycle slurry falls from the spray zone into the reaction tank that forms the base of the absorber. This tank is sized to provide sufficient residence time for all of the WFGD chemical reactions to take place; for the design sulfur coal, the liquid turnover time is generally about 4 minutes and the solids residence time is 15-30 hours. Fresh reagent slurry is added to the reaction tank where it reaches equilibrium with the bulk of the recycle slurry prior to being returned to the spray banks by the recycle pumps.

Gypsum bleed pumps discharge slurry to the primary dewatering system to maintain the desired reaction tank slurry concentration and liquid level.

Forced Oxidation

Forced oxidation of the recycle slurry in a limestone wet FGD system produces byproduct that can be more easily handled and utilized than the byproduct from partially or non-oxidized systems. To produce fully oxidized byproduct, a centrifugal blower supplies compressed air to a sparging system in the reaction tank. The oxygen in the air converts the dissolved calcium sulfite ($CaSO_3$) to calcium sulfate ($CaSO_4$), which then crystallizes as $CaSO_4 \bullet 2H_2O$, gypsum.

The oxidation air, which has been heated in the compression process, is quenched and saturated with a stream of clean process water. This is done to prevent any scaling or buildup that could occur at the sparger tips due to localized evaporation of recycle slurry.
Mist Elimination: After leaving the spray zone, the scrubbed gas flows upward through a two-stage mist elimination system. The stages consist of multi-pass chevron baffles that remove entrained slurry droplets by inertial impaction. The first stage chevrons act as a barrier to keep the major portion of process slurry droplets entrained in the gas stream from leaving the absorption zone. The small fraction of entrained droplets that passes through the first stage mist eliminator is removed by the second stage.

The front face of the first stage mist eliminator is washed intermittently in zones with a stream of process water. The back face of the first stage mist eliminator and the front face of the second stage mist eliminator are washed simultaneously, also on an intermittent, zone basis, with a stream of fresh process water. The mist eliminator wash cycles, flux rates and pressures have been designed to provide effective rinsing of any solids or chemically reactive liquids.

Absorber Island Materials

The goal of the material selection strategy for the absorber island is to ensure continuous, reliable operation between maintenance outages at the lowest lifecycle cost. The absorber shell - from the reaction tank sidewall through the outlet cone – can be fabricated in a variety of materials, depending upon the absorber slurry steady state chloride concentration. Material selection includes mild carbon steel with corrosion and abrasion resistant lining, corrosion resistant stainless steel, alloys, FRP and concrete. Agitator shafts and impellers are manufactured of corrosion resistant stainless steel. Oxidation air sparge lances and recycle spray headers as well as the mist eliminator wash piping are made of fiberglass reinforced plastic (FRP). The mist eliminator blades are manufactured of polypropylene.

4.4.1.4. Reagent Preparation and Slurry Delivery

Limestone is generally delivered either as a crushed (3/4 x 0 in) stone or pre-ground (90-95% < 40 µ) powder. For large (>300 MWe) systems, economics usually favor the delivery of crushed stone and on-site grinding with wet ball mills.

Limestone Storage

Outdoor, uncovered, long-term on-site storage of crushed limestone is possible in most locations. In extreme climates, covered storage may be required. Limestone is conveyed from the long-term storage area to a day silo, which is sized to contain 16-24 hours supply.

Limestone Grinding

Limestone is fed from the day silo via a weigh belt feeder to a wet ball mill. The wet ball mill consists of a rubber-lined cylinder filled with hardened steel balls. In the ball mill, water is added and limestone is pulverized by the action of the balls as the mill rotates. Process make-up water is used for preparation of the limestone slurry, which is delivered to the reagent feed tanks for storage and use by the FGD system.

Slurry Feed

The reagent feed tank is sized to contain limestone slurry sufficient for 8 hours of operation of the entire plant at full load and design sulfur content. Reagent slurry is transported from the reagent feed tank to the FGD absorbers through the use of a recirculating feed loop.

Reagent slurry is added to the reaction tank in response to two control signals. The primary control is a feedforward loop driven by the SO_2 concentration in the flue gas entering the FGD system. The pH in the reaction tank drives a feedback loop that trims the feed valve. The pH-trimmed system responds rapidly, is essentially independent of plant load, and is therefore highly stable.

Materials

The day silo is fabricated of mild steel with a stainless steel or polymeric lining in the hopper. The ball mill is rubber lined steel. The reagent feed tank is fabricated of carbon steel with an abrasion- and corrosion-resistant flakeglass lining. The piping of the feed loop and stubs is manufactured of rubber-lined carbon steel, in order to ensure high resistance to abrasion during permanent operation at economic pipe velocities.

4.4.1.5. Dewatering and Product Handling

Primary Dewatering

Gypsum product slurry is pumped from the reaction tank by means of the gypsum bleed pumps to a cluster of hydrocyclone classifiers that separate the slurry into a low density stream of fines (the overflow) and a high density stream of coarse crystals (the underflow). In so doing, the hydrocyclones also classify the slurry chemically. Unreacted limestone is relatively fine and preferentially reports to the overflow; while the byproduct gypsum is a coarser material and it preferentially reports to the underflow. One dedicated set of hydrocyclones is provided for each absorber in a multi-unit application; the sets are combined in one hydrocyclone cluster assembly, if possible. Installing a spare cyclone in each set of hydrocyclones provides redundancy.

A gypsum bleed pump feeds each set of hydrocyclones whenever the solids content in the reaction tank reaches the upper value of the control range, and the feed is bypassed once the lower value of the control range is reached. The majority of the overflow from the hydrocyclone classifiers flows by gravity directly back to the respective reaction tanks. A portion of the overflow is available by gravity as blowdown stream to control and limit the chloride content in the reaction tanks, whenever the hydrocyclone is in operation.

The hydrocyclone underflow product flows by gravity directly onto the operating belt filter.

Secondary Dewatering

Horizontal belt vacuum filters are provided for secondary dewatering. The concentrated byproduct gypsum slurry flows from the primary dewatering hydrocyclone underflow to the belt filter. The gypsum slurry is vacuum-dewatered to produce a cake comprised of at least 90 percent byproduct gypsum solids and not more than 10 percent residual moisture. The belt filter includes equipment for washing of the gypsum cake during dewatering to reduce the concentration of soluble materials - particularly chloride ions - in the byproduct gypsum. Cooling tower blowdown is foreseen for washing of the cake as long as the concentration of soluble components are significantly lower than the corresponding values allowed in the final gypsum cake.

In the event that a drier byproduct is desired, centrifuges can produce moisture levels as low as 7-8%.

Byproduct Storage & Handling

Several alternatives are available for product transport and storage. In the simplest case, the belt filters are installed above ground level and the gypsum falls directly into a bunker or silo. In other cases, the gypsum is transferred from the filters to a storage building via belt conveyors. The building can be equipped with stackers and reclaimers for ease of handling.

4.4.1.6. Water Handling

Filtrate Water

Filtrate from the vacuum filters is collected in the FGD area sump, which is designed to accommodate this additional flow in addition to the runoff from all area trenches. Filtrate, along with the other sump contents, is pumped back to the reaction tank(s) as a function of the sump level.

Process Water

Process make up water for FGD systems is typically taken either from a nearby river/lake (clean water), or from the on-site waste water (cooling tower blowdown) supply. Other sources such as seawater, ash pond water, coal pile run-off, etc. can be considered. The need for pumps, storage tanks, and piping must be coordinated with the customer.

Process water will be boosted to a higher pressure by the mist eliminator wash pumps to satisfy the pressure requirements for the mist eliminator wash nozzles at their elevated location.

The majority of the process water will be used to maintain water balance in the absorber (reaction tank level control). Smaller amounts will be used for mist eliminator wash and secondary dewatering. All occasional equipment and pipe flushes will be performed with process water.

Chloride Bleed Stream

The absorber system is typically designed from a materials and performance standpoint for a dissolved chloride level in the absorbing slurry and related streams of 15,000 – 20,000 ppm. Due to the water balance requirements when producing wallboard quality gypsum, additional chloride ion and other dissolved solids must be bled from the system in another stream to prevent accumulation to excessively high levels. A controlled side-stream of hydrocyclone overflow is discharged by gravity as blowdown to a waste water treatment system or disposal pond in order to maintain the required maximum system chloride concentration.

4.4.2. Performance

4.4.2.1. Performance Predictions

Following the completion of the installation of the equipment for the WFGD system described ALSTOM predicts the following performance based upon the stated process design parameters:

Unit/Boiler Data			
No. Units:		3	
Gross Generation/Unit:	MW	175	
Fuel		Oil	
Sulfur Content	%	2.2	
		Per Boiler	Total Plant
	lb/hr	91,827	275,480
Fuel Firing Rate	acfm	551,950	1,655,850
Flue Gas Generation			
SO2 Production	lb/hr	4,040	12,121

FGD Performance Data			
SO2 Removal Efficiency	%	95	
Limestone Purity	%	95	
Gypsum Purity	%	95	
Gypsum Moisture	%	10	
		Per Boiler	Total Plant
Limestone Consumption	lb/hr	6,502	19,507
	ton/hr	3.3	9.8
Gypsum Production	lb/hr @ 10% moisture	12,065	36,195
	ton/hr	6.0	18.1
Make-Up Water Consumption	gpm	315	945
WFGD Power Consumption	kW	2,600	7,800
Booster Fan Power Consumption	kW	600	1,800
Total Power Consumption	kW	3,200	9,600
% of Gross Generation	%	1.8	

4.4.3. Materials and Services

The following is a listing of the major equipment included within the scope of the WFGD system.

Item	Quantity	Description
1.0	One (1)	Absorber island (including one absorber, recycle pumps, spray levels and mist elimination system)
2.0	One (1)	Reagent handling/preparation (including one ball mill complete with accessories, limestone silo, powder limestone back-up system)
3.0	One (1)	Gypsum dewatering/storage (including one hydrocyclone and one horizontal vacuum belt filter with accessories)
4.0	As Req'd	Ducts/dampers
5.0	As Req'd	Booster fans
6.0	As Req'd	Foundations
7.0	As Req'd	Electrical (switchgear, MCCs, cable, raceway)
8.0	As Req'd	Piping and supports
9.0	As Req'd	Structural support/access steel
10.0	One (1)	WFGD building (control/electrical, pump, equipment)

Note that the Holyrood Generating Station Master Site Plan Drawing B1-1403-121-C-003 Rev 8 was used to investigate the feasibility of locating the above recommended equipment arrangement at this site. Although a more detailed investigation and discussion with site would have to take place, it appears as though it would be feasible. The equipment above has been superimposed onto a portion of this site plan, and for reference, this layout sketch is contained in Appendix A.

4.4.4. Work Not Typically Included

N/A

5. PRICE AND SCHEDULE

5.1. PRICING

5.1.1. Capital Costs

The following are order of magnitude capital costs (Design, Supply, Installation) for the scope of equipment described in this report for each system:

	Unit 1	Unit 2	Unit 3
Firing System Technologies			
T-Fired In-Windbox Low NOx Mod's	$700,000.00	$700,000.00	N/A
T-Fired SOFA Based Low NOx System	$3,700,000.00	$3,700,000.00	N/A
Wall Fired Low NOx Burner	N/A	N/A	$1,300,000.00
Wall Fired SOFA Based Low NOx System	N/A	N/A	$2,700,000.00
SNCR Process	$4,100,000.00	$4,100,000.00	$4,100,000.00
Capture Technologies			
Mechanical Collector	$2,000,000.00	$2,000,000.00	$2,000,000.00
Electrostatic Precipitator	$6,000,000.00	$6,000,000.00	$6,000,000.00
Dry Flue Gas Desulfurization System		$60,000,000.00	
Wet Flue Gas Desulfurization System		$95,000,000.00	

All costs are in Canadian Dollars.

The above prices are present day estimated prices only and are not given by ALSTOM Canada Inc. as an offer, nor as terms of any contract, nor as an undertaking that the estimated price shall be the final price.

Note that the above numbers are representative only of the scope of equipment discussed in the report. There is other capital equipment required for most of the options noted above, and this other equipment in some cases can have a significant impact on the total capital cost, however, this additional equipment was not sized or estimated as part of the scope of this report, but these issues could be investigated further if the study direction focuses on specific technologies in Phase III.

5.1.2. Operating & Maintenance Costs

5.1.2.1. Firing System Technologies

The Firing System Technologies do not have large operating costs associated with them since they do not require new equipment which has high power consumption, or the requirement for additonal operating staff. Maintenance requirements do increase moderately since additional inspections should be performed during annual outages, and the new equipment and instruments require typical maintenance attention. In general the firing system technologies discussed do not have a significant affect on yearly operating and maintenance costs.

The SNCR NOx OUT system by Fuel Tech Inc is a relatively inexpensive NOx reduction technique when considering the capital costs compared with the predicted reductions in emissions, however, the technology comes with high operating costs. The system consumes approximately 140 gallons per unit, per hour (gph) of urea. The yearly consumption costs of urea could range between $1,000,000 to $1,500,000 CDN per unit depending upon the capacity factor of the unit.

5.1.2.2. Capture Technologies

The following table summarizes the typical maintenance and operating costs associated with the capture technologies discussed in this report. Note that although there is no specific power consumption associated with the Mechanical Collector, the pressure drop associated with this system would likely result in the requirement for a new fan, which would consume additional power. The selection and sizing of fans was not considered during this preliminary review of the different technologies.

	Maintenance Requirements	**Maintenance Costs**	**Power Consumption**
Capture Technologies	Yearly Outage Inspection	Yearly Estimate	Yearly Estimate
Mechanical Collector	(1-2 days)	$5,000	None
Electrostatic Precipitator	(3-5 days)	$24,880	208.5 kW
Dry Flue Gas Desulfurization	(3-5 days)	3% Capital Cost	No Data Available
Wet Flue Gas Desulfurization	(10 days)	No Data Available	1.2% - 1.5% of Generation

All costs are estimated in Canadian Dollars.

5.2. SCHEDULE

5.2.1. Typical Lead Times

The following are typical time spans from Notice to Proceed to Initial Operation for the scope of equipment described in this report for each system:

	Span
Firing System Technologies	
T-Fired In-Windbox Low NOx Mod's	< 12 months
T-Fired SOFA Based Low NOx System	< 12 months
Wall Fired Low NOx Burner	< 12 months
Wall Fired SOFA Based Low NOx System	< 12 months
SNCR Process	< 12 months
Capture Technologies	
Mechanical Collector	< 12 months
Electrostatic Precipitator	12-14 months
Dry Flue Gas Desulfurization	24 months
Wet Flue Gas Desulfurization	32 months

APPENDIX A – DRAWINGS

Capture Technology Drawings

Multicyclone Mechanical Collectors

20037-GA-200-002 Rev AA Mechanical Collector General Arrangement

Dry Electrostatic Precipitator

20037-GA-200-001 Rev AA Electrostatic Precipitator General Arrangement
Holyrood Site Plan ESP Location

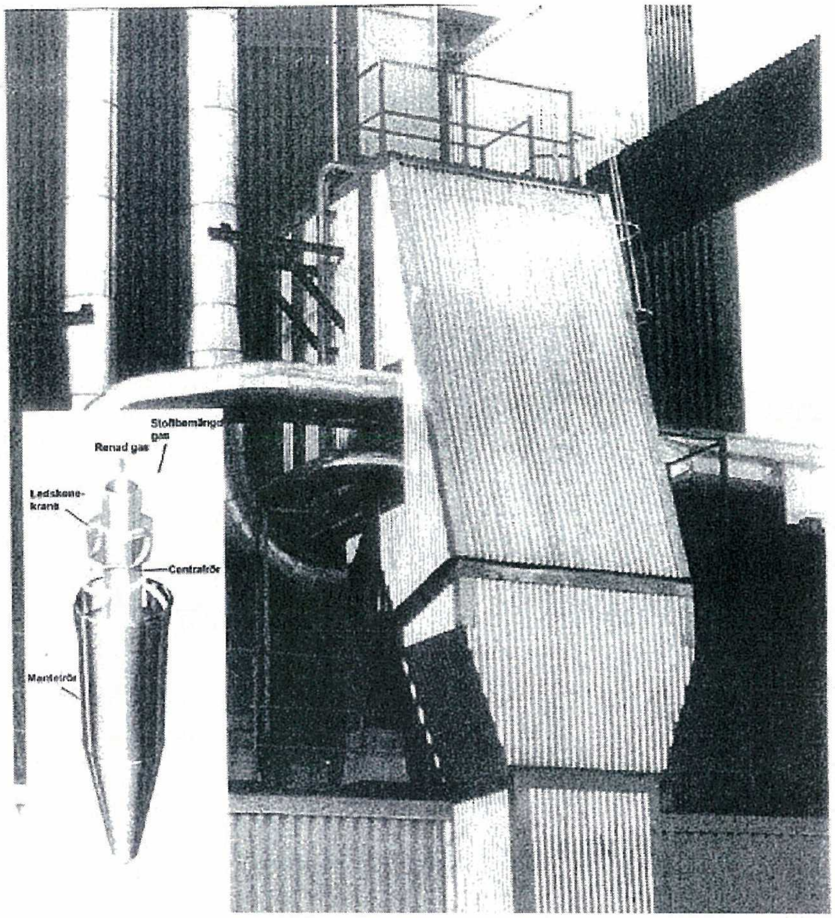
Dry Flue Gas Desulfurization

Typical Arrgt SDA and LKP Fabric Filter Side Elevation
Typical Arrgt SDA and LKP Fabric Filter Plan View
Holyrood Site Plan DFGD Location

Wet Flue Gas Desulfurization

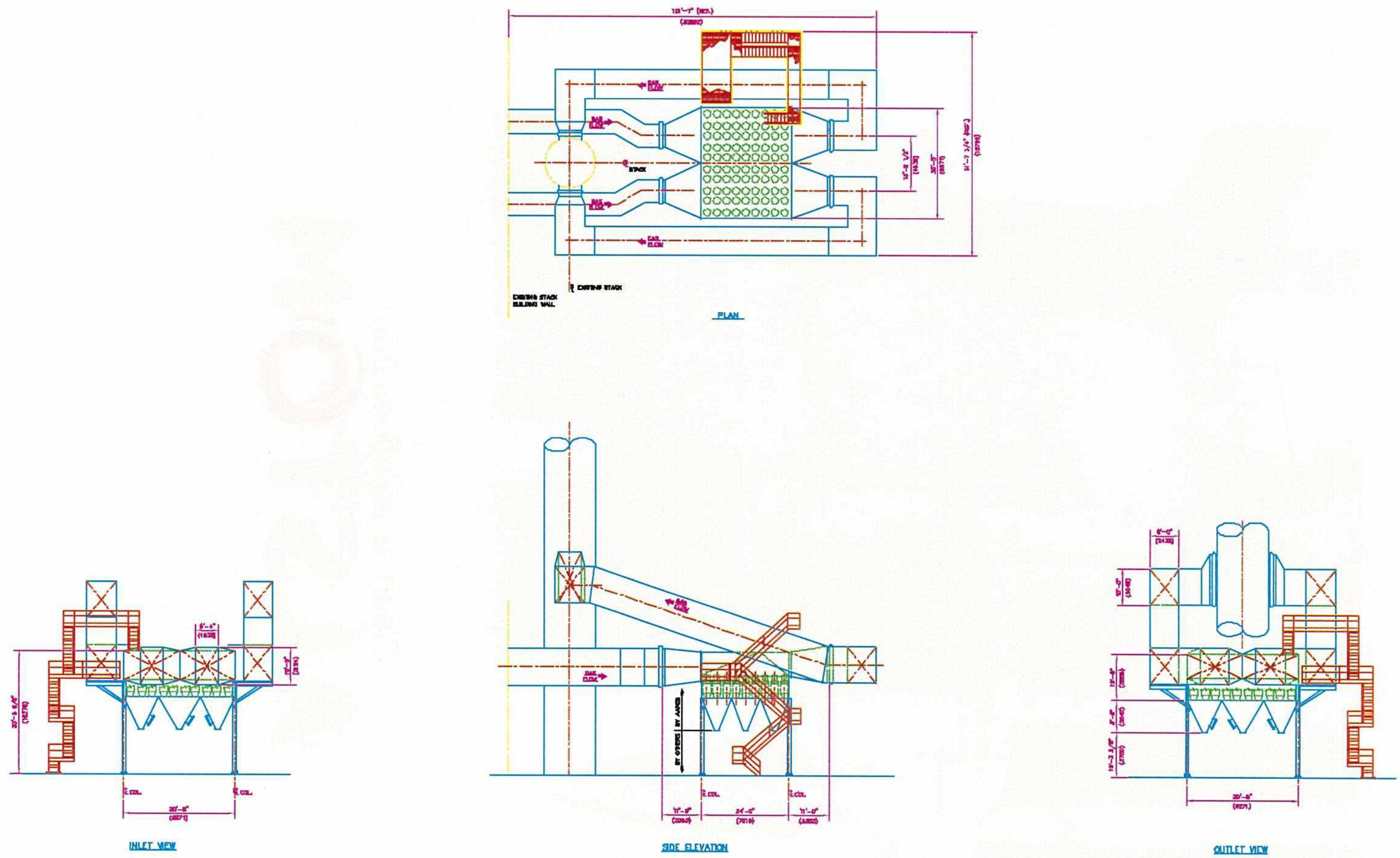
Typical Absorber Arrangement
Typical WFGD Arrangement
Holyrood Site Plan WFGD Location

MULTICYCLONE MECHANICAL COLLECTORS



Clean air solutions from

ALSTOM



REV.	DESCRIPTION	DRAWN / APPR.	DATE

ABB
ASEA BROWN BOVERI

ABB ENVIRONMENTAL SYSTEMS

SCALE: NONE
ABB REFERENCE NUMBER: 20037
DRAWN BY: F.McPHERSON DATE: 5/14/02

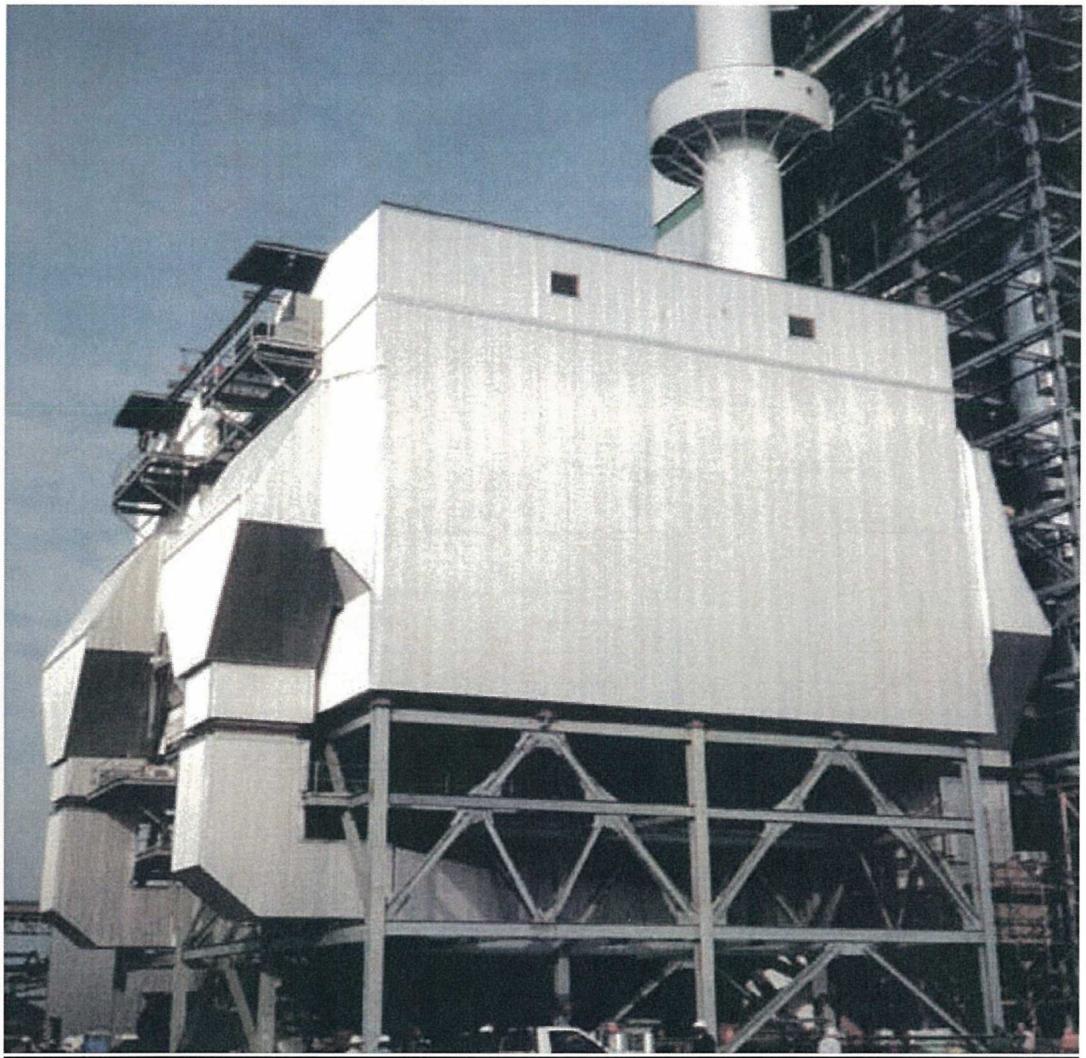
NEWFOUNDLAND AND LABRADOR HYDRO
HOLYROOD GENERATING STATION
OPTION 1 – MECHANICAL COLLECTOR

GENERAL ARRANGEMENT

DWG. NO. 20037-GA-200-002 REV. AA

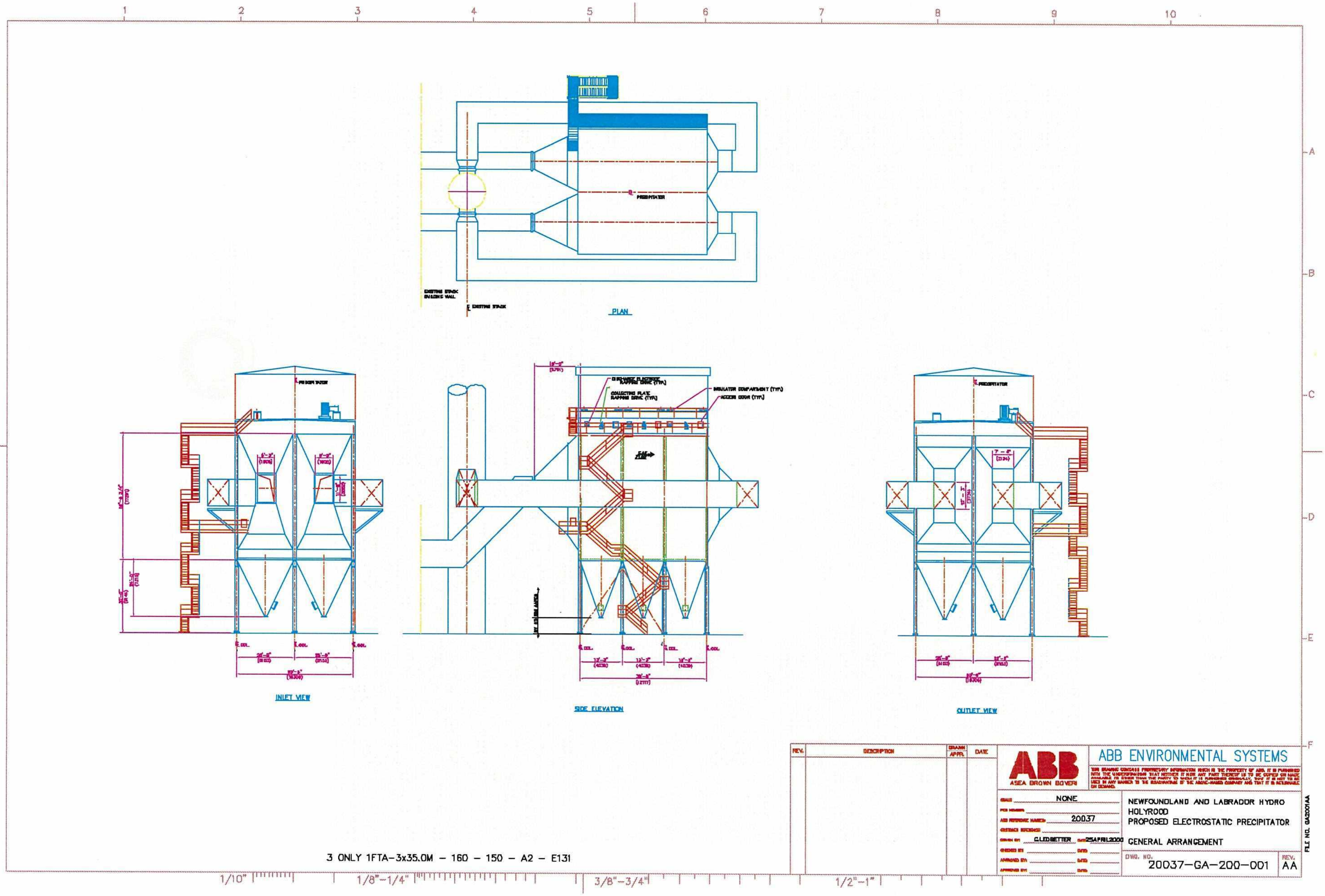
FILE NO. 1110002-GA-200-002RAA

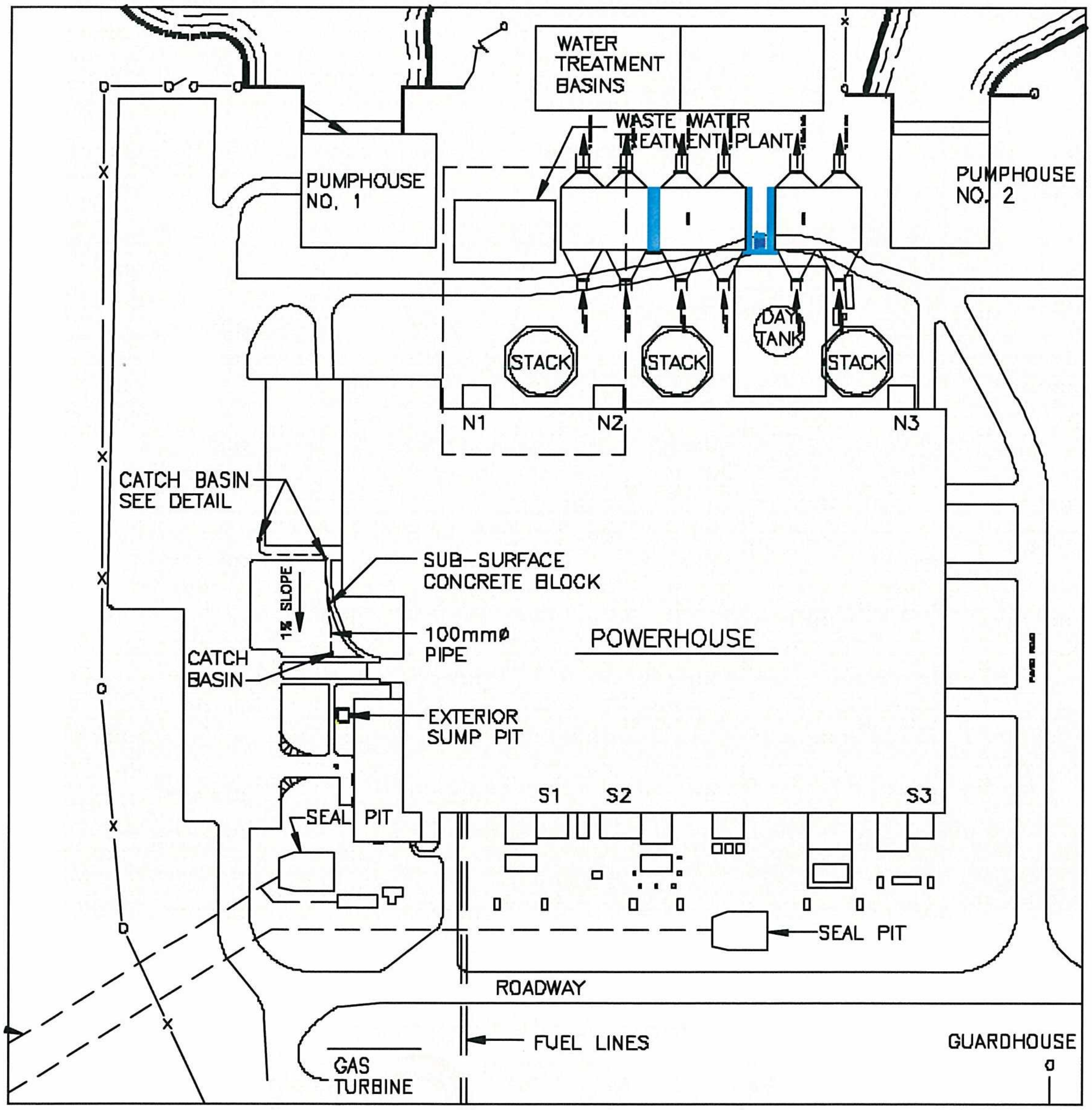
DRY ELECTROSTATIC PRECIPITATOR



Clean air solutions from

ALSTOM


PLAN
INLET VIEW
SIDE ELEVATION
OUTLET VIEW
ABB
ASEA BROWN BOVERI
ABB ENVIRONMENTAL SYSTEMS
NONE
20037
NEWFOUNDLAND AND LABRADOR HYDRO
HOLYROOD
PROPOSED ELECTROSTATIC PRECIPITATOR
GENERAL ARRANGEMENT
20037-GA-200-001
AA
3 ONLY 1FTA-3x35.0M - 160 - 150 - A2 - E131

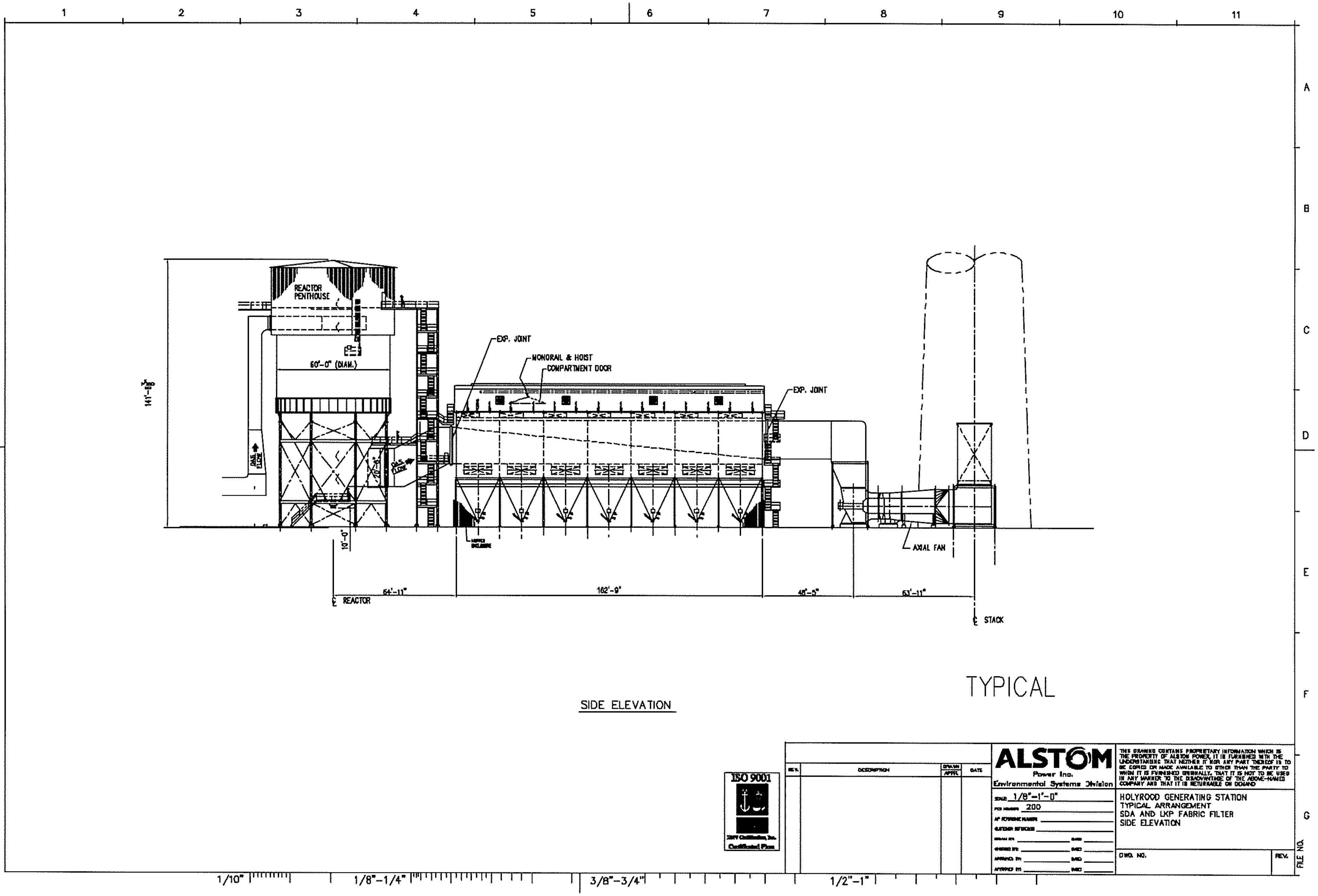


Holyrood Site Plan ESP Location

DRY FLUE GAS DESULFURIZATION

Clean air solutions from

ALSTOM


REACTOR PENTHOUSE
60'-0" (DIAM.)
141'-8"
GAS FLOW
GAS FLOW
10'-0"
EXP. JOINT
MONORAIL & HOIST
COMPARTMENT DOOR
EXP. JOINT
AXIAL FAN
64'-11"
162'-9"
45'-5"
63'-11"
℄ REACTOR
℄ STACK
SIDE ELEVATION
TYPICAL
ISO 9001
ALSTOM
Power Inc.
Environmental Systems Division
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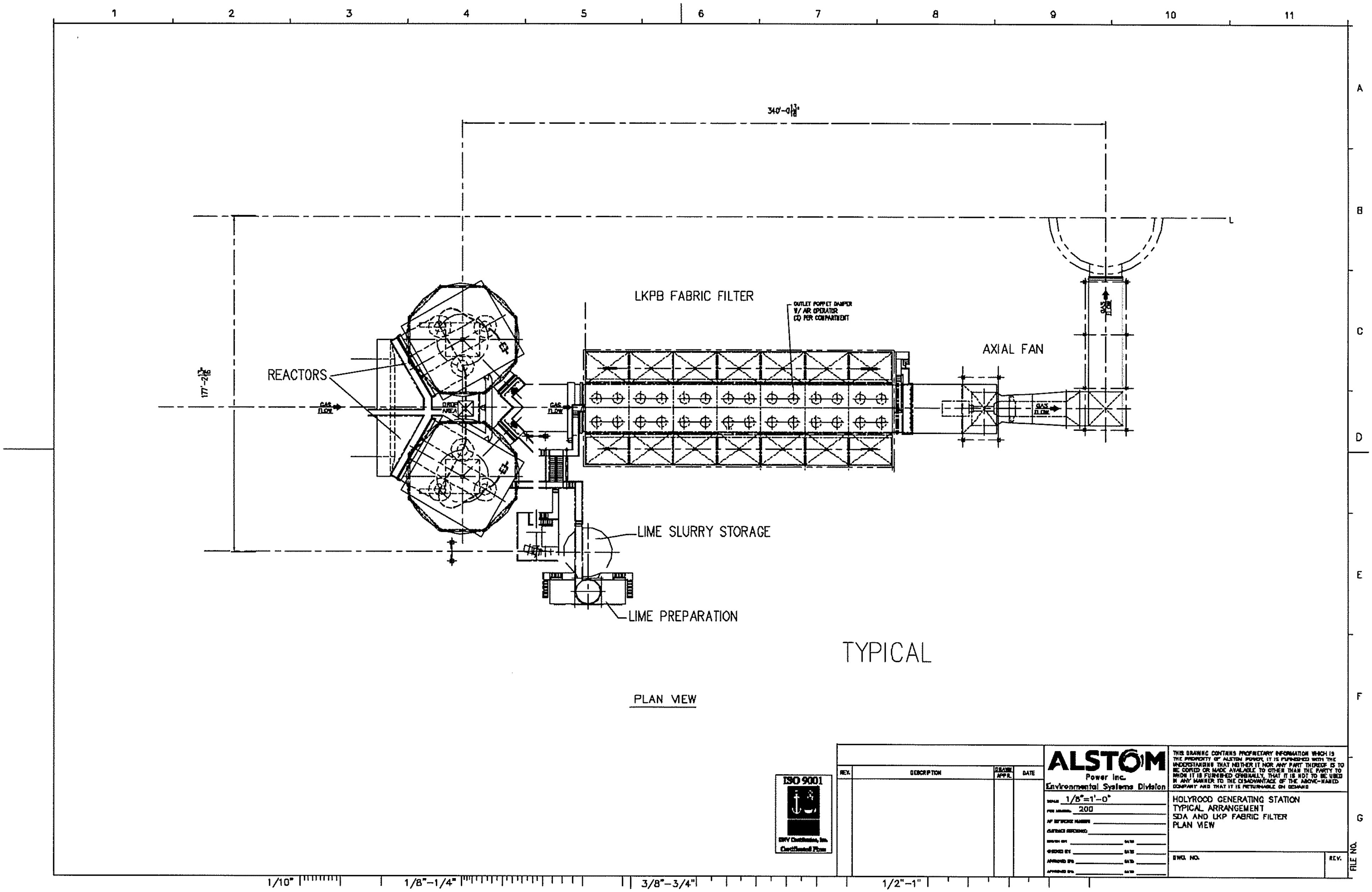
SCALE 1/8"=1'-0"
200
HOLYROOD GENERATING STATION
TYPICAL ARRANGEMENT
SDA AND LKP FABRIC FILTER
SIDE ELEVATION
DWG. NO.
REV.
FILE NO.
DESCRIPTION
DATE
1/10"
1/8"-1/4"
3/8"-3/4"
1/2"-1"


LKPB FABRIC FILTER
OUTLET POPPET DAMPER W/ AIR OPERATOR (2) PER COMPARTMENT
AXIAL FAN
REACTORS
GAS FLOW
LIME SLURRY STORAGE
LIME PREPARATION
TYPICAL
PLAN VIEW
ISO 9001
ALSTOM
Power Inc.
Environmental Systems Division
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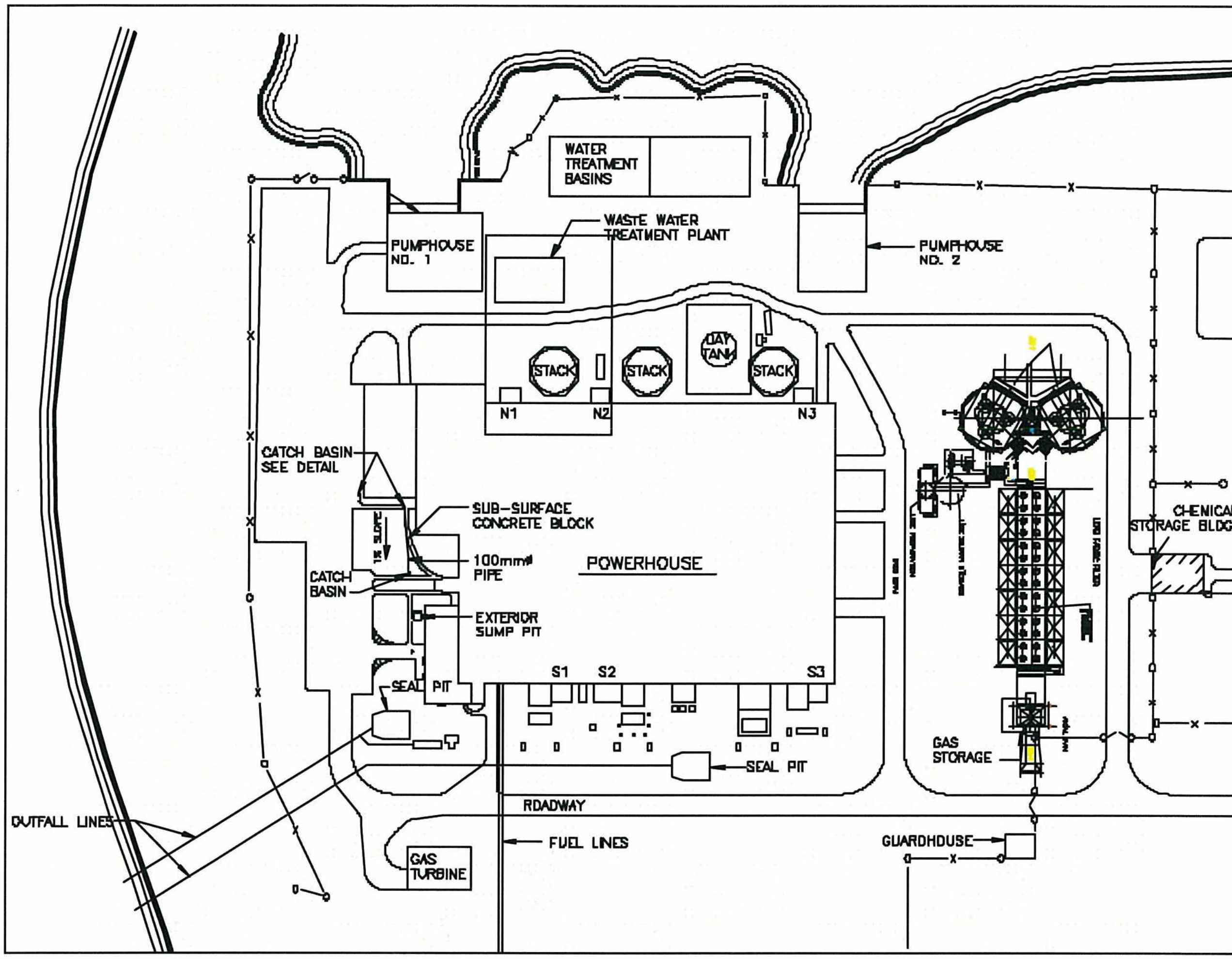
1/8"=1'-0"
200
HOLYROOD GENERATING STATION
TYPICAL ARRANGEMENT
SDA AND LKP FABRIC FILTER
PLAN VIEW
DWG. NO.
REV.
FILE NO.
REV.
DESCRIPTION
DATE
1/10"
1/8"-1/4"
3/8"-3/4"
1/2"-1"

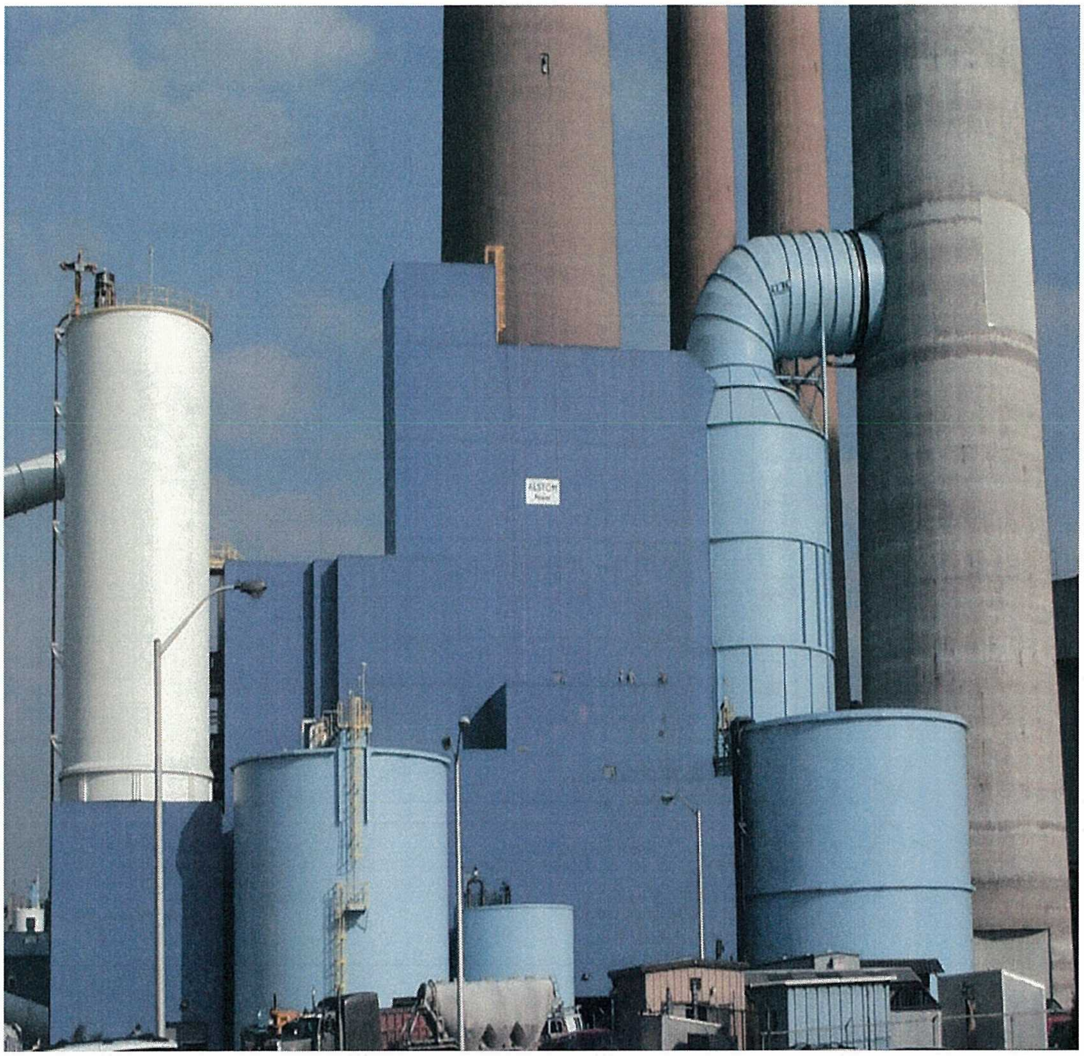
ALSTOM

Study Number 40233000
ALSTOM Canada Inc.



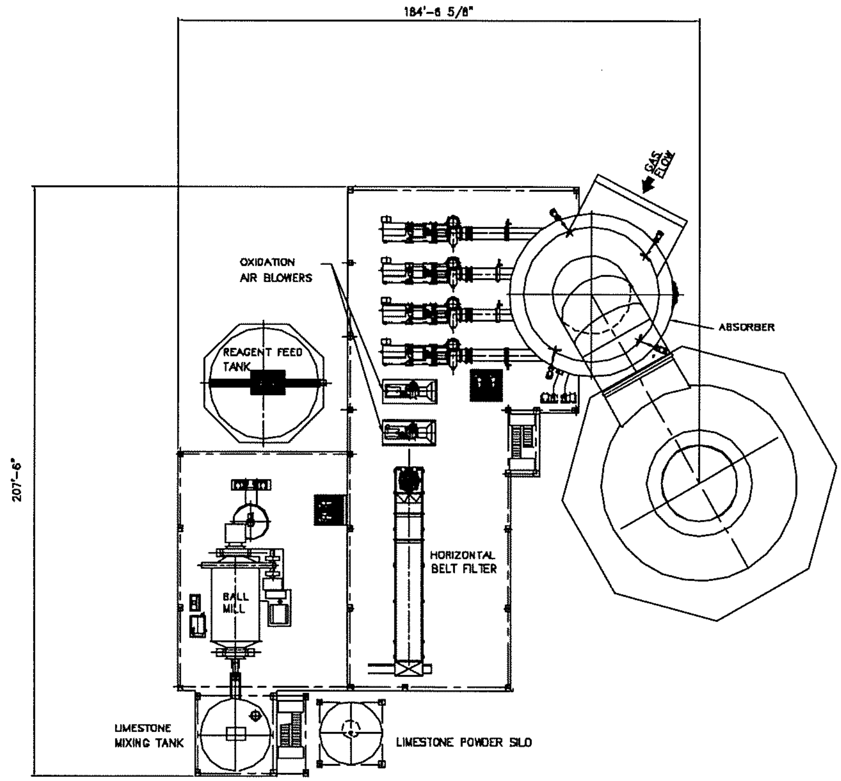
Holyrood Site Plan DFGD Location

WET FLUE GAS DESULFURIZATION



Clean air solutions from

ALSTOM



TYPICAL

PLAN

ALSTOM
Power Inc.

HOLYROOD GENERATING STATION
TYPICAL WFGD ARRANGEMENT

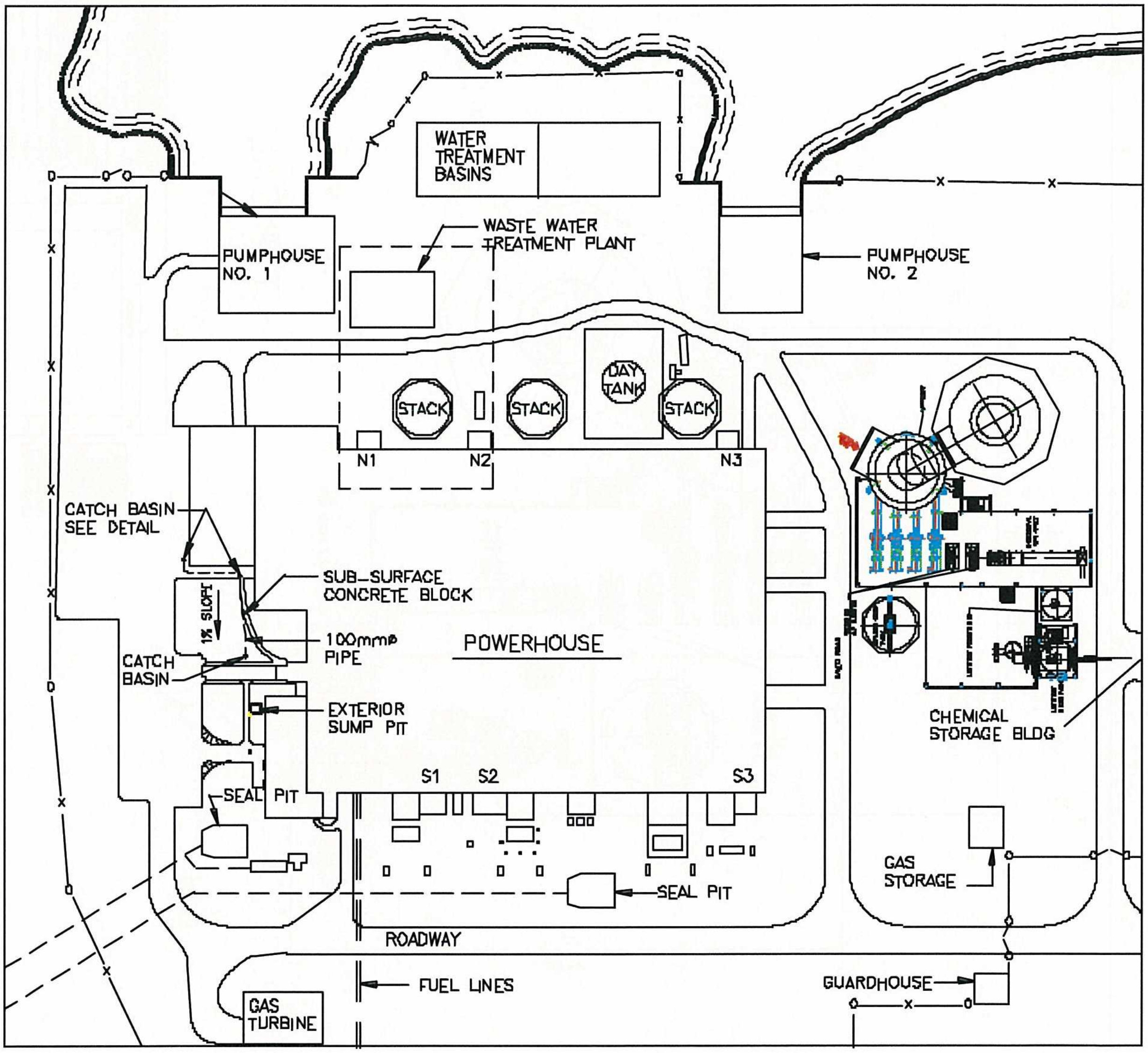
SCALE 1"=20'
200

REV.	DESCRIPTION	DRAWN / APPR.	DATE

DWG. NO.
REV.
FILE NO.

ISO 9001
Certificated Firm

1/10" 1/8"-1/4" 3/8"-3/4" 1/2"-1"



Holyrood Site Plan WFGD Location

APPENDIX B – SNCR BROCHURE

NO$_x$OUT®
NO$_x$ Reduction Process

TECHNICAL BENEFITS

- 30-80% NO$_x$ reduction
- No liquid or solid by-product for disposal minimizes waste management
- Easy to retrofit – little downtime required
- Minimum space required
- Can be "hybridized" with other NO$_x$ reduction technologies
- Is "Flexible" - can adjust NO$_x$ reduction target
- Reagents not subject to SARA, Title III reporting

FUEL TECH™
Technology for a renewed environment™

The NO$_x$OUT process is a urea-based Selective Non-Catalytic Reduction (SNCR) process. It provides cost-effective NO$_x$ reduction for fossil and waste-fueled stationary combustion sources.

Fuel Tech introduced the NO$_x$OUT process to provide an economical solution for meeting stringent requirements for NO$_x$ reduction from fossil-fueled and waste-fueled combustion sources. The NO$_x$OUT process converts NO$_x$ to harmless nitrogen and water.

From 1976 to 1981, research sponsored by the Electric Power Research Institute (EPRI) discovered that urea was an effective reagent for this conversion, and patented the chemical process.

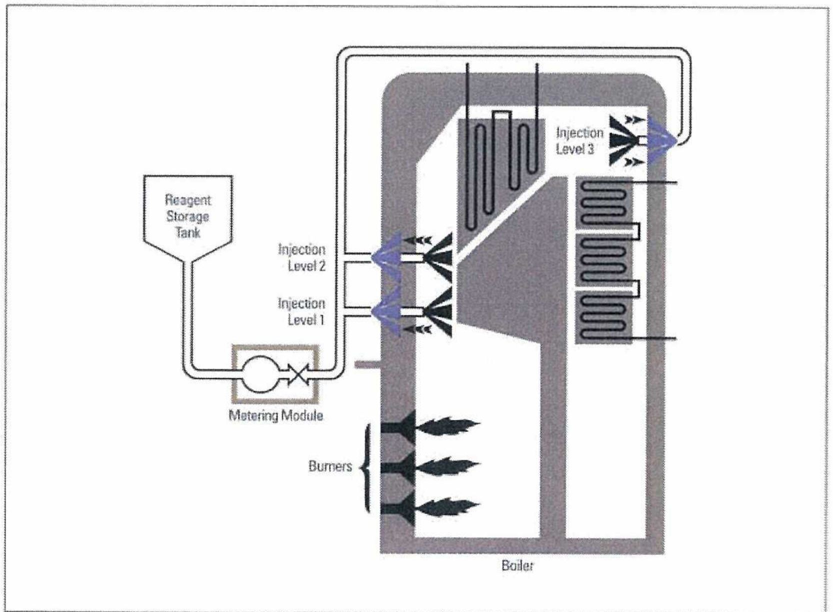
However, this reaction takes place only in a narrow temperature range, below which ammonia (NH_3) is formed and above which NO$_x$ emission levels are compromised.

The NO$_x$OUT system uses process and mechanical modifications to significantly widen the temperature range over which the process is effective. Fuel Tech has developed this technology and commercially licenses it both directly and through selected licensing agents throughout the world.

What Makes the NO$_x$OUT Process Different?

Two of the most important features of the NO$_x$OUT process are its low energy consumption, typically 20-40 kW, and its ability to control ammonia slip, which may occur as a by-product of incomplete NO$_x$ reduction. The NO$_x$OUT process uses particle momentum control technology instead of "brute force" (in the form of high volume mixing air or steam– 1 to 4% of flue gas volume) to achieve appropriate reagent distribution.

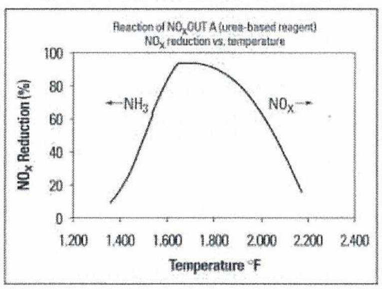
Figure 1: *The NO$_x$OUT Process*



Excessive ammonia slip adds another pollutant to the flue gas, can cause plugging of air preheaters through the formation of ammonium bisulfate, and also can cause contamination of fly ash and flue gas desulfurization waste water. Unlike other SNCR processes, the NO_xOUT technology is able to control ammonia slip to very low levels. (Refer to Figure 3.)

Combustion modification such as low NO_x burners and over-fire air are effective, yet normally only permit NO_x reductions up to 50% on liquid- or solid- fueled boilers. To date, there has been a sharp increase in cost when further NO_x reductions are required using selective catalytic reduction (SCR). SCR entails substantial capital cost and high operating costs associated with reactor construction and erection, catalyst replacement, pressure drop through the system, and ammonia consumption.

***Figure 2**: NO_xOUT Temperature Window*

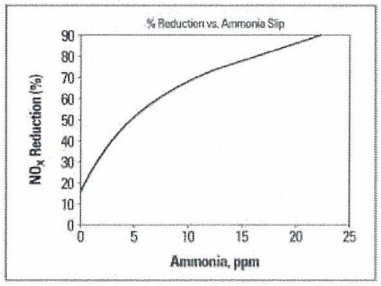


The NO_xOUT process can be used as a "stand-alone" technology to achieve up to 80% NO_x reduction, or it can be combined or "hybridized" with other NO_x reduction technologies to achieve SCR-type performance (>85% NO_x reduction) at a significantly lower cost.

The NO_xOUT process has been commercially installed on a wide range of combustion units burning such fuels as:

- Coal
- Lignite
- Oil
- Gas
- Sludge
- Wood
- Fiber
- Biomass
- Municipal solid waste
- Refinery/CO gas

***Figure 3**: Ammonia Slip*



Commercial combustion units include:

- Refinery crude heaters and CO boilers
- Sludge combustors
- Industrial power boilers
- Municipal waste combustors
- Incinerators
- Circulating fluidized bed boilers
- Stoker-fired boilers burning wood and coal
- Package boilers
- Tangentially-fired utility boilers
- Cyclone-fired utility boilers
- Wall-fired utility boilers (wet & dry)

The NO_xOUT process is also well suited to process combustion units, such as:

- Cement kilns
- Glass furnaces
- Ethylene furnaces
- Calciners
- Coke ovens

The NO_xOUT process can be easily retrofitted to most existing units. Fuel Tech can perform a NO_xOUT process demonstration, via mobile equipment, to predict and optimize the technology's operating results on a commercial application.

In the design phase of a NO_xOUT process application, Fuel Tech uses computational fluid dynamics (CFD) and chemical kinetic modeling (CKM) to aid in injector location selection, and determine the appropriate reagent droplet size distribution. Combustion unit temperature mapping and operating data are model inputs and are used to achieve high NO_x reduction and low by-product emissions, and prevent impingement on heat transfer surfaces.

***Figure 4**: CFD Model of Tangential Boiler*

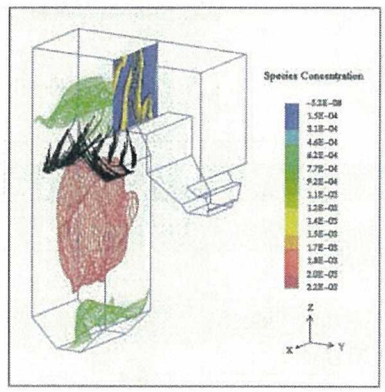


Figure 4 shows modeling results from a 750-MW tangentially-fired utility boiler burning coal. It shows 14 injectors placed at a certain elevation, spraying at a certain angle. The model then predicts the reagent concentration at various cross-sections and superimposes this information on flue gas temperatures and velocity. This modeling information is used to design a NO_xOUT process application to meet the needs for tightening pollution control restrictions in the Northeast United States.

Under Engineering Services Agreements, Fuel Tech performs CFD/CKM modeling studies on combustion units to predict NO_x reduction performance and by-product emissions. To optimize the NO_xOUT technology, Fuel Tech has developed equipment and components including:

- Specific injection equipment to ensure that the NO_xOUT reagents are distributed optimally in the combustion unit flue gases
- Control hardware and software to enable the NO_xOUT process to follow load changes and spikes in stack NO_x with the appropriate flow rates and mixtures of reagents
- Modular equipment for storing, mixing, metering, and pumping the NO_xOUT reagents to reduce retrofit costs

Figure 5: *Cost and Performance of the NO_xOUT Process on Various Units*

Electric Utility NO_xOUT Applications

	Boiler Type	MW	NOx REDUCTION %	CAPITAL $/kw	TOTAL ANNUALIZED USE COST $/Ton NOx REMOVED
Coal	Tangentially Fired	150	40%	$ 23.00	$ 1,775
	Wall Fired	600	25-30%	$ 10.50	$ 1,300 *
	Cyclone	160	36%	$ 12.50	$ 980
	Cell Fired	600	30%	$ 12.00	—
	Circulating Fluidized Bed	45	60%	$ 14.30	$ 1,380
	Wet Bottom, Wall Fired	320	30-35%	$ 13.00	$ 1,275 *
Oil					
	Tangentially Fired	160	40 %	$ 15.00	$ 1,200
					* Ozone Season Only

Industrial Units

INDUSTRY TYPE	NO_x REDUCTION %	TOTAL ANNUALIZED USE COST $/Ton NO_x REMOVED
Refining Industry		
CO Boiler	65%	$712
GT HSRG	50%	$1,135
Package Boiler	60%	$1,900
Process Heaters	60 - 75%	$1200 - 1600
Pulp and Paper Industry		
Power Boiler	50%	$1,032
Recovery Boiler	60%	—
Sludge Combustor	50%	$1,424
Industrial Boilers	50%	$1,012
Municipal Waste Combustor Industry		
Municipal Waste Combustor	40 - 70%	$1040 - 1553
Wood Fired IPP / Cogen Industry		
Wood Fired IPP / Cogen	35 - 70%	$918 - 2222
Tire Burner Industry		
Tire Burners	50%	$1,418

Fuel Tech is an international company working at the forefront of combustion technology, with a particular objective to meet the increasing demands for cost-effective pollution control technologies and equipment.
In addition to the NO_xOUT process, Fuel Tech's products include:

- Enhanced fuel additive technologies
- Control programs for corrosion, particulate emissions, and fireside deposition
- The NO_xOUT Cascade® Process can remove up to 90% of NO_x using a compact SCR catalyst in conjunction with the NO_xOUT SNCR process.
- The AEFLGR™ Process (Amine-Enhanced Fuel Lean Gas Reburn) can provide an alternative to full SCR systems, but without the capital expense, catalyst replacement expense, or "stranded asset" potential of a SCR system.
- The NO_xOUT SCR® Process for industrial generators provides a cost-effective and safer alternative to ammonia-based SCR systems.

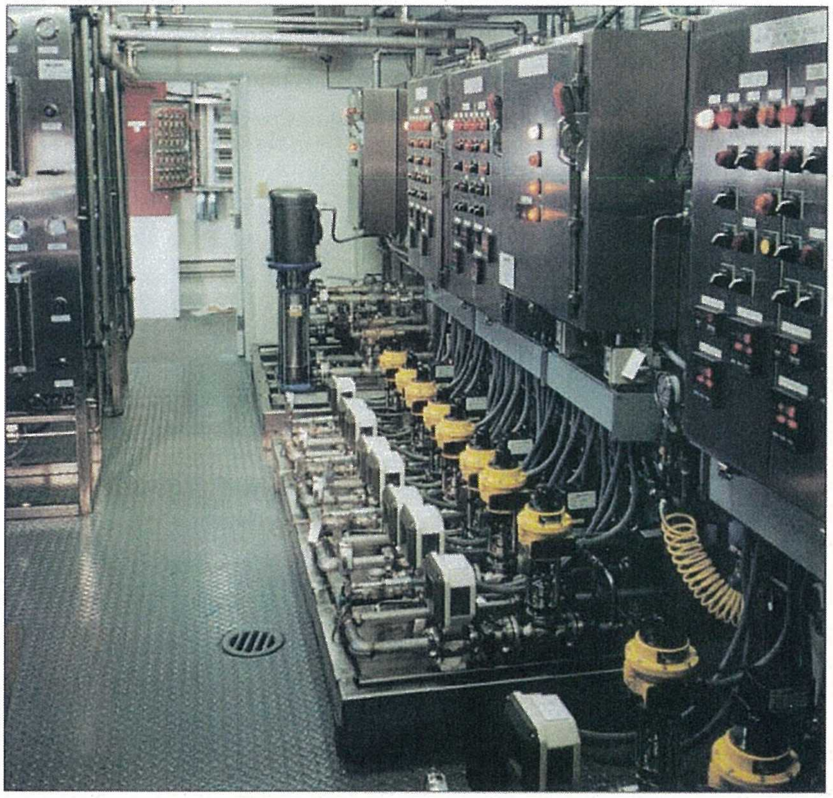


Figure 6: *Modular control and feed system delivered to site ready for hook-up*

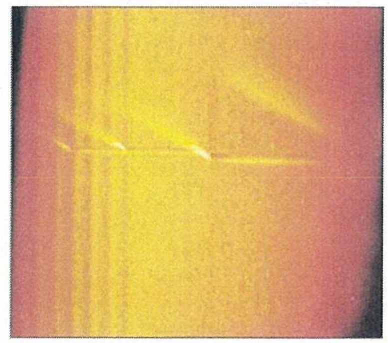


Figure 7: *Typical through-wall NO_xOUT injector*

For more information on NO_x reduction programs available from Fuel Tech, call, fax, or write us at:

Fuel Tech, Inc. • 512 Kingsland Drive • Batavia, IL 60510
Phone 800.666.9688 • 630.845.4500 • Fax 630.845.4501
www.fueltechnv.com • webmaster@fueltechnv.com

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APPENDIX C –EXPERIENCE LISTS

ALSTOM Power
Reference list: Electrostatic Precipitators for oil fired boilers

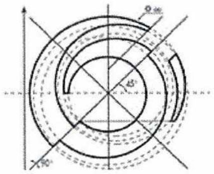
Country	Plant	End User	Start Up	Capacity	Unit	Process	Boiler Type	Gasflow (m^3/hr)	Temp. (°C)
Germany	Wesseling/Uk	Union-Kraftstoff	1978	220	TPH	Oil	Boiler	360000	210
Italy	Lamarmora	Asm Brescia	1990	35	MW	Oil	Boiler	262440	120
Italy	Lamarmora	Asm Brescia	1989	35	MW	Oil	Boiler	262440	120
Italy	Brescia	Asm Brescia	1993	90	MW	Oil	Boiler	351720	180
Italy	Ravenna	Enel	1966	170	MW	Oil	Boiler	894500	148
Italy	Civitavecchia	Enel	1989	240	MW	Oil	Boiler	1051000	154
Italy	Sermide	Enel	1982	320	MW	Oil	Boiler	1400000	145
Italy	Termini Imerese	Enel	1975	320	MW	Oil	Boiler	1416000	145
Italy	Tavazzano	Enel	1982	320	MW	Oil	Boiler	1400000	145
Italy	Sermide	Enel	1982	320	MW	Oil	Boiler	1400000	145
Italy	Melilli	Enel	1975	320	MW	Oil	Boiler	1416000	145
Italy	Termini Imerese	Enel	1975	320	MW	Oil	Boiler	1416000	145
Italy	Melilli	Enel	1975	320	MW	Oil	Boiler	1416000	145
Italy	Sermide	Enel	1983	320	MW	Oil	Boiler	1400000	145
Italy	Sermide	Enel	1982	320	MW	Oil	Boiler	1400000	145
Italy	Tavazzano	Enel	1982	320	MW	Oil	Boiler	1400000	145
Japan	Shingu Mill	Tomoegawa Seishi K.K.	1977	0		Oil	Boiler	33850	245
Japan	Toshiba Denki	Toshiba Denki Kk,Transistor Works	1974	0		Oil	Boiler	31700	300
Japan	Wakamatsu	Mitsui Alumina Seizo K.K.	1975	0		Oil	Boiler	131000	190
Japan	Kashima Pst	Kashima Minami Kyodo Hatsuden K.K.	1992	0		Oil	Boiler	439300	177
Japan	Shingu Mill	Tomoegawa Seishi K.K.	1977	0		Oil	Boiler	33850	245
Japan	Mie Mill	Yokohama Gomu K.K.	1974	7	MW	Oil	Boiler	168000	171
Japan	Fukuoka	Fukuoka Seishi K.K.	1973	39	TPH	Oil	Boiler	55450	200
Japan	Ikeda Mill	Daihatsu Kogyo K.K.	1974	39	TPH	Oil	Boiler	72800	250
Japan	Mie Power St.	Chubu Denryoku K.K.	1974	65	MW	Oil	Boiler	378200	140
Japan	Sakai	Sakai Kyodo Karyoku K.K.	1973	75	MW	Oil	Boiler	385600	147
Japan	Sakai	Sakai Kyodo Karyoku K.K.	1973	75	MW	Oil	Boiler	385600	147
Japan	Mie Power St.	Chubu Denryoku K.K.	1974	75	MW	Oil	Boiler	413000	140
Japan	Mie Power St.	Chubu Denryoku K.K.	1974	75	MW	Oil	Boiler	413000	140
Japan	Wakamatsu	Mitsui Alumina Seizo K.K.	1972	75	TPH	Oil	Boiler	132600	188
Japan	Nobeoka	Asahi Kasei Kogyo K.K.	1975	110	TPH	Oil	Boiler	190600	200
Japan	Chiba/Dai	Dai Nippon Inc K.K.	1976	114	TPH	Oil	Boiler	191500	250
Japan	Sofue Mill	Sanko Seishi K.K.	1975	120	TPH	Oil	Boiler	1782000	150
Japan	Ishikawa	Okinawa Denryoku K.K.	1974	125	MW	Oil	Boiler	531000	133
Japan	Ishikawa	Okinawa Denryoku K.K.	1978	125	MW	Oil	Boiler	541600	135
Japan	Toyama	Hokuriku Denryoku K.K.	1972	156	MW	Oil	Boiler	708000	142
Japan	Toyama	Hokuriku Denryoku K.K.	1972	156	MW	Oil	Boiler	708000	142
Japan	Yokkaichi Refinery	Daikyo Sekiyu K.K.	1972	170	TPH	Oil	Boiler	260000	200
Japan	Mizushima	Nippon Kogyo K.K.	1972	220	TPH	Oil	Boiler	44200	200
Japan	Tomakomai Kyodo	Tomakomai Kyodo Hatsuden K.K.	1972	250	MW	Oil	Boiler	1090000	140
Japan	Tomakomai Kyodo	Tomakomai Kyodo Hatsuden K.K.	1972	250	MW	Oil	Boiler	1096400	140
Japan	Date P.St	Hokkaido Denryoku K.K.	1975	350	MW	Oil	Boiler	1543000	140

ALSTOM Power
Reference list: Electrostatic Precipitators for oil fired boilers

Country	Plant	End User	Start Up	Capacity	Unit	Process	Boiler Type	Gasflow (m^3/hr)	Temp. (°C)
Japan	Shiriuchi Pst	Hokkaido Electric Power	1997	350	MW	Oil	Boiler	1702800	165
Japan	Date P.St	Hokkaido Denryoku K.K.	1979	350	MW	Oil	Boiler	1543000	140
Japan	Taketoyo	Chubu Denryoku K.K.	1972	375	MW	Oil	Boiler	1613000	140
Japan	Taketoyo	Chubu Denryoku K.K.	1972	375	MW	Oil	Boiler	1613000	140
Japan	Taketoyo	Chubu Denryoku K.K.	1972	375	MW	Oil	Boiler	1607000	140
Japan	Taketoyo	Chubu Denryoku K.K.	1989	375	MW	Oil	Boiler	1785200	140
Japan	Taketoyo	Chubu Denryoku K.K.	1991	375	MW	Oil	Boiler	1598600	100
Japan	Makiminato	Okinawa Denryoku K.K.	1981	405	TPH	Oil	Boiler	604000	140
Japan	Shin Tokushima	Shikoku Denryoku K.K.	1973	435	TPH	Oil	Boiler	580000	135
Japan	Shin Tokushima	Shikoku Denryoku K.K.	1973	710	TPH	Oil	Boiler	900000	140
Korea	Vanguard	Kyungin Energy Co	1992	0		Oil	Boiler	121000	180
Korea	Ssangyong	Ssangyong Heavy Ind Co Ltd	1987	0		Oil	Boiler	428500	167
Korea	Vanguard	Kyungin Energy Co	1992	0		Oil	Boiler	69000	180
Korea	Gumi	Kolon Engineering Enc.	1992	65	TPH	Oil	Boiler	120000	200
Lithuania	Lithuania	Lithuanian Power Station	1996	0		Oil	Boiler	0	170
Netherlands	Dordrecht	Geb Dordrecht	1981	320	MW	Oil	Boiler	1470000	175
Saudi Arabia	Sceco Rabigh	Saudi National Co. Ltd	1985	250	MW	Oil	Boiler	1320000	164
Saudi Arabia	Sceco Rabigh	Saudi National Co. Ltd	1985	250	MW	Oil	Boiler	1320000	164
Saudi Arabia	Sceco Rabigh	Saudi National Co. Ltd	1984	250	MW	Oil	Boiler	1320000	164
Saudi Arabia	Sceco Rabigh	Saudi National Co. Ltd	1985	250	MW	Oil	Boiler	1320000	164
Singapore	Seraya Stage Iii	Public Utility Board, Singapore	1995	250	MW	Oil	Boiler	1062000	130
Singapore	Seraya Stage Ii	Public Utility Board, Singapore	1992	250	MW	Oil	Boiler	1024200	125
Singapore	Seraya Stage Iii	Public Utility Board, Singapore	1996	250	MW	Oil	Boiler	1062000	130
Singapore	Seraya Stage Ii	Public Utility Board, Singapore	1992	250	MW	Oil	Boiler	1024200	125
Singapore	Seraya Stage Ii	Public Utility Board, Singapore	1992	250	MW	Oil	Boiler	1024200	125
Singapore	Seraya Stage Iii	Public Utility Board, Singapore	1995	250	MW	Oil	Boiler	1062000	130
Spain	Granadilla	UNELCO	1995	80	MWE	Oil	Boiler	401760	170
Spain	Baranco D Tirajan	UNELCO	1995	80	MWE	Oil	Boiler	401760	170
Spain	Granadilla	UNELCO	1995	80	MWE	Oil	Boiler	401760	170
Spain	Baranco D Tirajan	UNELCO	1995	80	MWE	Oil	Boiler	401760	170
Sweden	Fyriskraft	Uppsala Energi AB	1973	0		Oil	Boiler	1015000	152
Sweden	Hammarby	Stockholms Energi Produktion AB	1987	80	MW	Oil	Boiler	155000	180
Sweden	Värtan	Stockholms Energi Produktion AB	1976	250	MW	Oil	Boiler	1105000	140
Sweden	Karlshamn	Kkab Karlshamn	1996	350	MWE	Oil	Boiler	0	130
Sweden	Hässelbyverket	Stockholms Energi Produktion AB	1967	490	TPD	Oil	Boiler	750000	150
Switzerland	Basel	Elektricitätswerk Basel	1975	0		Oil	Boiler	411200	210
Taiwan	Talinpu	Chinese Petroleum Corporation	1993	130	TPH	Oil	Boiler	192000	160
Taiwan	Hsieh Ho	Taiwan Power Co	1992	500	MW	Oil	Boiler	2391000	150
Taiwan	Hsieh Ho	Taiwan Power Co	1992	500	MW	Oil	Boiler	2391000	150
Taiwan	Hsieh Ho	Taiwan Power Co	1992	500	MW	Oil	Boiler	2481000	150
Taiwan	Talinpu	Chinese Petroleum Corporation	1995	130	TPH	Oil&gas	Boiler	193313	180

RETROFIT LOW NOX EXPERIENCE
OIL AND GAS FIRED UNITS (TANGENTIALLY FIRED)

Customer	Plant	Fuels	Contract Year
Keyspan	Ravenswood #20	Oil	1989
ENEL (Italy)	Fusina #2	Coal/Oil/Gas	1990
Philadelphia Electric Co.	Cromby #2	Gas/Oil	1991
Keyspan	Northport # 1	Oil	1992
NRG	Bridgeport Harbor #3	Coal/Oil	1993
Keyspan	Northport # 4	Oil/Gas	1993
Keyspan	Northport # 2	Oil/Gas	1994
Keyspan	Northport # 3	Oil	1995
Keyspan	Port Jefferson #3	Oil	1994
Keyspan	Barrett #2	Oil/Gas	1995
Iberdrola (Spain)	Santurce	Oil/Gas	1997
Keyspan	Yorktown #3	Oil	1999
Keyspan	Ravenswood #10	Oil	2000
Keyspan	Ravenswood #30	Oil/Gas	2001



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LOW NOx RETROFIT EXPERIENCE LIST – WALL-FIRED BURNER

ORDERED	CUSTOMER	PLANT	DESCRIPTION	FUEL	BURNERS	COMMISSIONED YEAR
1995	Pfizer	Groton	105,000 lb/hr CE VU40 Boiler	NG/#6	4 @ 40 MBtu/hr	1996
1996	Richmond Power & Light	Whitewater	Riley Stoker 300,000 lb/hr 32 MWe Utility Boiler 1	East. Bit. Coal	6 @ 70 MBtu/hr	1996
1996	ABB Site Services	Windsor Site	24 MBtu/hr Heating Boiler	NG/#6/#2	1 @ 30 MBtu/hr	1996
1996	ABB Alamsas	Tupras Refinery	330,000 lb/hr CE 37/VP18 Boiler	NG/RFO/PG	4 @ 119 MBtu/hr	1998
1997	Electricity Supply Board – Dublin, Eire	Poolbeg	120 MWe Foster Wheeler Reheat Boiler	NG/#6	12 @100 MBtu/hr	1998
1997	PLN Gresik, Indonesia	Gresik	100 MWe IHI – FW Utility Boiler	NG/RFO	12 @127 MBtu/Hr	1997
1997	Hoechst Celanese	Clear Lake	200,000 lb/hr CE 34-VP-18W Boiler	NG	1 @ 280 MBtu/hr	1998
1997	International Paper	Riegelwood	200,000 lb/hr CE 30-VP-14W Boiler	NG/#6	1 @ 280 MBtu/hr	1997
1997	Santee Cooper	Grainger	650,000 lb/hr Riley Stoker Utility Boiler	East. Bit. Coal	8 @ 130 MBtu/hr	1998
1997	Omaha Public Power District	North Omaha 5	1,600,000 lb/hr FW Utility Boiler	PRB Coal/Gas	12 @ 175 MBtu/hr	1999
1997	United Power Association	Stanton	172 MWe FW Utility Boiler	Lignite Coal	12 @ 125 MBtu/hr	1998
1998	ABB SA Portugal	C. N. P. Borealis	(3) FW Utility Boilers approx. 390,000 lb/hr	NG/#6	18 @ 80 MBtu/hr	1999

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LOW NOx RETROFIT EXPERIENCE LIST – WALL-FIRED BURNER

1998	ABB CE SpA Italy	ISE/Taranto	(3) B&W/Ansaldo Boilers @ 1,058,000 lb/hr	NG/COG BFG/#6 Other Wastes	20 @ 90 MBtu/hr 40 @ 90 MBtu/hr	1999
1998	Formosa Heavy Industries	Lung-Teh No. 1 (LT-1)	120 T/Hr (264,600 Lb/Hr) Kawasaki Heavy Industry Boiler RSFC™ Burners with OFA system	PC/Oil	6 @ 58 MBtu/hr	1999
1998	Formosa Heavy Industries	Lin – Yuan No. 1 (LP-1)	120 T/Hr (264,600 Lb/Hr) Hitachi Boiler RSFC™ Burners with OFA system	PC/Oil	4 @ 89 MBtu/hr	1999
1998	Virginia Power	Bremo No. 4	170 MWe B&W Utility Boiler	PC/Oil	16 @ 95 MBtu/Hr	1999
1998	Virginia Power	Chesapeake No. 3	170 MWe B&W Utility Boiler	PC/Oil	16 @ 95 MBtu/Hr	1999
1998	Western Farmers Electric Cooperative	Hugo No. 1	400 MWe B&W Utility Boiler – OFA Addition with modifications to existing burners	PRB Coal	35 @ 135 MBtu/Hr	2000
1998	CDE ITABO	Unit No. 1	880,000 Lb/Hr Foster Wheeler Boiler	Oil/PC	8 @ 148 MBtu/Hr	1999
1999	E. I. DuPont	Waynesboro No. 2	120,000 lb/hr C-E VU-40 Boiler	East Bit. Coal/ NG/Oil	4 @ 54 MBtu/Hr	2000
2000	Rock-Tenn	Lynchburg No. 3	90,000 Lb/Hr B&W Stirling	NG/Oil	1 @ 100 M Btu/Hr	2001
2000	Ameren	Mermac No. 4	360 MW FW Boiler	PRB Coal	18 @ 200 MBtu/Hr	2001
2001	E. I. DuPont	Waynesboro No. 1	120,000 lb/hr C-E VU-40 Boiler	East Bit. Coal/ NG/Oil	4 @ 54 MBtu/Hr	2001