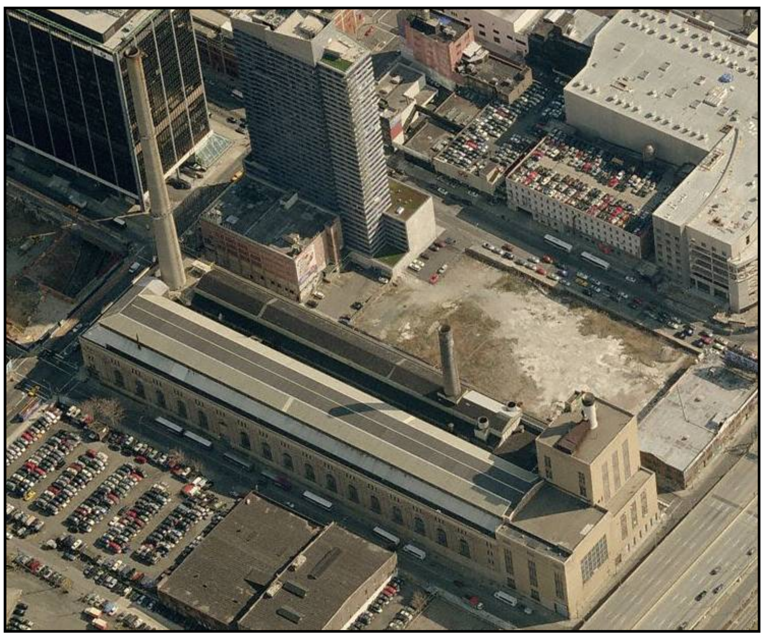
APPENDIX F
AIR QUALITY

59th Street
Generating Station

Modification of GT Exhaust #1



Preliminary Engineering Study Final Report

Phase 1 – Review of Ducting GT #1 to Stack #1

May 4, 2010

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Con Edison's existing West 59th Street Generating Station (Station) is fully compliant with all federal and state air emissions permitting requirements, and operates under a New York State Department of Environmental Conservation (NYSDEC) Air Title V Permit that is renewable after May 15, 2013. Extell Development Company (Extell) is planning the construction of a large mixed-use development called Riverside Center, directly north of the Station, which would create new high-rise residential and commercial buildings in close proximity to the existing Station (the Proposed Project), introducing the potential for emissions impacts at new receptor locations. In preparation for development of the Riverside Center Draft Supplemental Environmental Impact Statement (DSEIS) for the Proposed Project, Extell conducted preliminary wind tunnel modeling of air quality impacts that accounts for the location and height of the proposed new buildings and the exhaust stack emissions from combustion equipment at the Station, namely boiler emissions from the approximately 500 foot tall Stack No. 1 and the gas turbine emissions from a separate, shorter stack. The initial results indicated that some modeled elevated receptor locations on these buildings would potentially exceed the City of New York's current interim guidance for fine particulate matter, $PM_{2.5}$. The gas turbine exhaust, due to its relatively low stack height elevation and the exhaust plume affected by building-induced downwash, was identified as the main contributor to the higher $PM_{2.5}$ levels.

Parsons Brinckerhoff (PB) was retained to evaluate, preliminarily, the performance, operational, and maintenance impacts of potential solutions that would produce modeled $PM_{2.5}$ concentrations at these elevated receptors that are within the limits of the City's interim guidance criteria.

The following options were initially identified in Phase 1 of the engineering study:

- Exhaust to Stack 1 - Duct the exhaust from the gas turbine to the existing 485 foot tall (liner length) boiler stack No. 1 located at the opposite end of the plant. This will increase the height of the gas turbine emissions and so increase the dispersion and reduce the pollutant concentrations at the various receptors.
- Utilize the Existing Stack – Perform an industry search for a control technology that has the potential of an approximately 98% reduction in particulate matter mass flow from the existing stack.
- Fuel Switch – A change in the main gas turbine fuel from the existing low sulfur kerosene to natural gas or Ultra Low Sulfur Distillate (ULSD)

Due to the perceived technical issues with back-end cleanup of the high temperature turbine exhaust, the second option was eliminated prior to PB's actual start of the project. It was determined to focus PB's efforts on evaluating the rerouting of the turbine exhaust to the taller stack, and preliminary results indicated no fatal flaws in the technical aspects of rerouting the turbine exhaust to Stack No. 1. Alternate fuel options for the gas turbine were also evaluated; however, it was quickly determined that fuel conversion by itself would not be sufficient to meet the stated $PM_{2.5}$ concentration levels under the City's interim guidance.

Con Edison identified the criteria for the acceptability of the options, principally that the plant would not suffer any performance or operational limitations as a result of any of the changes. Additional air dispersion modeling was not included in the PB scope of work. However, Extell's modeling indicated that if the exhausts of the boilers and gas turbine are combined into Stack No. 1, $PM_{2.5}$ concentration levels would be within the City's interim guidance criteria. PB and Con Edison have proceeded on the assumption that this assessment is correct.

A primary concern identified during the analysis and subsequent meetings was the capability of the present self-support steel liner in Stack No. 1 to withstand the approximately 900°F temperatures when the turbine is operating without any boilers in operation. Several approaches were discussed, including providing ductwork from the turbine to the stack that was designed for the high temperature and providing a protective lining of the stack.

The following summarizes the major technical results of the preliminary study.

<u>DUCT ROUTING AND CHIMNEY CONSIDERATIONS</u>

The following duct configuration and routing is recommended as the most practical and cost-effective within the stipulated constraints:

- Approximately 600 linear feet of high temperature ductwork (inner stainless steel liner plates, ceramic wool insulation, and an exterior carbon steel structural layer) having a total equivalent hydraulic length (for determining pressure losses) of approximately 1,900 feet.

- Due to space constraints within the plant, the ductwork size is limited to an internal diameter of 9 feet for round sections and 9' x 7'-6" for a portion of the run with a rectangular cross section.

- Significant costs are associated with adding steel to the existing structure to support the new ductwork which weighs over 500,000 lbs.

- The duct can be connected to an existing breeching in the stack without affecting the concrete shell.

- The ductwork has a total calculated head loss of 4.67" water column (W.C.) from the current outlet of the gas turbine after the monitoring probes, to the inlet to the stack. The losses are based upon full turbine design flow at 900°F, for conservativeness.

A computerized flue gas pressurization model was developed to calculate the conditions at the base of the stack under various operating scenarios. The key results of this model are:

- The worst case for additional pressure losses and stack draft changes occurs when all the boilers are in operation and the GT is running. Although the theoretical draft is increased due to the higher mixed temperature caused by the GT, the increased flow and higher velocities in the stack result in increased pressure losses. In combination, this results in a theoretical calculated net draft loss at the base of the stack of 1.35" W.C. (this is alternatively expressed as -1.35" W.C. gauge pressure.) This is a reduction of 0.27" W.C. compared to the calculated draft of 1.62" W.C. in the current worst case condition with all boilers in operation. It should be noted that this is a theoretical calculation and at some point should be compared to the actual measurements under defined conditions.

- As inferred above, since the current equipment pressurization levels have not been clearly identified, it can not be definitively determined at this time if flue gas leakage back through either a non operating boiler or in the existing boiler ductwork will occur as a result of this small pressurization increase. It is recommended that new high performance dampers be considered for installation on the existing boilers and that the existing ductwork be inspected both for condition and for current pressurization levels.

- Lining the stack with a 1.5" thick gunite coating to provide thermal protection from the elevated temperatures will require additional structural improvements and will further reduce stack draft by 0.36" W.C. There may be an opportunity to only partially gunite the stack to an intermediate elevation. Additional testing and evaluation is recommended, particularly on the temperature limitations of the stack. In addition to the costs associated with guniting the stack, it will require a significant outage of the entire plant. Although a prolonged plant outage is possible, it is an enormous scheduling issue.

As a result of these increased pressures and the resulting backpressure on the gas turbine, the turbine is projected to have a peak power loss due to increased backpressure of 145 kW, or 161 kW if the gunite liner is required to the top of the stack. For the relatively limited occurrences that this situation may occur, it is possible that the power loss can be made up by a slight increase in firing (although this violates the basic criteria of the modification). It is estimated that the project would be completed 28 months from the start of the preliminary design work (assuming that the permitting process would begin 2 months after the start.)

2. INTRODUCTION

The Con Edison West 59th Street Generating Station is located in Manhattan on the block covering 58th and 59th Streets between 11th and 12th Avenues. The 59th Street plant, formerly the Interborough Rapid Transit Company Powerhouse, was built in 1904 to generate and supply electricity for New York City's first subway lines.

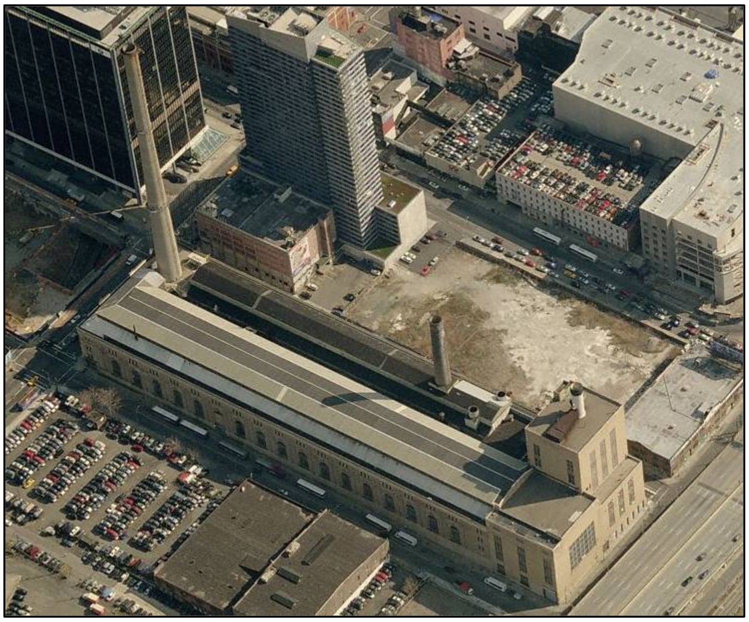


Figure 1 – Aerial View of 59th Street Plant

The primary function of the plant is steam generation for Con Edison's steam system. There are five boilers which are connected to a 16.5 foot internal diameter, 485 foot tall stack on the east end of the building:

- Two 550,000 lbs/hr Combustion Engineering boilers (burning No. 6 fuel oil) exhaust through independent breechings in the north side of the stack.

- Three 150,000 lbs/hr Foster Wheeler dual-fuel package boilers (burning natural gas or no. 6 fuel oil) exhaust through a common breeching on the south side of the stack.

Power generation capacity at the plant presently consists of one 17.5 MW Stahl-Laval combustion turbine which only operates for approximately 90 hours per year to provide critical black start capability and peaking capacity to Con Edison. The machine was installed in 1967 and is fired on kerosene. It currently exhausts to its own 12 foot diameter, 127 foot tall stack on the west end of the building.

Two additional stacks were recently demolished, a 250 foot elevation brick stack to the east of the gas turbine stack and a short metal stack located on the roof of a penthouse on the west end of the building.

The plant operates under a New York State Department of Environmental Conservation (NYSDEC) Air Title V Permit ID 2 – 6202 – 0032/00013 that is renewable after May 15, 2013. A permit review report dated May 19, 2008 indicates that the facility is in compliance with all (Title V Permit) requirements.

Extell is planning the construction of a large mixed-use development called Riverside Center, directly north of the Station, which would create new high-rise residential and commercial buildings in close proximity to the existing Station, introducing the potential for emissions impacts at new receptor locations. In preparation for development of the Riverside Center DSEIS, Extell conducted wind tunnel modeling of air quality impacts that accounts for the location and height of the proposed new buildings and the exhaust stack emissions from combustion equipment at the Station, namely boiler emissions from the approximately 500 foot Stack No. 1 and the gas turbine emissions from a separate, shorter stack. The initial results indicated that some modeled elevated receptor locations on these buildings would potentially exceed the City of New York's current interim guidance for fine particulate matter, $PM_{2.5}$. The gas turbine exhaust, due to its relatively low stack height elevation and the exhaust plume affected by building-induced downwash, was identified as the main contributor to the higher $PM_{2.5}$ levels.

PB was retained to evaluate, preliminarily, the performance, operational, and maintenance impacts of potential solutions that would produce modeled $PM_{2.5}$ concentrations at these elevated receptors that are within the limits of the City's interim guidance criteria. Due to perceived technical issues with back-end cleanup of the high temperature turbine exhaust, it was determined to focus the majority of the project on evaluating rerouting the turbine to the taller stack. Alternate fuel options for the gas turbine were also evaluated, including conversion to natural gas or ultra low sulfur diesel. However, a fuel conversion by itself is not sufficient to meet the stated emissions requirements.

3. SCOPE OF WORK

PB was requested to investigate three technical changes that together or individually would reduce $PM_{2.5}$ emissions in accordance with the Extell request. The three changes were:

- Divert the GT exhaust from the present stack (127 ft. height) to Stack 1 (485 ft. height)
- Utilize the existing stack with exhaust control technology to produce a $PM_{2.5}$ emission rate of approximately 0.0013 lb/MMBtu or less
- Change the main fuel from the existing kerosene to either natural gas or ultra low sulfur diesel to achieve a $PM_{2.5}$ emission rate of approximately 0.0013 lb/MMBtu or less

PB undertook a limited review of the issues relating to fuel conversion of the gas turbine. The alternative fuel options considered were natural gas and ultra low sulfur diesel (ULSD). Conversion to natural gas firing would potentially require modification of the Title V permit, even though this is a cleaner fuel than distillate oil. Preliminary estimates indicated that a fuel switch alone would not be sufficient to meet the emissions requirements.

Therefore, the work of this study focuses primarily on issues with routing the gas turbine exhaust to the existing boiler stack.

<u>Fatal Flaw Analysis</u>

- Hold kickoff meeting to confirm initial scope, schedule and lines of communication
- Initial site visit for PB to become familiar with facility
- Obtain additional drawings as necessary and verify present conditions at the plant
- Make recommendations based on the above findings
- Determine feasibility and reveal any critical flaws of options being considered
- Identify any potential alternative options
- Begin preliminary discussions with subcontractors to verify feasibility and begin to prepare cost estimates for the next task
  - Site visit with a contractor to determine potential flaws in proposed duct routing and identify alternative routings
  - Meet with Wood Group Pratt & Whitney Industrial Turbine Services to determine feasibility of fuel conversion and backpressure impacts on performance
- Conduct literature searches, contact vendors and utilize PB Network to investigate critical issues with the options
- Meet with and present findings to Con Edison

<u>Preliminary Engineering Study Report</u>

- Detail changes in turbine output due to draft changes and/or duct losses
- Quantify steam, electrical and plume effects for all configurations outlined in RFP (all boilers and turbine on, some boilers on with turbine on, no boilers on with turbine on, etc.)
- Clearly mark duct routing on general arrangement

- Include specifications for a booster fan if one is required to overcome duct losses.
  - Fan sizing, location and connections to energy supply will be defined
  - Report on any fan O&M concerns
  - Wiring or piping requirements clearly shown on one-line, P&ID, and piping detail drawings
- Evaluate effects on black start
- Identify structural, operational and aesthetic steel or structure changes
- Identify any impenetrable interferences ducts may encounter
- Determine effects of hotter turbine exhaust on boilers and stack lining
- Recommend adding, replacing or relocating CEMS equipment if required
- Estimate resulting stack plume height and constituent concentration
- Determine effects of fuel switch on turbine output
- Discuss preliminary report with Con Edison to determine necessary changes
- Incorporate Con Edison's comments into the final report

<u>ENGINEERING SERVICES AND DELIVERABLES PROVIDED</u>

PB performed engineering and design evaluations of the following systems and areas based on necessity:

- Civil, Structural, Architectural
- Mechanical
- Electrical Supply and Load
- Instrumentation and Controls
- Operating and Maintaining Considerations
- Operating Configurations

4. ANALYSIS PARAMETERS

In order to complete this study, a number of technical parameters were required. These parameters and their basis are documented in the following table:

Parameter	Value	Source or General Notes
Atmospheric Pressure	14.7 psia	Standard ISO Reference Conditions
Turbine Exhaust Temperature	900°F	Grace Consulting Particulate Test Report
Turbine Mass Flow	245 lbs/sec	Stahl-Laval O&M Manual
Boiler Exhaust Temperature	403°F	Grace Consulting Particulate Test Report
Boiler Peak Volumetric Flow	808,000 ACFM	Grace Consulting Particulate Test Report
Outside Air Temperature	100°F	Conservative (Assumes Hot Summer Day)
Steel Stack Liner Roughness	0.0003 ft	Average of Steel Surface Roughness Ratings
Gunite Stack Liner Roughness	0.01 ft	Conservative (Assumes Very Rough Surface)

In some cases, conflicting information on the current operating conditions was obtained from different sources. Every effort has been made to ensure the accuracy of all assumptions, and for conflicting sources of information the more conservative numbers were used for analysis. Since the accuracy of the engineering calculation results is highly dependent on the accuracy of the source data, the results of all calculations should be considered as relative values to the base conditions.

PB highly recommends that all calculated conditions, such as draft conditions at the base of the stack, be confirmed with empirical measurements prior to any detailed design work.

5. ASSESSMENT OF TECHNICAL NEEDS

The primary objective of this study is to evaluate the requirements for exhausting the gas turbine to the existing 485 foot stack. Con Edison initially targeted the following specific areas of concern which must be addressed:

- Excessively large duct sizing may result in impenetrable interferences within the plant
- Excessive duct losses may adversely affect the performance of the gas turbine
- Draft impact and possible positive pressurization of the boilers must be evaluated
- Temperature limitations on the current stack liner must be evaluated

The first step in evaluating the impact of exhausting the gas turbine into the taller stack is to do a flue gas pressure model to evaluate the conditions at the base of the stack.

<u>FLUE GAS PRESSURE CALCULATION METHODOLOGY</u>

The primary objective of the flue gas pressure calculations is to determine the temperature and draft conditions at the base of the stack. Since this will help with determining the performance impact on the gas turbine, the effect on the existing boilers, and the temperature on the stack liner, it is a critical initial step for evaluating the technical needs of the system.

The major components of the flue gas pressure calculations (and how they impact the gas turbine) are illustrated in Figure 2:

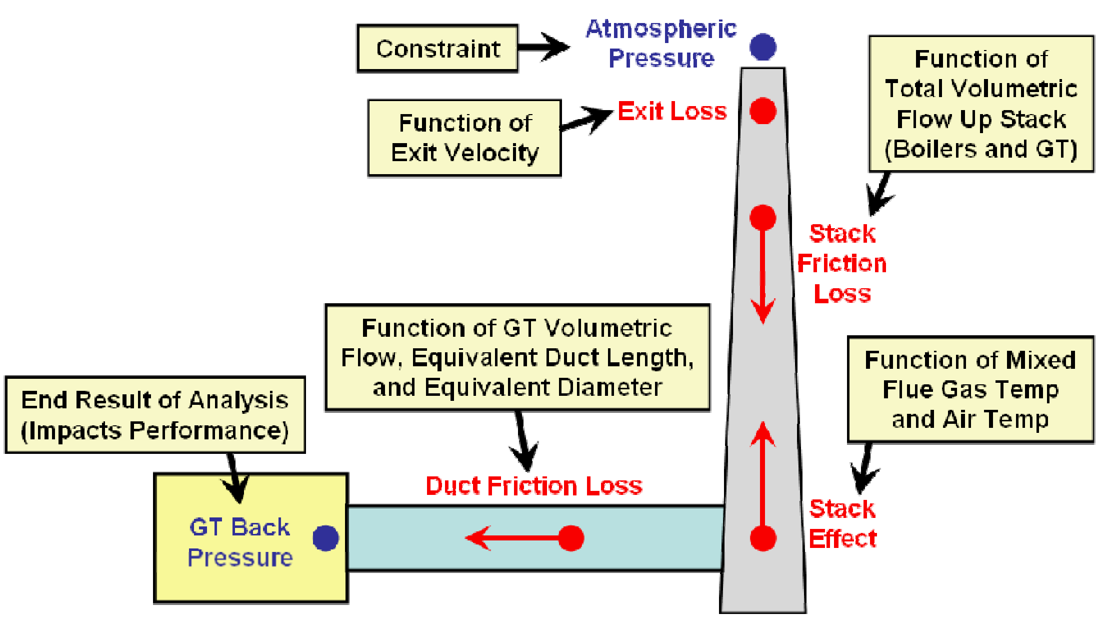


Figure 3 - Flue Gas Pressure Model

The calculation of the draft (negative gauge pressure at the base of the stack) is used as a reference point for the ductwork calculations and is based on the following elements:

Atmospheric Pressure – This is used as a reference point for all conditions and is assumed to be 14.7 psia (standard ISO conditions.) By definition, all gauge pressures are measured relative to this pressure. Since the reference atmospheric pressure will affect both the inlets and exhausts of all combustion and power equipment on the system equally, normal changes to the barometric pressure will have a negligible impact on the results of the model.

Ambient Temperature – The ambient air temperature has a substantial impact on the stack effect calculated in the model. Since higher ambient temperatures result in a lower stack effect (and more conservative results) an ambient air temperature of 100°F was selected to represent a hot summer day.

Flue Gas Conditions – The mixed flue gas conditions are based on the contributions of the equipment (boilers and gas turbine) which are in operation at the case being evaluated. A number of parameters from the mixed flue gas conditions are required for other calculations in the flue gas pressure model:

The combined mass flow (m_{tot}) from two streams is calculated simply as:

$$m_{tot} = m_1 + m_2$$

The combined temperature (T_{tot}) for two streams is calculated as:

$$T_{tot} = (T_1 m_1 + T_2 m_2) / m_{tot}$$

The density (ρ_{tot}) in lbs/CF of the combined stream is calculated as:

$$\rho_{tot} = 144\ p_{atm} / RT_{tot,\,abs} = (144 \times 14.7) / (53.3 \times (460°R + T_{tot}))$$

The volumetric flow rate is therefore calculated from the mass flow and density:

$$V_{tot} = m_{tot} / \rho_{tot}$$

Stack Effect – The stack effect (also known as theoretical draft) is a pressure difference caused by the difference in the ambient air and flue gas densities. It is calculated as:

$$D_{theoretical} = H_{stack} \times (\rho_{air} - \rho_{flue\ gas})$$

Since the density is inversely proportional to the absolute temperature (in °R), an increase in the flue gas temperature will decrease the density relative to the ambient air and will increase the stack effect.

Stack Friction Loss – The friction loss in the stack is pressure loss due to friction with the stack walls. The general formula for friction loss is:

$$\Delta P_{friction} = \rho\, f\, L\, v^2 / 144\, D\, 2g$$

ρ = density in lbs/CF
f = friction factor
L = stack length in feet
v = velocity in ft/sec
D = stack diameter in feet

g = gravitational constant, 32.2 ft/s²

Since the stack is effectively three different sections (a wide diameter at the base, a tapered transition section, and a long narrower upper section) the friction loss must be calculated independently for each section and combined to obtain the total value:

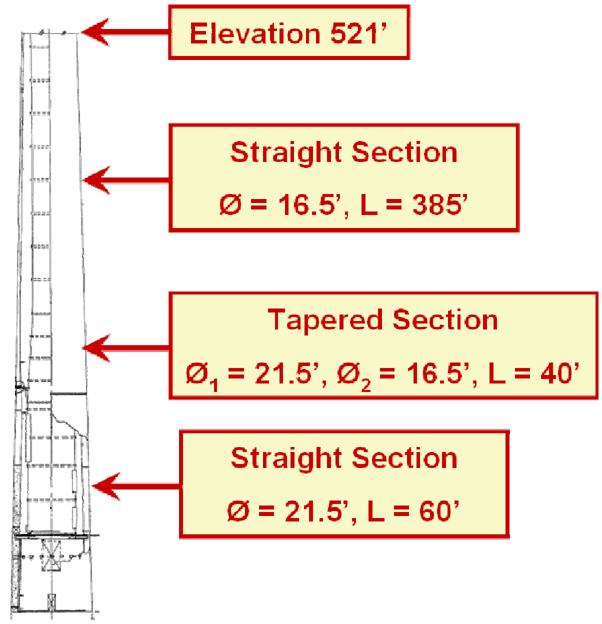


Figure 4 - Stack Dimensions for Analysis

Besides directly affecting the diameter parameter in the friction loss calculation, the varying stack diameter also affects the flue gas velocity parameter through the following relationship:

$$v_{ft/sec} = V_{CFM} / 60\, A_{stack} = V_{CFM} / 60\, \pi (D_{stack}/2)^2$$

Of the all the parameters in the friction loss calculation, the friction factor (*f*) is the most involved to calculate. The Colebrook equation for friction factor is:

$$1 / \sqrt{f} = -2 \log_{10} \left((\varepsilon / 3.7\, D) + (2.51 / R \sqrt{f}\,) \right)$$

f = friction factor
ε = absolute roughness (use 0.0003 for steel)
D = diameter in feet
R = Reynold's Number

Since the Colebrook equation is non-factorable for *f*, a numerical curve fitting algorithm was used for obtaining friction factors for different input parameters. From this formula, it is found that substantial increases in the surface roughness of the liner have significant, but not proportional, impacts on the total friction. For example, changing the liner absolute roughness from steel (0.0003) to rough concrete (0.01) increases the total friction by approximately 70%.

The Reynold's Number (*R*) for use in the friction factor calculations is found using:

$$R = D_{stack}\, v_{ft/sec} / \nu$$

ν = *kinematic viscosity*

An increase in flue gas temperature increases the kinematic viscosity according to the relationship in the following chart (based on empirical data):

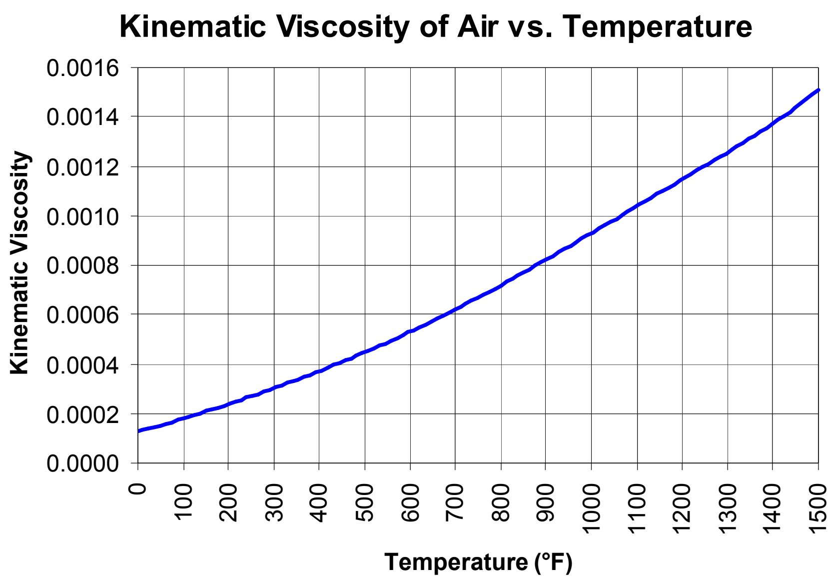


Figure 5 - Kinematic Viscosity of Air vs. Temperature

The kinematic viscosity used in the flue gas pressure model is calculated using a numerical curve fit of the empirical data.

Exit Loss – The pressure loss due to flue gas exiting the stack to atmosphere is equal to the velocity head calculated using the following formula:

$$VP_{in\ wg} = \rho\ v_{ft/min}{}^{2} / 1.2 \times 10^{6}$$

Since the exit loss is proportional to the square of the velocity, an increase in the volumetric flow of the flue gas (which is directly proportional to the exit velocity for a fixed cross sectional area) will result in a substantial increase in the overall exit loss. Doubling the exit velocity, for example, will quadruple the total exit loss.

COMPUTERIZED FLUE GAS PRESSURE MODEL

In order to rapidly evaluate the impact of changing parameters on the pressurization at the base of the stack, a computerized model was developed. The model calculates all combinations of gas turbine and boiler flue gas flow in the stack from zero to maximum in increments of 1% of flow for a total of 10,000 calculation points. The worst case conditions (minimum draft) can be evaluated from this, as well as specific operating cases requested by Con Edison.

The primary input parameters for the flue gas pressure model are:

- Peak Boiler Stack Flow (CFM)
- Boiler Flue Gas Temperature (°F)
- Gas Turbine Exhaust Mass Flow (lbs/sec)
- Gas Turbine Exhaust Temperature (°F)
- Dilution Air Mass Flow (lbs/sec)
- Dilution Air Temperature (°F)
- Dilution Air Fan Estimated Total Pressure (in. W.C.)
- Dilution Air Fan Efficiency (%)
- Ambient Air Temperature (°F)
- Stack Liner Material (Steel or Gunite)
- Stack Liner Coating Thickness (inches)

By changing any of the above parameters, the model automatically calculates any dependent variables for the pressure calculations (for example, a change to the gas turbine exhaust temperature will automatically change the mixed flue gas temperature at the base of the stack, the density for the stack effect and volumetric flow calculations, the kinematic viscosity used to derive the Reynold's Number for use in the Colebrook Equation, etc.)

Out of the 10,000 operating scenarios which are evaluated, seven key operating conditions (labeled Case 0 to Case 6) are given special consideration at the request of Con Edison:

Case 0: All boilers operating (no gas turbine)
Case 1: Gas turbine with no boilers
Case 2: Gas turbine with one large boiler operating
Case 3: Gas turbine with one package boiler operating
Case 4: Gas turbine with both large boilers operating
Case 5: Gas turbine with all three package boilers operating
Case 6: Gas turbine with all five boilers operating

The model provides output calculations for each operating scenario for the following items:

- Dilution Air Volumetric Flow (CFM)
- Dilution Air Fan Brake Horsepower
- Total Stack Mass Flow (lbs/sec)
- Stack Flue Gas Temperature (°F)
- Stack Volumetric Flow (CFM)
- Stack Exit Velocity (ft/sec)
- Stack Friction Loss (in. W.C.)
- Stack Exit Loss (in. W.C.)
- Stack Effect (in. W.C.)
- Net Draft at Base of Stack (in. W.C.)

RESULTS OF FLUE GAS PRESSURE ANALYSIS

From the flue gas pressure analysis for the anticipated range of operating conditions at 100°F ambient air with no dilution air, the following key points can be concluded:

- The worst case from a stack pressurization standpoint is when the gas turbine is operating with all five boilers at full capacity. This results in a net draft of approximately **1.35”** at the base of the stack, representing a **draft loss of 0.27”** compared to the current worst case conditions (all five boilers operating at full load simultaneously.)

- Since current equipment pressurization conditions are not known, it is unknown if flue gas leakage will occur. However, **improved dampers are advisable** to ensure proper isolation.

- The worst case draft of 1.35” represents the total target pressure loss for the new gas turbine ductwork that is required to avoid any increase in backpressure (and therefore any reduction in power output.)

- Under all conditions with the gas turbine in operation, there is a substantial increase in the flue gas temperature compared to the existing conditions. This temperature ranges from **544°F** under the best circumstances (when the gas turbine is operating in combination with all five boilers) to **900°F** at the worst condition (when the gas turbine operates alone.)

- The increase in stack temperature raises potential problems with the current stack liner, which are discussed in the following sections.

EXISTING STACK CONSTRUCTION AND TEMPERATURE LIMITATIONS

The existing boiler stack to which the gas turbine exhaust will be routed to consists of four distinct layers:

1. The innermost layer is a self-supporting ASTM A242 carbon steel stack liner. This is 7/16" thick at the base with an internal diameter of 21'-6". At a height of 60', the liner tapers over the next 40' to a final thickness of 3/8" and a diameter of 16'-6" which extends the final 385' to the top of the stack (see Figure 6 for an illustration of the chimney sections.)

2. The steel liner is surrounded by ceramic wool insulation held in place with a wire mesh.

3. The next layer is an insulating air gap.

4. The outermost layer is a free standing reinforced concrete wind shield which is 37" thick at its base and tapers to 11.5" thick at its top. This layer acts as the primary structural component and is designed to protect the steel liner from outside environmental conditions.

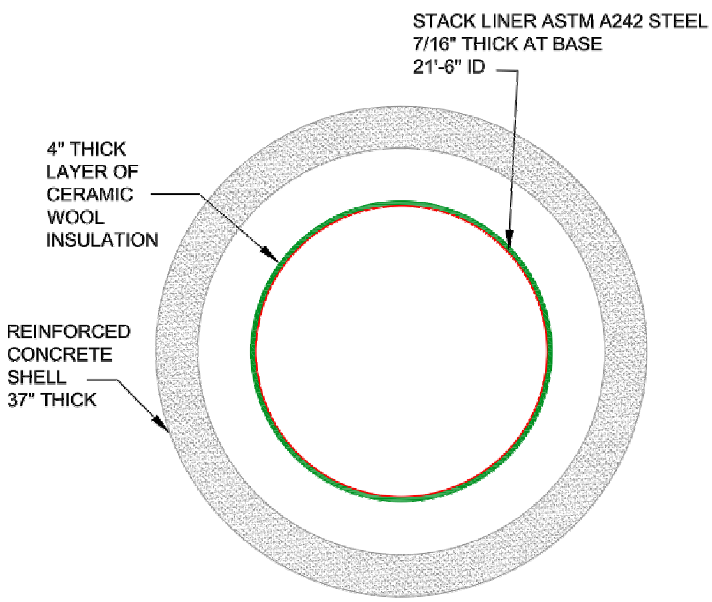


Figure 7 - Stack Construction

The inner steel liner is the only layer which comes into direct contact with the flue gas. The insulation and air gap layers work to protect the structural concrete layer from the high temperatures. Both the steel liner and the concrete wind shield are anchored at their bases.

The ASTM A242 steel used in the liner is a high-strength, low-alloy steel which incorporates approximately 2% copper for a self-weathering protective oxidation coating. This eliminates the need for painting and results in approximately four times the corrosion resistance of normal carbon steels. This type of steel is typically used in structural members where savings in weight or added durability are required. Common applications include buildings, bridges, industrial equipment, and railroad rolling stock. Trade names for ASTM A242 include COR-TEN™ (a registered trademark of United States Steel Corporation) and MAYARI-R™ (a registered trademark of Bethlehem Steel, which is how the material was specified on the original engineering drawings.)

Of particular concern is the impact of higher flue gas temperatures on the existing steel liner, which was only intended for a stack temperature of approximately 400°F. Under the proposed conditions with the gas turbine, the stack will be required to withstand potential temperatures as high as 900°F. ASTM A242 begins to weaken at around 750°F due to an increase in strain from constant stress at high temperature (known as creep.) There is an increasingly sharp drop in creep-rupture strength at temperatures above 900°F, making the addition of the high temperature gas turbine exhaust a concern for the structural integrity of the steel liner. Anecdotal evidence from chimney manufacturers indicates that in some cases an ASTM A242 liner will experience delamination (a condition under which entire layers will shear off) under the temperature ranges associated with gas turbine exhaust.

Good engineering practice would dictate limiting the existing stack liner temperature in order to avoid potentially catastrophic structural issues. The exact temperature limit of the stack is unknown and it will require a CFD analysis to asses a safe flue gas temperature. Two methods for limiting the temperature of the stack liner, a protective gunite lining and the introduction of dilution air, are discussed in Section 6 (Development of Engineering Solutions.)

CHANGE OF FUEL FOR GAS TURBINE

PB contacted Wood Group Pratt & Whitney (Wood Group) to develop options for a potential change of fuel for the gas turbine. Although Stal Laval was the packager of the 59th Street gas turbine, Wood Group currently has a maintenance contract for the gas generator (which was purchased from Pratt & Whitney.) Wood Group also maintains two similar units at the Con Edison 74th Street Station.

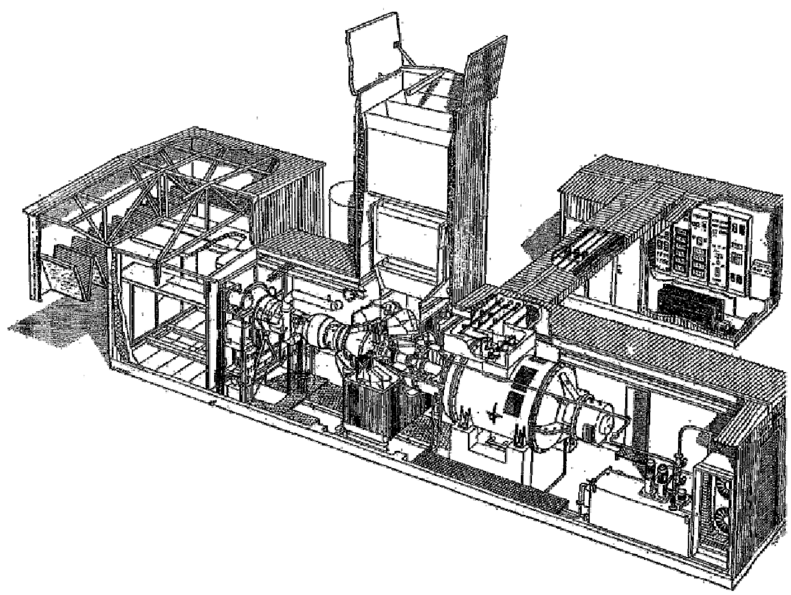


Figure 8 – Diagram of 59th Street Gas Turbine Package

The 59th street gas turbine currently burns kerosene, but Wood Group has advised that the engine lends itself well to dual fuel firing. Both natural gas and ultra low sulfur diesel fuel were considered, but natural gas was the main focus because of Con Edison's plans to evaluate the installation of natural gas-burning capability to the two large boilers in the plant. Three main fuel conversion options were developed:

1. Convert to natural gas only
2. Convert to dual fuel (natural gas and liquid fuel)
3. Convert to natural gas with water injection (for NOx reduction)

All of these options require disassembly and conversion of the engine to install new fuel manifolds, however Options 2 and 3 are considerably more involved because of the lack of both gas and liquid ports on the diffuser. New controls would be required for any conversion to natural gas (the addition of a gas-purge cycle and controls conversion to include spark-proof relays and other upgrades.)

The current gas main for the plant is located adjacent to boiler B-115, near column line 1 and column line X. Con Edison is considering upgrading the large Annex boilers to dual-fuel, and the new gas service would have a nominal pressure of 300 psig. If a fuel conversion is implemented for the turbine, the work can be accomplished at the same time. Depending on the actual available gas pressure and the needs of the turbine, a duplex gas compressor station may be required.

BACKPRESSURE IMPACT ON GAS TURBINE

One of the major technical needs which must be addressed is the potential impact of increased backpressure on the gas turbine. Computer modeling of the gas turbine using *Thermoflow GT Master* software and an evaluation by Wood Group Pratt & Whitney both point to the same results:

- 0.25% loss in power production for each 1” of additional backpressure
- 0.125% increase in heat rate for each 1” of additional backpressure

Of these two items, the loss in power production is the most significant concern for Con Edison. Even though the gas turbine only operates for a limited time, it is critical for black start and peaking operation within its load pocket (which has limited import capability available.)

The gas turbine is rated for 17.5 MW of output at ISO conditions with a design backpressure of 2” (accounted for by the baffles in the existing exhaust ductwork, which must remain for NOx and particulate matter testing purposes.) Each incremental inch of backpressure is therefore added onto this base design point. The projected power reduction as a function of backpressure at ISO conditions is shown in the following graph:

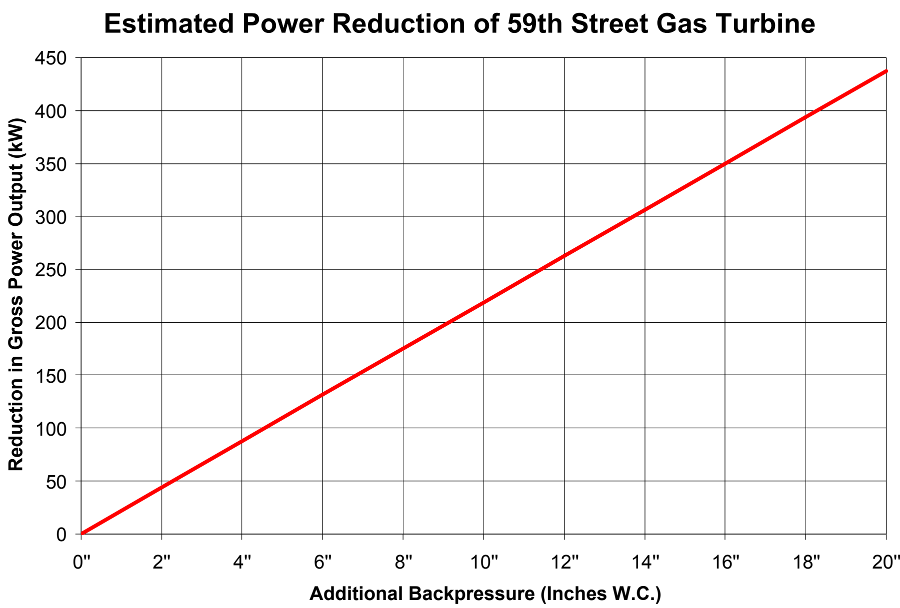


Figure 9 - Impact of Additional Backpressure on GT Output

6. DEVELOPMENT OF ENGINEERING SOLUTIONS

With the major technical needs identified, it is possible to develop options for ensuring that the requirements are addressed. Key items for evaluation include the duct sizing and design, possible use of an inline duct fan to overcome friction losses, duct routing, options for thermal protection of the stack liner, and isolation of equipment which is not in operation.

DUCT SIZING AND DESIGN

Based on Con Edison's intention that there be no reduction in the gross power output of the gas turbine, the target for overall head loss of the ductwork should equal the draft at the base of the stack. This will result in the two canceling each other out and will result in a gauge pressure of zero at the ductwork connection to the existing turbine exhaust. The flue gas pressure model calculated a worst case draft of 1.35", so this is the target for the total head loss of the duct.

The head loss of the duct is equal to exit loss plus friction loss. This is most easily calculated using the loss coefficient method:

$$\Delta P_{in\ wg} = K \rho v_{ft/min}^2 / 1.2 \times 10^6$$

K = loss coefficient
ρ = density of turbine exhaust = 0.02912 lbs/CF at 900°F
v = velocity = 500,000 CFM / π(D/2)²

The total head loss is equal to the loss coefficient (*K*) times the velocity head. The individual loss coefficients are summated for to determine the total loss coefficient for the system. For the exit loss, *K*=1. For the friction loss of the ductwork, the loss coefficient is calculated using the following formula:

$$K = f L / D$$

f = friction factor, calculated as approximately 0.01 from Moody Diagram
L = duct equivalent length in feet
D = duct hydraulic diameter in feet

Based on the preferred duct routing (outlined in the "Duct Routing" section of this report) the total equivalent length including all straight runs and fittings is approximately 1,900 feet. The formula for the total friction loss as a function of duct diameter is therefore:

$$\Delta P_{in\ wg} = (1+(0.01 \times 1900 / D)) \times 0.02912 \times (500{,}000/ \pi(D/2)^2)^2 / 1.2 \times 10^6$$

Based on this formula, the effect of duct diameter to total head loss is illustrated in the following graph:

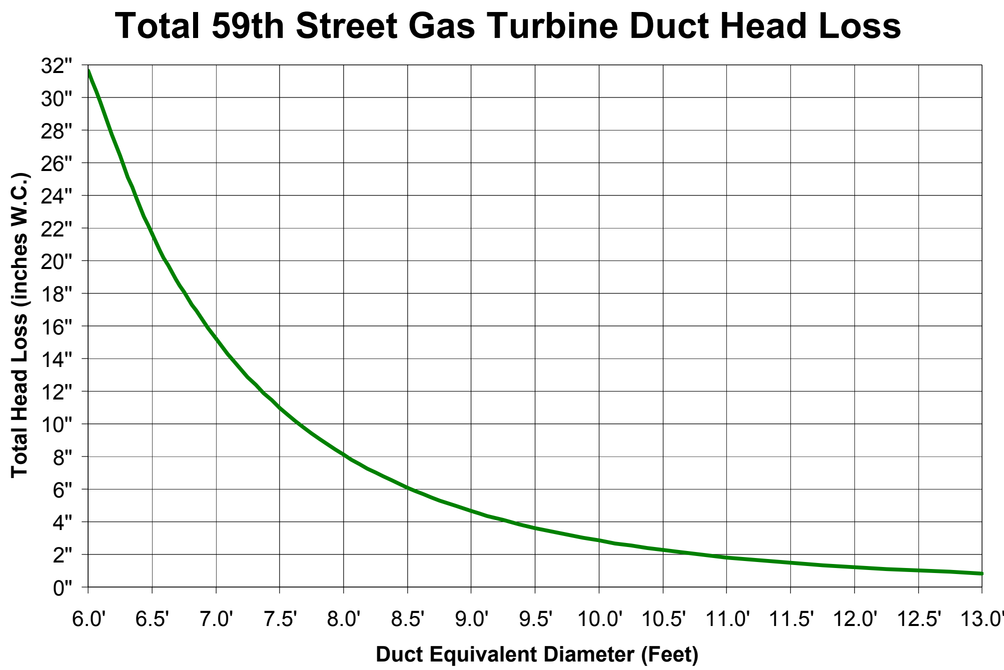


Figure 10 - GT Duct Head Loss vs. Diameter

In order to achieve a target head loss of 1.35” to balance out the worst-case draft, a round duct with an internal diameter of approximately 11’-9” would be required.

Due to space limitations within the plant, this is not a practical duct size. The largest duct which can be run within the plant from a practical standpoint is a round duct with an internal diameter of **9 feet**. This will result in a total head loss of 4.67”, or a **net backpressure of approximately 3.32”** on the turbine (when balanced by the stack draft.)

The impact of this additional backpressure on the turbine will result in an **anticipated gross power reduction of approximately 145 kW**.

Round ductwork provides a number of advantages over rectangular ductwork including:

- Ease of fabrication
- Less weight for a given equivalent diameter
- No requirement for turning vanes (which add cost and friction loss) at bends

The major drawback with round ductwork is that it requires more physical space to run than an equivalent rectangular duct. For this reason, in significant stretches of the proposed duct run it is not practical to run a round duct because of a lack of available space. For a rectangular duct, the equivalent diameter is found using the following formula:

$$D_e = 1.3\,(W \times H)^{5/8} \;/\; (W + H)^{1/4}$$

There is a long straight run where only 8’-9” is available between columns (meaning a duct internal width restriction of 7’-6” after insulation.) Using the above formula, in order to maintain an equivalent diameter of 9 feet a **rectangular duct with internal dimensions of 9’ tall and 7’-6” wide** is required.

The exhaust gases from the gas turbine are discharged at approximately 900°F. Since carbon steel starts losing its strength near 700°F, a traditional carbon steel exhaust duct with exterior lagging is not sufficient for this temperature. The proposed design used in similar high-temperature simple cycle gas turbine installations has the following configuration:

1. Exterior structural layer of 1/4" thick ASTM A36 carbon steel. All exterior welds are to be seal welds.
2. Insulation layer of 4" thick ceramic wool.
3. An interior liner consisting of 10 gauge ASTM A240 Type 409 stainless steel liner plates.
   a) The internal stainless steel liner plates overlap and are arranged similar fish scales so as to enable differential expansion.
   b) The internal stainless steel liner plates are typically held place using stainless steel pins rigidly attached to the carbon steel casing by welding.
   c) The liner plates will have a single fixed point and the other attachment points have slotted holes in the liner plates to allow for thermal expansion.

This design was selected for the following reasons:

- The stainless steel liner is an appropriate choice for direct exposure to the high temperature gas turbine exhaust.
- Using a system of liner plates instead of a continuously welded liner would allow the liner to expand independently of the structural layer
- The ceramic wool insulation reduces the surface temperature to 140°F, which is required by OSHA.
- Welded gas tight joints using ¼" carbon is an excellent choice for structural strength at considerably lower cost.
- Since the structural layer has a peak temperature of 140°F, substantially fewer expansion joints are required than if the structural layer were facing a higher maximum temperature.

Although dilution air is discussed in a later section, one potential benefit of dilution air which was considered is the ability to use a lower temperature design for the ductwork, similar to conventional boiler exhaust ducts. However, after discussions with contractors it was determined that the cost reduction would be negligible for the following reasons:

- Conventional ductwork is lagged in the field as opposed to factory-installed insulation for the turbine ductwork. Due to the size and complexity of the run, this would not save any cost.
- Although the cost of the stainless steel liner will be avoided, since the structural steel will now be at a higher temperature (perhaps 600°F instead of 140°F) then roughly four times as many expansion joints would be required.

For these reasons, as well as energy implications which will be addressed later, dilution air in the ductwork is not recommended.

INLINE FAN FOR DUCT LOSSES

One option which was considered for overcoming the increased backpressure on the gas turbine due to duct losses was an inline fan. As stated in Section 5, each additional inch of backpressure on the turbine results in a power reduction of 0.25% (equal to 43.8 kW at ISO conditions.) In order for an inline fan to provide any benefit for regaining lost power capacity, the fan energy requirement would need to be less than 43.8 kW per inch of pressure gain.

The formula for fan mechanical power is:

$$P_{fan\ br} = V_{CFM}\ p_{in\ wg}\ /\ 6536\ \eta_{mech}$$

$P_{fan\ br}$ = *fan brake horsepower*
V_{CFM} = *turbine flue gas volumetric flow, 503,000 CFM*
$p_{in\ wg}$ = *pressure, 1" w.g.*
η_{mech} = *fan mechanical efficiency, assume 65%*

This results in a fan brake horsepower of 118.4 bhp per inch of pressure gain. Assuming a motor efficiency of 95%, this is equal to fan electrical power consumption of **92.9 kW per inch** of pressure gain. Therefore since this exceeds the power gained by the gas turbine, there is no electrical power benefit to adding an inline fan to overcome duct friction losses.

DUCT ROUTING

The GT is located towards the west end of the plant, with a vertical exhaust and connection to a dedicated exhaust stack. In order to connect to Stack 1, it is necessary to devise a route within the building as no external changes to the plant are allowed. The main east-west (numbered) columns are on 18 ft centers but the Con Edison numbering scheme is irregular as intermediate points are also indicated on other plant drawings. The north – south (letter) columns are also included.

The GT is on floor datum 22'-9" at a position between column lines 46 and 47. The connection between the GT exhaust and the new duct is approximately datum 55'–0". It is necessary to run duct in an approximately easterly direction towards the existing Stack 1, a distance of 27 column spacings or 486 ft horizontal. However, there is a change in vertical datum between the GT connection point and the breech into Stack 1 at approximately 78'–0" and there are obstructions to a straight route. Therefore PB considered three different paths during the first site visit.

1) Route the GT # 1 Ductwork at 110'-0" Elevation

2) Route the GT #1 Ductwork at around 54'-3" Elevation

3) Route the ductwork at some intermediate level

Route #1 was initially the preferred path during the first site visit before PB had gathered information about the building. Route # 2 was also discussed but not considered favorable as it required a route that avoided interference with the feed water treatment area and switch gear room. Route # 3 was also discussed but was considered not feasible as it would not be possible to route the ductwork at that level without penetrating the un-used but substantial coal bunker.

During the second site visit PB determined that Route #2 would be most appropriate path in terms of exhaust flow, pressure drop, installation, and pitch from the GT to stack 1. This route minimizes potential penetration through the coal bunkers and also avoids the cost of building scaffolding, which would have been necessary for Route #1. Route #2 is indicated on Drawings M-1 and M-2.

The ductwork from column lines 47 to 35 will be 9' internal diameter with the bottom of the duct (BOD) at 54' elevation, supported from the bottom of steel. From column line 35, BOD will be at 70'-3" elevation to avoid the feed water treatment area and switch gear room. The route shifts from column lines Q and R to column lines Q and P to avoid penetration of the coal bunker. There is an 8'-9" restriction on duct external width in the space between columns Q and P so in this area the duct internal dimensions are 7'-6" wide by 9' tall (to accommodate the thickness of insulation and the structural casing). Near column 8 there is a 3'–8" increase in level and at column 7, there is an approximate 45 degree bend then a divergent section and flow turning vanes at the connection into the Stack 1 breech point.

OPTIONS FOR THERMAL PROTECTION OF STACK LINER

The self-supporting steel stack liner was designed for use with the existing boilers having exhaust temperatures of approximately 400°F. The GT full load exhaust temperature is 900°F and the machine must be operable irrespective of how many boilers are in service. When boilers are in operation, there will be mixing of gases but the worst-case scenario when no boilers are in operation is that 900°F gases will impinge the liner and lead to structural damage. **Prior to any final assessment of temperature limitations on the liner and possible solutions, a detailed chimney inspection is required**. PB has assessed two potential solutions that avoid over-heating the liner:

- Thermal Lagging of the Liner
- Introduction of Dilution Air

Thermal Lagging of the Liner

A suitable lining method is to spray a refractory concrete such as Gunite, a proprietary brand with good reputation. The process was invented in 1909 and involves a mixture of Portland cement and a suitable mix of sand/refractory aggregate that is thoroughly mixed dry, passed through a cement gun, hydrated at a mixing nozzle at and spray-deposited onto the work surface. When properly mixed and applied, the cured product is extremely strong, dense, heat resistant and highly resistant to weathering and many forms of chemical attack. The bond to the work surface bond is equal to or greater than the shearing strength of the material to which it is applied and the coefficient of expansion is almost identical to that of low carbon steel.

Gunite product No. 54LW is a Sauereisen acid-proof concrete with sufficient insulation properties that a 1.5 inch thick layer would reduce the temperature from 900°F to 300°F at the Gunite/steel interface, effectively shielding the steel chimney liner from excessive exhaust temperatures. Although bonding is good, it is recommended that T anchors be used to assure integrity of the Gunite structure within the liner. Gunite No. 54LW can withstand temperatures up to 1600°F and has a thermal conductivity of 3.2 BTU/ft^2-hr-F.

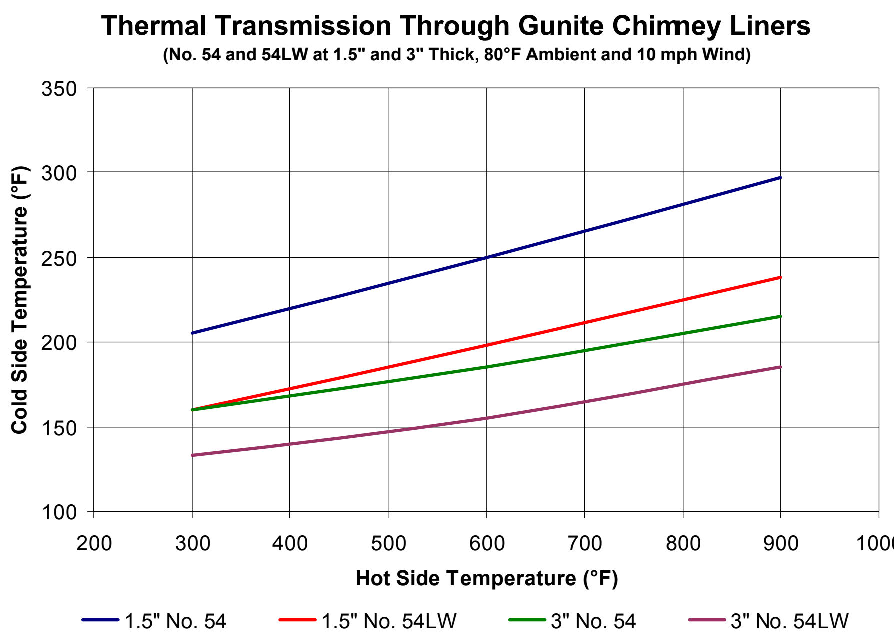


Figure 11 - Thermal Transmission of Gunite Liner

The addition of a 1.5" thick gunite liner, if required all the way to the top of the stack, is calculated to **reduce the net draft at the base of the stack by an additional 0.36"** at the worst-case conditions (down to a total projected net draft of 0.99".) This draft reduction is due to higher friction loss and exit loss from increased flow velocity (due to the reduced cross sectional area) and increased stack surface roughness. The increased draft loss results in an **additional loss in generator capacity of approximately 16 kW**.

Introduction of Dilution Air

In order to reduce the temperature of the flue gas to a temperature acceptable for the existing stack lining, dilution air may be introduced. This is different to dilution air which is a technique that reduces the mass of exhaust constituents per volume of exhaust flow or enhances the rise (and therefore dispersion) of an exhaust plume. Therefore, while dilution cannot be used to reduce model-predicted ambient air concentrations of air pollutants, there is precedent that cooling air has been accepted at some gas turbine installations for the sole purpose of cooling the exhaust.

PB and its consultant, AECOM, have assessed the impact of gas turbine exhaust/cooling air on the existing Continuous Emissions Monitoring System (CEMS) for the boilers. With a single CEMS in the boiler stack, a procedure will likely be needed to account for the limited hours of turbine operation concurrent with boiler operation to subtract gas turbine emissions based on the fuel consumption rate. Since the concentration values monitored by the CEMS are corrected to a standard percent O_2, the addition of turbine exhaust/cooling air will not change this correction; therefore there should be no effect on the CEMS accuracy. There is no need to measure the volumetric flow rate of the cooling air.

Opacity monitoring will not be affected by the merging of plumes or by the addition of cooling air. The amount of cooling air is related to the simultaneous flow produced by the boilers. Some adjustment of the Continuous Opacity Monitoring System (COMS) equipment may be required if the temperature of the exhaust gas changes the dimensions of the stack liner due to thermal expansion. The Title V permit requires visual observation of the turbine exhaust once per day during operation to demonstrate compliance with opacity requirements.

PROTECTION AGAINST FLUE GAS LEAKAGE

Since there is not currently a problem with flue gas leakage in the plant, it can be inferred that there is currently negative pressurization and/or properly sealed ductwork on the existing equipment. However, since there will be a reduction in draft and the exact pressurization conditions on the existing equipment has not been verified with measurements, **it can not be quantified at this time if there will be positive pressurization in the ductwork on operating equipment which would result in possible leakage**.

Since there is negative pressurization at the base of the stack under all projected operating conditions, most of the equipment in the plant is not at risk of flue gas leakage due to positive pressurization when it is not in operation. The gas turbine and the two large boilers each have their own individual ductwork leading to the stack, so there is relatively little risk of positive pressurization of that equipment while it is inactive (since no flow is occurring within the equipment duct when it is not operating, there is no friction loss and therefore the duct remains at the same negative pressurization as the stack.)

However, the small package boilers all share a common duct leading up to the stack so there are certain conditions which may result in positive pressurization of an inoperative package boiler. These conditions are most likely to occur when one or two of the package boilers is operating (resulting in a friction loss in the duct that raises the pressure above the pressure at the base of the stack) in conjunction with the large boilers and gas turbine (resulting in high friction and exit losses in the stack and therefore reduced draft at the base of the stack.) Since there is only a minor reduction in draft due to the addition of the gas turbine and the package boilers are not having any pressurization problems under the current conditions, there may not be a problem. **However, without pressure readings of the existing boiler flue gas ductwork and a detailed condition assessment to guarantee proper closure of the ID fan dampers, this can not be verified.**

As the leakage of flue gas into the plant is a potential life safety issue, the installation of new dampers is advised. In order to ensure total isolation of non-operating equipment, zero leakage guillotine dampers with a seal air system are recommended. Modern guillotine dampers use rigid seats to reduce leakage to the range of 0.4% to 1.1% of flow, and the addition of a seal air fan to pressurize a peripheral seal air chamber (located between the damper blade and the housing) and ensure full isolation is recommended to avoid leakage.

Manufacturers typically do not advise using normal guillotine dampers for systems with a temperature above 500°F because of warping due to the temperature gradient across the blade. However, there are special high performance “hot blade” designs which are intended to function at higher temperatures (such as with the gas turbine exhaust.)

For an additional level of personnel protection while maintenance work is being done on a single piece of equipment, a duct balloon or frame isolation barrier can be used in conjunction with the damper.

7. STRUCTURAL REQUIREMENTS

The goal of the structural investigations was to determine if the plant building structure can support the proposed duct work and concrete liner. The duct work will run between the turbine and Stack #1 and the concrete liner will be applied to the inside surface of the existing steel liner of Stack #1.

As a part of the investigation, visual walk-through observations were performed. The structural system is a conventional steel structure with cross bracings, roof trusses, and masonry walls. Individual structural steel members, which are either standard rolled shapes or custom built-up sections, are connected each other through riveted joints. Although significant deteriorations through corrosion were observed at some locations, most structural steel members seem to remain intact. Stack #1 is a reinforced concrete chimney with a steel liner and a steel frame that supports the liner.

Given that the physical plant is approximately a century old, there was some unavailable information and discrepancies between existing conditions and the available construction documents. The preliminary analysis performed based on the limited information shows that the existing structural steel members may be overstressed or close to the allowable limit to support the proposed duct work. A judgment was also made that the existing steel frame to support the existing steel liner would be overstressed due to the weight of the proposed concrete liner. In addition, the existing steel liner itself may experience some complicated behaviors under an elevated temperature, increased weight due to the concrete liner, and possible existing deteriorations or defects. Further detailed investigations are suggested to find an ideal solution to avoid possible structural failure of the liner. Other structural elements are presently assumed to be adequate due to elimination of coal weight, which requires a future verification through additional study. Additional attention was given to limit the increase of the loads to the building to avoid possible stringent requirements of the future building code and to alleviate the impact to the existing structures.

Finally, a total tonnage of new steel members required to support the proposed duct work and concrete liner is estimated for an approximate construction cost estimation related to the structural steel work.

During the visits to the plant building, no invasive or controlled inspections were performed. Observations were limited to certain areas of the building. Discussions and suggestions in this investigation are mainly to provide preliminary and general ideas only.

8. SCHEDULE AND TIMELINE

In order to meet the requirement of having the modifications completed and commissioned, the following major project tasks will be required:

Task No.	Task Description	Start Date *Months from Project Start*	End Date *Months from Project Start*
1	Preliminary Design	0	5
2	Permitting and Filing	2	11
3	Bid Process and Contract Award	5	9
4	Detailed Design	9	15
5	Fabrication	15	19
6	Construction	19	27
7	Close Out and Commissioning	27	28

PB highly recommends that detailed analysis and chimney inspections be performed to have clear indication about the condition of the stack liner. The analysis will determine if the stack needs a gunite liner or not, and if so then the height of the liner. The inspection and detailed analysis of existing stack is a critical task which will determine the overall scope of work for the remainder of the project. Since the liner is a possible solution which must be considered, provisions are included in the project timeline. The installation of the gunite liner and final ductwork connections to the stack and turbine will require outages to be scheduled.

9. CONCLUSIONS AND RECOMMENDATIONS

Following are the conclusions drawn from the preliminary engineering study:

- A minor reduction in worst-case draft on the existing boiler stack is expected to occur with the addition of the gas turbine (0.27” W.C. without any stack liner modifications, or 0.63” W.C. total with a 1.5” thick gunite coating on the entire liner.)
- Since the current gauge pressures of the boiler ductwork at the ID fan exits is not known, it can not be definitively assessed whether positive pressurization or flue gas leakage at the boilers will occur under the new conditions, therefore, PB highly recommends that all calculated conditions, such as draft conditions at the base of the stack, be confirmed with empirical measurements prior to any detailed design work.
- The stack liner will face a peak flue gas temperature of approximately 900°F, which occurs when the gas turbine operates alone.
- It is not definitively known what the temperature limits on the existing stack are without a CFD analysis, but a consistent response from multiple sources is that 900°F is likely too high.
- Because of space limitations within the Station, the largest duct size which can be practically run is an internal diameter of 9 feet.
- Due to head losses within the system, there will be an increased backpressure on the gas turbine which results in a peak power loss ranging from 145 kW (with no stack liner change) to 161 kW (with a 1.5” gunite coating in the stack liner.)
- Switching fuel to natural gas or ultra low sulfur diesel is not sufficient alone to meet the stated emissions requirements.

Based on these conclusions, the following steps are recommended:

- Perform a CFD analysis and inspection of the existing chimney and obtain a recommendation from a specialist on temperature limitations.
- Develop options for complying with stack temperature limitations including full or partial gunite coating, or other potential solutions, such as dilution air, water spray, etc.
- Obtain accurate pressure readings at the base of the stack and at the ID fan exits for each of the boilers to verify the stack pressurization model and evaluate whether flue gas leakage will occur.
- Investigate improved dampers for protecting personnel and equipment from flue gas leakage if required.
- Coordinate proposed plans with CEMS manufacturer to ensure the equipment is compatible.
- Investigate alternative options.