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NOX RACT FEASIBILITY EVALUATION
Hazardous Waste Incinerator

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Executive Summary

Ross Incineration Services, Inc. (RIS) operates a hazardous waste incinerator at its Grafton, OH (Lorain County) waste handling facility. As part of its environmental reviews, Ross retained Ramboll Americas Engineering Solutions, Inc. (Ramboll) to prepare a Reasonably Available Control Technology (RACT) feasibility evaluation to identify whether technologies to reduce nitrogen oxide (NO_x) emissions from the existing hazardous waste incineration are technically and economically feasible.

Pursuant to Ohio Administrative Code (OAC) Rule 3745-110, existing, new and modified sources of NO_x in Lorain County are required to demonstrate RACT for NO_x with limited exceptions. Rule 3744-110-03 has established RACT emissions limits for various combustion operations, but not for waste incinerators. Thus, RIS is subject to the provisions of Paragraph J of Rule 3745-110-03, which requires a detailed engineering study be performed by an engineering firm or other person experience in the field of air pollution control. These studies must address the technical and economic feasibility of various RACT controls for the source.

This report addresses the technical and economic feasibility of add-on NO_x controls. As such, budgetary capital and operating cost estimates have been developed for several add-on air pollution control technologies through a variety of means, including:

- Budgetary vendor quotations
- Standard cost estimating guidance
- Engineering experience

Based on this analysis, Ramboll concludes that the only technically feasible post-combustion air pollution control options for NO_x reduction is selective catalytic reduction (SCR). Selective non-catalytic reduction (SNCR), flue gas recirculation (FGR) and aqueous scrubbing technology were not deemed to be technically feasible for this application.

The technically feasible solution (SCR) is considered by Ramboll to be economically infeasible, considering current cost-effectiveness criteria. Thus, Ramboll has concluded that RACT for this application is continued good combustion control.

1. Background

1.1 Need for RACT Analysis

On April 15, 2004, the eight counties of Northeast Ohio (including Lorain County) were re-designated as being in moderate non-attainment for the ozone National Ambient Air Quality Standard (NAAQS).

On August 3, 2018[1], the U.S. EPA designed this area as “marginal nonattainment”. However, this area did not meet the ozone standard by the end of the 2020 ozone season, and on November 11, 2022, seven counties of Northeast Ohio (including Lorain County) were re-designated as being in moderate non-attainment in the Ohio 2015 Eight-Hour Ozone Nonattainment Areas classification.

Subsequently, RIS became subject to the requirements of OAC 3745-110-03(I)(4) - *RACT requirements and/or limitations for emissions of* NO_x *from stationary sources* (which became effective on March 25, 2022). In accordance with Clean Air Act (CAA) §182, the emissions threshold that establishes which stationary sources are considered major stationary sources depends upon the classification of the ozone nonattainment area, summarized in Table 1.

Table 1: Classification of Ozone Nonattainment (in tons per year (tpy))

In 1999, RIS successfully demonstrated that the incinerator incorporated Best Available Technology (BAT), required pursuant to OAC rule 3745-31-03(A)(3). The Ohio Environmental Protection Agency (OEPA) subsequently acknowledged this demonstration when it issued an air Permit-to-Install (PTI) to RIS for its incineration system on March 13, 2003, stating under Part 1 – *General Terms and Conditions,* (A)(11) – *Best Available Technology,* “As specified in OAC Rule 3745-31-05, all new sources must employ Best Available Technology (BAT). Compliance with the terms and conditions of this permit will fulfill this requirement.”

Various post-combustion NO_x control options for the incineration system were analyzed for technical and economic feasibility. This document summarizes the results of the analyses and recommends RACT for the proposed hazardous waste incineration system.

1.2 General Facility Description

RIS operates a rotary kiln hazardous waste incinerator system at 36790 Giles Road, Grafton, OH. Operations at this location are generally classified under Standard Industrial Classification code 4953 (Refuse Systems) and North American Industrial Classification System 562211 (Hazardous Waste Treatment and Disposal). The OEPA facility identification number is 0247050278.

RIS operates the Grafton facility in accordance with the terms and conditions identified in OEPA Title V Permit No. P0108010, which was renewed on February 5, 2019. The emissions unit number for RIS’ incineration system is N001. The current incineration system was installed in

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[1] https://epa.ohio.gov/divisions-and-offices/air-pollution-control/state-implementation-plans/state-implementation-plan-sip-2015-eight-hour-ozone-planning

September 1991, with the secondary combustion chamber being rebuilt in July 2003. The normal operating schedule for the incineration system is 24 hours a day, 7 days a week, 365 days a year, with an on-stream time target of 93%.

1.3 Process Description

The incineration system consists of a co-current rotary kiln operated in series with a counter-current main chamber. It should be noted that this incinerator system has been custom designed by RIS and is considered to be unique in the commercial hazardous waste incineration industry.

The incinerator utilizes waste to maintain temperature of the kiln and secondary combustion chamber. The waste fuels can be solids, sludges or liquids. The heating value of the waste can vary from 0 (no heat value) to above 20,000 Btu/lb. RIS must find a balance of high, medium and low BTU waste to maintain temperatures in the incineration process. Beyond maintaining the minimum temperature requirements for the process, other compliance limits such as allowable chlorine, mercury, SVM (Pb, Cd), LVM (Cr, AS, Be) feed rates are set during CPT testing. In FY2023, RIS processed over 15,500 waste profiles. These compliance limits are unique to the RIS incineration process based on CPT testing. The incineration process has three solid waste feeds for the kiln, one solid waste feed for the main chamber, and six liquid waste feeds for the main chamber. The way the feed locations are utilized and the throughputs by feed location are specific to RIS.

This differentiation further complicates this RACT evaluation, since technologies that can be effectively applied to conventional hazardous waste incinerators may not be applicable to RIS' operation.

Operating temperatures within the rotary kiln are approximately °F, while the combustion temperature within the main chamber averages approximately °F. Occasionally, the temperatures in the kiln and main chamber can exceed °F. As per the permit P0108010, the operation of the incinerator is constrained by operating parameter limits in order to meet minimum destruction requirements. As such, the minimum kiln temperature is °F while the minimum main chamber temperature is °F. The appendices 2 and 3 provides a process flow diagram (PFD) of the incineration and associated air pollution control equipment train and a General Layout of the facilities.

Air emissions generated from the rotary kiln and main chamber are controlled using a series of air pollution control devices including:

- Quench
- Cyclone
- Radial flow wet scrubber
- Gas/Liquid Contactor
- Two wet electrostatic precipitators (WESPs).

The above air pollution control equipment was installed in August 2002.

Emissions from these treatment operations are discharged to atmosphere through a stack. It is important to note that these air pollution control systems do not appreciably control NO_x emissions that may be generated from either thermal or process means.

According to RIS' Title V permit, the maximum capacity of the incinerator is 26,057 lb/hr and 105,120 tons/yr of waste including the weight of containers. The normal and maximum daily production rates are summarized in Table 2 and are based on hourly data provided by RIS. Of note, the feed rate of waste is the production rate in the case of waste incineration.

Table 2: Normal and Maximum Production and Emission Rates, CEMS[2]

					Yearly production

Waste materials, consisting of both solid and liquid wastes, are co-fired in such a way as to maintain an approximate average heat input capacity of million British thermal units per hour (MMBtu/hr) from process operations in 2023 and a maximum daily average of MMBtu/hr[4].

Ohio Rule 3745-110-03 (J) (g) requires calculating the maximum daily NO_x emissions data based upon the average NO_x emission rate for the average production and extrapolated (ex.) to the maximum production rate. Ramboll has compiled in Table 3: CEMS Reporting Data, Compiled by Year the average and maximum hourly NO_x data provided by RIS based on their Continuous Emissions Monitoring System (CEMS) historian data as well as required calculated values.

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[2] NO_x Emission monitor.xls received 2/2/2024

[3] Production provided by RIS 1/11/2024

[4] 2023 Production Analysis, received 1/26/2024

Table 3: CEMS Reporting Data, Compiled by Year

Using the extrapolated NO_x emission, the average NO_x emission based upon the highest average daily production rate, lb./hr., is lb/day (tpy), in 2023, while the maximum NO_x emission based upon the highest maximum daily production rate, lb./hr. in 2018, is lb/day (tpy).

However, due to the nature of a hazardous waste incinerator, burning liquid and solid fuel, and batches of fuels of different heating values and various nitrogen contents, using a rate method to estimate NO_x emission comes with limitations. This translates to significant differences between the daily maximums read by the CEMS and the calculated values. Thus, Ramboll reviewed permit limits to confirm that good combustion methods and practices are employed.

The permit P0108010 specifies that NO_x emissions shall not exceed 218.5 tons, per rolling, 365-day period, nor 18.21 tons per month averaged over a rolling, 12-month period. The charts below depict the NO_x emissions in relation to the limits. The permit mandates automatic feed shut-off should operating parameter limits or emissions limits be exceeded.

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The information on this page pertains to the design and operation of RIS' incineration system. For this reason, all confidential information has been removed from this page.

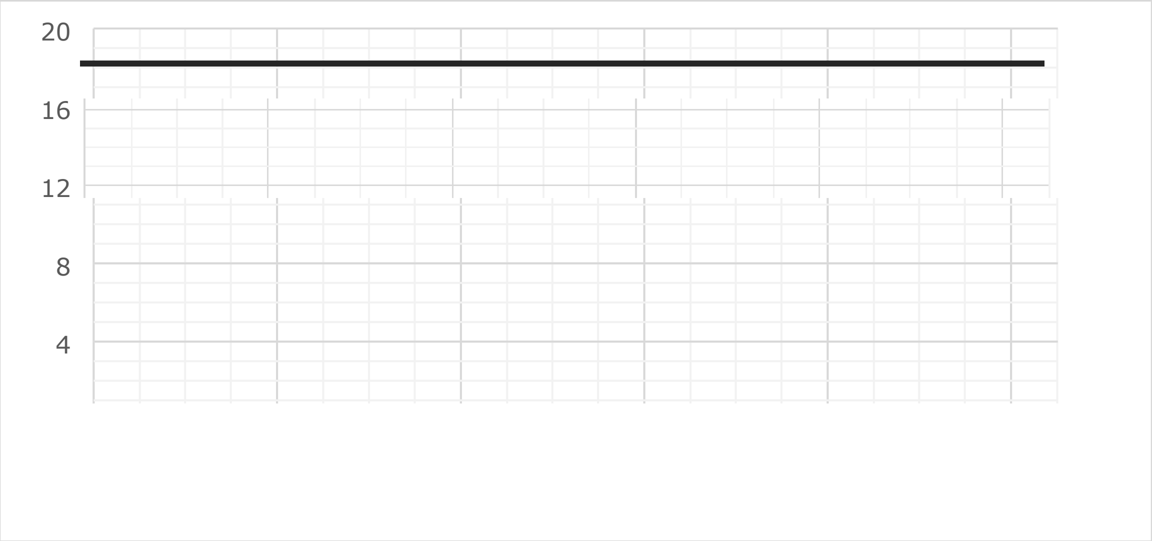

Figure 1: 12-month Rolling Average of Monthly NOx Emissions, tons.

Figure 2: 365-day Rolling Total of Daily NOx emissions, tons.

The charts above show that regardless of daily variability of NO_x emissions, the 365-days rolling total and 12-month average are constrained below their upper limits using good practices and combustion strategies.

Two independent stack tests from 2019 and 2022 were provided, and their NO_x testing results are summarized in Table 4. The results show consistency with the hourly average from the CEMS data, which are presented in Table 2.

Table 4: Stack Tests Summary

Measure	Unit	Value	Standard Deviation
NO_x hourly mass flow rate	lb/hr		

2. Review Of Available Control Technologies

2.1 Potential NO_x Control Strategies and Their Application

2.1.1 Available Control Technologies

RACT evaluations for a given air contaminant are primarily based on three criteria: energy considerations, the economic impact of control (i.e., cost per ton of pollutant removed) and potential environmental impacts associated with the control alternative. OAC 3745-110-03(I)(1)(h) lists twenty specific alternatives that an applicant needs to consider when performing a NOx RACT evaluation. Of the twenty alternatives, a few can be eliminated since they are not applicable to the operation of a hazardous waste incinerator. Some are eliminated as the technology is not available for the equipment present at RIS. Others are eliminated as their ultimate goal is to lower the flame temperature, which cannot be done at RIS while maintaining standard operational conditions as explained in section 1.3, mainly, the minimum temperature in the kiln and main chamber. Specifically, the following technologies are not considered applicable to the RIS facility:

Table 5: technologies deemed not technically feasible with no further analysis.

Ramboll identifies the following air pollution control technologies as potentially appropriate options to control the NO_x emissions from a hazardous waste incinerator:

- Low-NO_x burners (LNB)
- Close-coupled or separate over-fire air (CCOFA/SOFA)
- Burners out of beneficial service
- Steam/water injection (SWI)
- Dry low-NO_x burners (DLNB)
- Mid Kiln air injection
- Low excess air (LEA)
- Flue gas recirculation (FGR)
- Selective non-catalytic reduction (SNCR)

- Non-selective catalytic reduction (NSCR)
- Selective catalytic reduction (SCR)
- Wet Scrubbing

2.1.2 RACT/BACT/LAER Clearinghouse Review

Ramboll reviewed recently issued permits for determinations of feasible control technology for NOx. The USEPA RLBC Clearinghouse has compiled a summary of NOx emissions limits and control requirements for new and existing incinerators. These NOx controls, as well as NOx limits, are included in Table 6: Clearinghouse review summary for similar processes.

Table 6: Clearinghouse review summary

Examples of BACT and RACT for incinerators were found in the municipal waste and solid waste categories. SCNR and SCRS are present as both RACT and BACT. FGR is present as BACT. 3 SNCR equipped facilities have cost effectiveness deemed economically feasible. Others, including FGR and SCR are not verified. The average emission limit in PPMVD @ 7% O2 is 122 while RIS's incinerator is 167 uncontrolled[5]. The average emission limit in lb/hr is 12.21, while RIS's incinerator is 39 uncontrolled. No facility in the Hazardous Waste field, code 21.200, was found with add-on control methods for NO_x on incinerators of comparable size, throughput, or emission rates.

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[5] Calculated using stack testing data.

2.2 Technical Feasibility of Various Alternatives

Two primary principles apply to the control of NO_x emissions from combustion operations such as those at RIS:

1. Reducing the initial formation of thermal NO_x through limiting temperature, residence time, and/or combustion air-to-fuel stoichiometric ratios.
2. Removing NO_x through post-combustion chemical reaction.

This report addresses technologies that employ one or the other of these principles. However, it is important to note that because the activities at RIS involves hazardous waste incineration, a process that requires high temperatures and long residence times for effective treatment, there are limited steps that can be taken to control NO_x emissions via the first principle. Thus, the primary focus of this report will be the application of post-combustion control technologies.
The following paragraphs provide a brief description of various NO_x control technologies, and Ramboll’s understanding of their potential application to the unique operation that is RIS’ hazardous waste incinerator.

2.2.1 Low-NO_x Burners (LNB)

LNB reduce NO_x emissions by accomplishing the combustion process in stages. The use of stages delays part of the combustion, resulting in a cooler flame, which suppresses thermal NO_x formation. With up to 80% control efficiency, LNB tend to be one of the most common and generally one of the most cost-effective methods to control NO_x formation from natural gas-fired operations.

Based upon information provided by RIS, Ramboll believes that, as a consequence of the current application of over-fire injection of fuel and air, the existing burners already serve as a type of LNB. While it is possible that these burners could be “tuned” to confirm that NO_x emissions from this source are suppressed to the extent practical, it is doubtful that further reductions of NO_x can be achieved with this technology at RIS.

Commercially available LNB and ULNB are not applicable in the case of hazardous waste incineration. Burners with NOx reducing technology rely on combustion staging in the nozzles by atomizing the fuel finely and carefully mixing air and fuel. Because of the variability and physical properties of the solid hazardous wastes processed, the technology is not applicable to RIS Furthermore, premix burners are engineered for specific well-known fuels and conditions and are not tunable in-situ, other than the output and ratio. The nature of the liquid waste is also variable in viscosity and suspended solids up to ½”. Therefore, a finely tuned burner for a specific fossil fuel or homogeneous liquid or gaseous waste is not possible for this application where the waste constituency is continuously changing.

2.2.2 Close-Coupled or Separated Over-Fire Ports (CCOFA/SOFA)

When primary combustion uses a fuel-rich mixture, subsequent use of CCOFA/SOFA completes the combustion process. Because the mixture is always nonstoichiometric when combustion is occurring, the temperature is held down, reducing the formation of thermal NO_x. After other stages of combustion, the remainder of the fuel is oxidized in the over-fire air.

CCOFA/SOFA usually does not involve an excessive amount of air. While NOx control efficiencies for this technology can approach 20-30%, Ramboll believes that the over-fire injection of fuel and air in RIS' incineration system already essentially serves as CCOFA/SOFA. Technology labeled as such is commercially available for power generating boilers with repeatable fuel input where finer tuning can be achieved, as part of their original design, and further upgrades to RIS' system are not available.

Since no further benefit would be likely be realized through the installation or alteration of the existing system, this technology is deemed to be technically infeasible and will not be further evaluated.

2.2.3 Burners Out of Service

Combustion equipment with multiple burners can be operated in such a way as to have part of a burner array "out of service" (i.e., not feeding fuel, but supplying air or flue gas). This arrangement allows the burners around them to supply fuel and air to supplement the air or flue gas flowing from the "burners out of service." The result is combustion by stages with temperature always lower than when all burners are in service. Thus, emissions of thermal NO_x are lowered.

The degree to which NO_x generation is reduced depends upon the spatial relationship of the burners that are out of service to those that are in service. As noted above, efforts that change the combustion dynamics of a hazardous waste incinerator (e.g., placing certain burners out of service) could, in turn, compromise the performance of the incinerator and may adversely impact the quality of air emissions from this operation. For these reasons, Ramboll deems burner modifications technically infeasible, and this NO_x control strategy will not be further evaluated.

2.2.4 Steam/Water Injection (SWI)

Injection of water or steam causes the stoichiometry of the combustion mixture to be changed. Volatilization of water, and the heating of steam consume some of the combustion energy, thereby lowering the temperature of the combustion chamber and reducing the amount of thermal NO_x generated. As with other combustion modification options, reduced combustion temperatures from a hazardous waste incinerator may lead to increased emissions of other air contaminants, Thus, for this reason, Ramboll deems SWI as technically infeasible for this application and SWI will not be further evaluated.

2.2.5 Dry Low-NO_x Burners (DLNB)

As discussed above, Ramboll believes that the current arrangement of burners and over-fire injection serve as well as DLNB. No further benefit is expected to be realized through the application of DLNB; thus, this technology is deemed to be technically infeasible and will not be further evaluated.

2.2.6 Mid Kiln Air Injection

As discussed above, Ramboll believes that the current arrangement of burners and over-fire injection serve as well as Mid Kiln Air Injection. No further benefit is expected to be realized through the application of Mid Kiln Air Injection; thus, this technology is deemed to be technically infeasible and will not be further evaluated.

2.2.7 Low-Excess Air (LEA)

Excess air flow for combustion has been correlated to the amount of NO_x generated. Limiting the net excess air flow to less than 2% can significantly reduce NO_x emissions from combustion operations. Although there are fuel-rich and fuel-lean zones in the combustion region, overall net excess air is limited when using this approach.

Considering the nature of the process at RIS, complete combustion is critically important to reduce the residual risk associated with combusted materials. Thus, changes in system operation that affect the degree to which incinerator combustion efficiency is achieved should only be considered in rare circumstances. Due to concerns of increased emissions of undesirable byproducts associated with lower temperature in the combustion chamber, Ramboll deems LEA as technically infeasible for this application and LEA will not be further evaluated.

2.2.8 Flue Gas Recirculation (FGR)

FGR consists of recycling a portion of the furnace emissions from the stack back to the burner. The recirculated flue gas is typically either mixed with combustion air prior to combustion or recirculated directly to the combustion zone. The recirculated flue gas dilutes the oxygen concentration, simultaneously lowers the flame temperature and shortens the residence time at peak temperature. These changes can result in significant reductions in thermal NO_x emissions, but negligible reductions in fuel NO_x emissions. Control efficiencies for this technology, operating independently, generally range from 30-70%. Based upon the information provided by RIS, it appears that on average 90% of the NO_x generated from incineration is "thermal-NO_x", while the remainder is attributable to "fuel-bound NO_x".

Typically, FGR is capable of achieving greater NO_x reductions with clean fuels, such as natural gas, with a flame temperature above 3,000°F, where reducing the flame temperature yields great reduction in NO_x formation with no impact on the minimum efficiency required. The incineration system at RIS is a highly regulated operation, both with respect to applicable air emissions limits, as well as operating parameters. Installation of FGR would require a detailed engineering review and fluids modeling of the potential impacts on incinerator operation to confirm that the unit will still be capable of achieving required operating parameter limits (OPLs) and applicable emission standards. Effective September 2023, RIS is subject to the final emission standards and operating limitations imposed by the Maximum Achievable Control Technology Standards (MACT) for Hazardous Waste Combustors (e.g., 40 CFR Part 63 Subpart EEE), which includes a 99.99%, or more, DRE for, among other things, dioxins/furans, for existing sources[6].

For the reasons outlined above, flue gas recirculation is not considered to be technically feasible for this application.

2.2.9 Selective Non-Catalytic Reduction (SNCR)

SNCR involves the injection of a nitrogenous compound (ammonia or urea) into the hot flue gas. At high temperatures, typically 1,600°F to 2,100°F, these reagents react with NO_x in the flue gas to form nitrogen and water, as shown by the following reactions:

Equation 1

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

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[6] https://www.ecfr.gov/current/title-40/part-63/subpart-EEE#p-63.1203(c)

Equation 2

$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$

About 90-95% of the NO_x in combustion flue gas from RIS' proposed hazardous waste incinerator is expected to be in the form of NO, so the potential reaction expressed by Equation 1 offers the greatest opportunity for NO_x suppression. Typically, some trace amounts of carbon monoxide are also formed as a byproduct of these reactions, and a small amount of unreacted ammonia/urea is released ("ammonia slip"). The high temperature of the flue gas serves as the driving force for this reaction; therefore, a catalyst is not required. NO_x reductions of 30% to 50% have been demonstrated by this technology. Temperature control is critical; at 1800°F the efficiency of the SCNR is maximal. However, increasing temperature further decreases NO_x reduction, and as the temperature increases, the oxidation of the reagent may become prevalent over its reduction. Thus, creating more NO_x. Such challenges can be addressed in highly stable combustion processes, such as a single fuel boiler, with limited feed points. Residence time is also critical because sufficient time is required to complete the reaction between NO_x and ammonia.

The incinerator's maximum operating temperature of the main chamber can regularly reach °F, which will adversely affect NO_x removal and, in fact, may increase NO_x formation. In order to manage the flue gas temperature to be compatible with SNCR, the flue gas exiting the main chamber at °F would need to be cooled to a more suitable temperature between to °F, to account for process variability. Since the flue gas temperatures are too high for commercial heat exchangers, RIS would need to consider adding a secondary quench system for this purpose, including reagent injection and sufficient gas residence time for NO_x abatement.
The capital costs of this system have been estimated based on the construction materials and estimated direct and indirect costs based on the EPA Cost Control methodology 6th edition and Ramboll's experience.

Furthermore, the ammonia concentration profile across the furnace must match the concentration profile of NO_x. In boilers, this is done via sophisticated computer modeling based on mixing in a specially designed contact chamber. Boilers have consistent NO_x profiles at a given load, there is one fuel, and one firing geometry. The injection nozzles can be modeled and set to provide the molecular contact and mixing necessary to control both ammonia slip and NO_x. This is not possible for the RIS incinerator. The RIS incinerator has a large, rotary kiln combustion chamber followed by a secondary combustion chamber with multiple waste entry points. This design, coupled with variable waste chemistry, results in a complex, variable NO_x temperature profile and gradient along the chamber which would likely confound any attempt to locate a temperature zone appropriate for SNCR. For these reasons, it is Ramboll's opinion that SNCR is not technically feasible for application at RIS, unless adding a third combustion chamber. The costs of this chamber are estimated as highlighted in the paragraph above and part of the refractory lined arrangement.

In typical applications, SNCR commonly achieves NO_x reductions of 30-50%[7]. To be conservative, Ramboll used the higher end of this range, so that its estimated cost effectiveness is optimized. Because SNCR is technically feasible, we have developed the cost information for this technology.

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[7] EPA Air Pollution Control Cost Manual, 6th edition. January 2002.

However, retrofitting an SNCR will require significant downtime ; the lost revenue associated with this downtime have not been included in this analysis.

2.2.10 Selective Catalytic Reduction (SCR)

SCR is similar to SNCR in that it includes injection of a nitrogenous compound into the flue gas, with the primary difference being that SCR also utilizes a catalyst to promote the chemical reaction between the NO_x and the nitrogenous compound. The nitrogenous compound, typically ammonia or urea, is combined with either air or steam and the resulting gas mixture is subsequently injected into the flue gas stream. The gases are combined and then passed through a catalyst, such as titanium, vanadium, or molybdenum, where the nitrogenous compound reacts with the NO_x to form nitrogen and water. The presence of the catalyst reduces the temperature required for the reduction reaction. NO_x control efficiencies of greater than 90% have been demonstrated by this technology. As with SNCR, a disadvantage of utilizing SCR is the presence of ammonia slip, or emissions of unreacted ammonia. However, SCR systems are typically designed to achieve good mixing of ammonia in the flue gas for the purpose of minimizing ammonia slip.

According to information provided by RIS, the flue gas temperature after the two WESPs is approximately °F- °F. SCR technology generally requires an operating temperature of approximately °F- °F. Therefore, the WESP exhaust gas will need to be heated to this operating temperature, probably through a fossil fuel fired pre-heater, which will also contribute a small increase to overall facility NO_x and CO emissions. Natural gas is not present at the site and would require extra capital costs, therefore, delivered propane has been used as a substitute to estimate the fuel costs. However, given the propane demand of the system, additional capital costs would be incurred. The fuel costs associated with running the SCR are lowered by the use of a heat recovery on the exhaust stream. The capital costs of this heat recovery system have not been estimated. The calorific value of propane is 91,452Btu/gal, while the calorific value of natural gas is 1000 Btu/Scf. The current delivered cost of propane averages $1.8/gal whereas natural gas costs on average $5/1000cuft. This is equivalent to a cost per MMBtu of $5/MMBtu for natural gas versus $20/MMBtu for propane.

The effective application of SCR technology at RIS will require a robust catalyst, considering the harsh operating environment at RIS. The presence of trace amounts of certain heavy metal emissions in the exhaust gas may poison the SCR catalyst. Catalyst poisoning would result in increased frequency of catalyst bed changeouts, which will add significant operating costs to this technology. The variety of waste streams handled by RIS further increases the likelihood that SCR catalyst poisoning will occur, although the rate at which such poisoning occurs cannot be ascertained at this time.

Since SCR is technically feasible for this application, Ramboll has developed cost information for this technology, including the use of natural gas, despite its current lack of availability at the site.

2.2.11 Non-Selective Catalytic Reduction (NSCR)

Non-selective catalytic reduction utilizes a broad-function catalyst (platinum/palladium/rhodium) in combination with a supplemental fuel source (e.g., natural gas or hydrogen) to reduce NO_x emissions. In this technology, available oxygen within the flue gas enters the catalyst bed and is, in turn, consumed by the supplemental fuel, which must be fed in slight excess to stoichiometric ratios. The catalyst exhaust will contain unreacted fuel (e.g., methane, in the case of natural gas), small amounts of carbon monoxide, and, potentially, hydrogen cyanide.

This technology is primarily suitable to rich-burn internal combustion engines and is used by relatively few power/combustion facilities, probably because of the undesirable emissions of a greenhouse gas (e.g., methane) and a known toxic (HCN). For these reasons, Ramboll considers NSCR technically infeasible, and this technology will not be further evaluated.

2.2.12 Wet Scrubber

Gas absorbers (or scrubbers) are used extensively in industry for separation and purification of gas streams, as product recovery devices, and as pollution control devices. They are also used to control acid gas emissions from waste incinerators and a wide range of industrial processes. Commonly used designs include packed bed scrubbers, spray tower scrubbers, and tray tower scrubbers. Gas and liquid flow through an absorber may be co-current flow, counter-flow, or crossflow. Thus, water scrubbers are used to capture the air contaminant and transfers it into the aqueous phase.

Furthermore, control of NO_x via absorption is somewhat complex. NO is virtually insoluble in water, whereas NO_2 can be scrubbed. Thus, since about 90% or more of the NO_x from RIS' incineration process is in the form of NO, only modest reductions in NO_x can be expected from a traditional aqueous scrubbing system (without oxidative pretreatment needed to convert the NO to NO_2).

According to information provided by RIS, the Grafton facility does not have wastewater treatment equipment; instead, it discharges its wastewater directly to a deep well. Ramboll did not evaluate the hydraulic capacity of the current well, nor the extent to which aqueous waste from the water scrubber may require pretreatment, if any.

The high volumetric flow rate of the incineration process further suggests that scrubbing for NO_x control will not be economically feasible. Therefore, Ramboll concludes that wet scrubbing for NO_x control from the RIS facility is unlikely to be technically nor economically feasible and will not be further evaluated.

3. Economic Analysis

In general, the United States Environmental Protection Agency (USEPA) and OEPA advocate that RACT analyses follow a "top-down" approach, where the technology that achieves the highest reduction in air contaminant levels is considered first. If that technology is deemed to be either technically or economically infeasible, then the process continues until a suitable control option – one that is both technically and economically feasible – is identified. That technology is then deemed to be RACT for that application.

RACT evaluations for a given air contaminant are primarily based on three criteria: energy considerations, the economic impact of control (i.e., cost per ton of pollutant removed) and potential environmental impacts associated with the control alternative. Based on direction from RIS, Ramboll focused primarily on the economic feasibility of these potential control alternatives, but we do provide some commentary on the technical feasibility of these options.
Emission reductions, costs, and other factors were then evaluated for each technically feasible control option to identify RACT for the new hazardous waste incineration system.

3.1 Basis of Design

In order to establish a common basis upon which prospective NO_x control strategies can be reviewed, Ramboll gathered proposed process and emissions data from RIS, and developed the general basis of design summary as described in Table 7.

Table 7: Basis of Design, 2019 and 2022 Surveys Data

Measure	Unit	Value	Standard Deviation
NO_x hourly mass flow rate	lb/hr		
NO_x concentration	ppmvd		
average stack temp	°F		
actual flow, wet	ACFM		
normal flow, wet	SCFM		
volume moisture	%vol		
oxygen content	%vol		

3.2 Cost-Effectiveness Criteria

Pursuant to OAC Rule 3745-110-02, RACT is defined as:

> *"the lowest emissions limitation that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility."*

In Ramboll's experience, the typical upper bound of RACT cost effectiveness used by many state regulatory agencies for RACT is $3,000[8] (based on 1994 dollars), which equates to approximately

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[8] This value exceeds the $1,300/ton established in 1994 by the EPA, translating to $2,375 today.

$6,294 in December 2023 dollars (based on escalation in the Consumer Price Index). Indeed, this same approach was used in the 2010 RACT analysis that Ramboll completed for RIS (and was ultimately accepted by OEPA).

Ramboll has developed budgetary capital and annual operating cost estimates associated with the implementation of both SCR and SNCR technologies. These estimates were derived using a mix of vendor quotations, standard cost estimating guidance documents such as the USEPA's *Air Pollution Control Cost Manual*[9] and Ramboll's professional experience with similar systems. For the purposes of this evaluation, a 5% interest rate was assumed.

As previously indicated, the installed costs of the SCR and SNCR systems were estimated by adopting the estimating methodology outlined in the EPA Air Pollution Control Cost Manual for these systems. Published within the manual are empirical expressions to estimate direct costs derived in EPA reports prepared by The Cadmus Group, Inc., Bechtel Power Corporation, and Science Application International Corporation from cost estimates for SCR and SNCR systems installed on coal-fired utility boilers. The empirical equation relates boiler size (maximum output) to installed equipment cost. For process applications (such as RIS's) an equivalent boiler size can be estimated by establishing comparable process exhaust flow rates. Assuming a boiler fires bituminous coal at 3% residual excess air, 1 MMBtu/hr correlates to SCFH, dry of exhaust flue gas. Unit costs used in the empirical expression were scaled up to reflect 2024 dollars based on the consumer price index.

The Boiler Size Equivalent is estimated from the following expression[10].

Where:

Using the information above, H_{in} for RIS' system is MMBtu/hr. The boiler size equivalent in MW is:

Where:

The update EPA Cost Control Method, 7th edition, calculates the TCI directly, whereas the 6th edition calculates the Direct Capital Costs with factors. Highlights of the different calculation methods are summarized in the appendix Cost Estimates. In order to integrate vendor quotations, we have developed cost estimates using both sources. Detailed calculations steps and justifications can be found in the Appendix A
Cost Estimates.

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[9] https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution#cost%20manual

[10] EPA, EIP, Preferred and Alternative Methods for estimating Air Emissions from Boilers, 2001

3.3 Technology Comparison

Table 8 summarizes the economic feasibility analysis of the add-on air pollution control devices deemed technically feasible. The tables were created assuming the incinerator fires continuously in conditions deemed as normal, based on the OPLs, stack tests and feed rates.

Ramboll’s capital estimates for the SCR technology include a heater system, a 70% efficiency heat recovery system in order to minimize fuel usage, which explains in part the higher costs than the EPA cost control methodology. However, Ramboll did not include its capital costs, the costs to bring natural gas or other fuel to the site, nor did Ramboll estimate the emissions associated with the new combustion system. Therefore, Ramboll believes the cost values presented in Table 8 for the SCR technology may be understated, and the cost efficiency even higher than that presented below.

Similarly, the costs for the SNCR include the addition of a new combustion chamber to quench the process stream to a reaction appropriate temperature. The costs of this refractory lined chamber and ductwork have been estimated based on prior work and experience.

Table 8: Summary of Control Alternative Cost

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Removal Efficiency	%	90%			50%
Capital Costs, average	USD	6,898,962	9,921,248	10,295,839	7,337,281
Direct Annual Costs, average	USD	2,037,048	2,091,778	714,959	245,615
Total Annual Cost:	USD	2,590,639	2,888,809	1,542,048	834,378
Tons of NOx, uncontrolled	Tons/yr.				
Tons of NOx, controlled	Tons/yr.				
Cost ($/ton of NOx emoved)					

4. Conclusions and Recommendations

4.1 Conclusions

Add-on, post-combustion NO_x control alternatives were evaluated as potential RACT options for RIS' existing hazardous waste incineration system. The SCR technology has a cost effectiveness, ranging from $10,161 to $19,035 per ton of NO_x removed, above the current RACT threshold of $6,294/ton. Therefore, SCR technology is not considered to be economically feasible for this application.

SNCR technology, which is considered by Ramboll to be technologically feasible for this application, has an optimized cost effectiveness ($9,896 per ton of NO_x removed) that is well above the current RACT threshold of $6,294/ton, suggesting that this technology is economically prohibitive. Furthermore, given the technical complexity of retrofitting a SNCR system on a highly regulated incinerator, and limited space with which to cool down the exhaust stream to a suitable temperature and residence times, the estimated NO_x control cost removal efficiency is probably overstated, and the estimated costs of this technology are higher than estimated for this application.

4.2 RACT Recommendation

Based on the study presented in this RACT report, installing, maintaining and operating the source in accordance with the manufacturer's specifications and with good operating practices for the control of NO_x emissions from the source is RACT for RIS's incinerator. RIS can follow this RACT immediately.

The 158.1 pounds per hour, based on a rolling twenty-four hour average limit in OAC 3745-110-03(T) was set to allow for need to have operational flexibility in managing the wide variety of waste that is received at RIS's commercial incineration facility. That said, RIS is amenable to adjust its site-specific RACT NO_x emission limit to 105 pounds per hour, based on a 30 day rolling average.

RIS has evaluated the average hourly emission rate with a maximum actual calculated based on the average hourly rate. As such, by using the average hourly rate times the operating hours in a calendar year, RIS is amenable to accepting an appropriate trigger for a RACT reevaluation within a year if its NO_x emission rate for emission source N001 exceeds 110% of the baseline used in the RACT study, or 185.9 tons per year.

Appendix A

Cost Estimates

	SCR Cost Estimate[1]		
Plant:	**Ross Incineration**		
Process Description:	**Waste Incineration**		
Category	**Cost Factor**	**Applied to**	**Extended Cost**
Direct Installation Costs (DC):			
Equivalent Boiler Size, Qb (MMBtu/hr)[2]:			
NPHR			
HRF			
BMW			
NOx Removal Efficiency (%):			
Cost Factor, 2016 to 2024 dollars (CF_{16})			
SCR cost, eq 2.41			$2,157,778
RPC, eq 2.42			$355,885
BPC, eq. 2.43			$734,649
Heat Echanger, 70% efficinecy			$833,914
Total Capital Investment (TCI):			**$6,898,962**
Direct Annual Costs (DAC)			**$ 2,037,048**
Annual Maintenance Cost, eq 2.57		TCI	$34,495
Annual Reagent Cost, eq. 2.58[3]	$	Q_{sol}	$86,721
Annual Electricity Cost, eq. 2.60[4]	$	P	$80,415
Annual Catalyst Cost, eq. 2.64[5]	$	ACR*FWW*CF_{16}	$15,290
Fuel Cost, propane ($1.80/gal x 8760 hr/yr x 10.6 MMBtu/hr / 91,500Btu/gal)[6]			$ 1,820,127
Indirect Annual Costs (IDAC)			**$ 553,591**
Capital Recovery Cost, eq. 2.70[7]			$ 553,591
TOTAL ANNUALIZED EQUIPMENT COST (TAC)			**$ 2,590,639**

[1] Capital investment, installation costs, and indirect annual costs are based on the methodology outlined in the EPA Air Pollution Control Cost Manual, 7th Edition

[2] Based on a boiler size equivalent method, paragraph 3.2

[3] Based upon a Stoichiometric Ratio Factor (SRF) for urea of 0.53 and 2ppmv of ammonia slip, eq. 2.58

[4] Based upon an SCR system pressure drop of 5" W.C., eq. 2.60

[5] Based on a catalyst price of 227$/ft3 in 2016 dollars and 5 layers of Catalyst, eq. 2.64

[6] Propane cost assumed $1.80/gal, , required 40MMBtu/hr heat input, with a potential recovery of 29.6MMBtu/hr, assuming 70% efficiency heat exchanger

[7] Capital Recover Cost assuming an equipment life of 20 years and an interest rate of 5%.

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	SCR Cost Estimate[1]		
Plant:	Ross Incineration		
Process Description:	Waste Incineration		
Category	**Cost Factor**	**Applied to**	**Extended Cost**
Purchased Equipment Costs (PEC):			**$5,093,305**
Selective Catalytic Reduction (SCR) System[2]			$3,750,000
Reactor Housing			
NOx Catalyst			
Reagent Flow Control Unit (Skid Mounted)			
Reagent Injection Grid			
Instrumentation			
Preliminary & Detailed Engineering			
Burner assembly, piping and safety gas train			
New High Temp ID Fan			
New insulated stack			
Heat Echanger, 70% efficinecy			$833,914
2014 inflation factor based on CPI	32%		$266,852
Sales Tax	3%	**EC**	$145,523
Freight	2%	**EC**	$97,015
Direct Installation Costs (DC):			**$2,597,585**
Foundation & Supports	12%	**PEC**	$611,197
Handling & Erection	14%	**PEC**	$713,063
Electrical	10%	**PEC**	$509,330
Piping	10%	**PEC**	$509,330
Insulation for Ductwork	3%	**PEC**	$152,799
Painting	2%	**PEC**	$101,866
Indirect Installation Costs (IDC):			**$2,230,358**
Construction & Field Expenses	5%	**(PEC+DC)**	$384,545
Contractor's Fees	10%	**(PEC+DC)**	$769,089
Start-up & Commissioning	3%	**(PEC+DC)**	$230,727
Performance Test	3%	**(PEC+DC)**	$230,727
Contingencies	8%	**(PEC+DC)**	$615,271
TOTAL CAPITAL INVESTMENT:			**$9,921,248**
Direct Annual Costs (DAC)			**$ 2,091,778**
Electricity (kWhx 8760 hr/yr x $0.075/kWh) [3]			$ 51,598
50% Urea (8.6 gph x $1.35/gal delivered x 8760 hr/yr)[4]			$ 102,025
Propane ($1.80/gal x 8760 hr/yr x MMBtu/hr / Btu/gal) [5]			$ 1,820,127
Operating Labor ($31.27/hr x 0.5 hr/shift x 3 shifts/day x 365 days/year)			$ 17,120
Maintenance Labor ($31.27/hr x 0.5 hr/shift x 3 shifts/day x 365 days/year)			$ 17,120
Catalyst Replacement Cost (Catalyst Replacement Every 3 Years @ $200,000)			$ 66,667
Other Maintenance Material Costs (100% of Maintenance Labor Cost)			$ 17,120
Indirect Annual Costs (IDAC)			**$ 797,031**
Administrative Charges (0.03 x (Operator Labor Costs + (0.4 x Annual Maintenance Cost))[6]			$ 924
Capital Recovery Cost[7]			$ 796,107
TOTAL ANNUALIZED EQUIPMENT COST			**$ 2,888,809**

[1] Capital investment, installation costs, and indirect annual costs are based on the methodology outlined in the EPA Air Pollution Control Cost Manual, 6th Edition, 2002 and Ramboll's collective experience with the installation of similar systems..

[2] Based on a budgetary equipment quote from Zenviro Tech

[3] Based upon an additional SCR system pressure drop of 5" W.C.

[4] Based upon a Stoichiometric Ratio Factor (SRF) for urea of 0.53 and 2ppmv of ammonia slip.

[5] Propane cost assumed $1.80/gal, , required 40MMBtu/hr heat input, with a potential recovery of 29.6MMBtu/hr, assuming 70% efficiency heat exchanger

[6] Taken from Chapter 2 of the EPA Air Pollution Control Cost Manual, 2019.

[7] Capital Recover Cost assuming an equipment life of 20 years and an interest rate of 5%.

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	SCR Cost Estimate[1]		
Plant:	**Ross Incineration**		
Process Description:	**Waste Incineration**		
Category	**Cost Factor**	**Applied to**	**Extended Cost**
Purchased Equipment Costs (PEC):			**$5,285,610**
Selective Catalytic Reduction (SCR) System[2]			$3,750,000
Reactor Housing			
NOx Catalyst			
Reagent Flow Control Unit (Skid Mounted)			
Reagent Injection Grid			
Instrumentation			
Preliminary & Detailed Engineering			
New High Temp ID Fan			
New insulated stack			
Cost of bringing Natural Gas			$450,000
Heat Echanger, 70% effiency			$833,914
2014 inflation factor based on CPI			$0
Sales Tax	3%	**EC**	$151,017
Freight	2%	**EC**	$100,678
Direct Installation Costs (DC):			**$2,695,661**
Foundation & Supports	12%	**PEC**	$634,273
Handling & Erection	14%	**PEC**	$739,985
Electrical	10%	**PEC**	$528,561
Piping	10%	**PEC**	$528,561
Insulation for Ductwork	3%	**PEC**	$158,568
Painting	2%	**PEC**	$105,712
Indirect Installation Costs (IDC):			**$2,314,568**
Construction & Field Expenses	5%	**(PEC+DC)**	$399,064
Contractor's Fees	10%	**(PEC+DC)**	$798,127
Start-up & Commissioning	3%	**(PEC+DC)**	$239,438
Performance Test	3%	**(PEC+DC)**	$239,438
Contingencies	8%	**(PEC+DC)**	$638,502
TOTAL CAPITAL INVESTMENT:			**$10,295,839**
Direct Annual Costs (DAC)			**$ 714,959**
Electricity (79kWhx 8760 hr/yr x $0.075/kWh) [3]			$ 51,598
50% Urea (8.6 gph x $1.35/gal delivered x 8760 hr/yr) [4]			$ 102,025
Natural Gas ($ /MMBtu x 8760 hr/yr x MMBtu/hr) [5]			$ 443,308
Operating Labor ($31.27/hr x 0.5 hr/shift x 3 shifts/day x 365 days/year)			$ 17,120
Maintenance Labor ($31.27/hr x 0.5 hr/shift x 3 shifts/day x 365 days/year)			$ 17,120
Catalyst Replacement Cost (Catalyst Replacement Every 3 Years @ $200,000)			$ 66,667
Other Maintenance Material Costs (100% of Maintenance Labor Cost)			$ 17,120
Indirect Annual Costs (IDAC)			**$ 827,089**
Administrative Charges (0.03 x (Operator Labor Costs + (0.4 x Annual Maintenance Cost)))[6]			$ 924
Capital Recovery Cost, eq. 2.70 [7]			$ 826,165
TOTAL ANNUALIZED EQUIPMENT COST			**$ 1,542,048**

[1] Capital investment, installation costs, and indirect annual costs are based on the methodology outlined in the EPA Air Pollution Control Cost Manual, 6th Edition, 2002 and Ramboll's collective experience with the installation of similar systems..

[2] Based on an equipment quote from Zenviro Tech

[3] Based upon an additional SCR system pressure drop of 5" W.C.

[4] Based upon a Stoichiometric Ratio Factor (SRF) for urea of 0.53 and 2ppmv of ammonia slip.

[5] Natural gas cost assumed $5/MMBtu, required 40MMBtu/hr heat input, with a potential recovery of 29.6MMBtu/hr, assuming 70% efficiency heat exchanger

[6] Taken from Chapter 2 of the EPA Air Pollution Control Cost Manual, 2019.

[7] Capital Recover Cost assuming an equipment life of 20 years and an interest rate of 5%.

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		SNCR Cost Estimate[1]	
Plant:		**Ross Incineration**	
Process Description:		**Waste Incineration**	
Cateogry	**Cost Factor**	**Applied to/using**	**Costs**
Equivalent Boiler Size, Qb (MMBtu/hr)[2]:			
NPHR			
HRF			
BMW			
SNCRcost, eq		Bmw, HRF	$803,613
BOP, eq .		Qb, NPHR, $NOX_{removed}$, η_{NOx}	$1,262,826
Cost Factor, 2016 to 2024 dollars [3]	1.30		
Total Capital Investment (TCI_e), eq. 1.24			**$3,492,281**
Purchased Equipment Costs (PEC):			**$849,627**
Refractory, raw materials[4]			$307,094
Steel, raw materials[4]			$369,344
Gunnable concrete, specialty installation costs[4]			$61,753
Pump skids and nozzle arrays[5]			$7,500
PLC, instrumentation control system and monitoring[5]			$41,000
Sales Tax			3%
Freight			5%
Direct Installation Costs (DC):			$ 1,597,298
Foundation & Supports	6%	**PEC**	$ 50,978
Handling & Erection, including reworking cyclone and existing structure	175%	**PEC**	$ 1,486,847
Electrical	1%	**PEC**	$ 8,496
Piping	5%	**PEC**	$ 42,481
Insulation for Ductwork	0%	**PEC**	$ -
Painting	1%	**PEC**	$ 8,496
Indirect Installation Costs (IDC):			$ 1,394,747
Construction & Field Expenses, complex system	20%	**PEC + DC**	$ 489,385
Contractor's Fees	10%	**PEC + DC**	$ 244,692
Start-up & Commissioning	1%	**PEC + DC**	$ 24,469
Performance Test	1%	**PEC + DC**	$ 24,469
Contingencies	25%	**PEC + DC**	$ 611,731
Total Modifications Capital investment (TCI_m)[6]			**$3,845,000**
Total Capital Investment ($TCI_e + TCI_m$)			**$7,337,281**
Direct Annual Costs (DAC):			**$245,615**
Annual Maintenance Costs, eq. 1.39	15%	EPA factor	$ 52,384
Annual Reagent Costs, eq. 1.40	$ 1.35	Q_{sol}	$ 187,052
Annual Electricity Costs, eq. 1.43	$ 0.075	P	$ 3,551
Annual Water Costs, eq. 1.46	$ 0.00417	Q_{water}	$ 2,628
Annual Fuel Cost, eq. 1.49 [7]	$ -	MMBtu/hr.	$ -
Annual Ash Cost, eq. 1.51 [8]	$ -	NA	$ -
Indirect Annual Costs (IDAC):			$ 588,762
Capital Recovery Cost, eq. 1.55 [9]			$ 588,762
TOTAL ANNUALIZED EQUIPMENT COST			**$834,378**

[1] Estimate developed based on methodology outlined in the EPA Air Pollution Control Cost Manual, 7th Edition, 2022.
The method is applicable to study-level estimates

[2] Based on a boiler size equivalent method, paragraph 3.2

[3] Cost factor based on the consumer price index

[4] Based on a of residency time, ft diameter vessel, ft tall lined with 4" of gunnable refractory, for quench and SNCR, including provision for 60ft of 8ft diameter refractory lined ductwork. Equivalent to sqft of refractory and steel (study-evel estimate)
Costs estimated using the volume of steel and refractory required.
$120/55lbs estimated for gunnable refractory raw material costs
$3.6/Lb. of steel fabricated for shell and supports (3/8" thick)
Specialty hourly costs of 2hr./sqft at $60/hr. based on the Cement Handbook, Hoganas Borgestad

[5] Based on a quote from Tri-Mer for a similar size and complexity chemical feed system

[6] The TCI for project of high risk and complexity are often in the range of 4 to 5x the equipment cost, based on Ramboll's experience.
The handling & erection fees, as well as the construction & field expenses carry a large portion of the additional expenses compared to traditional projects.

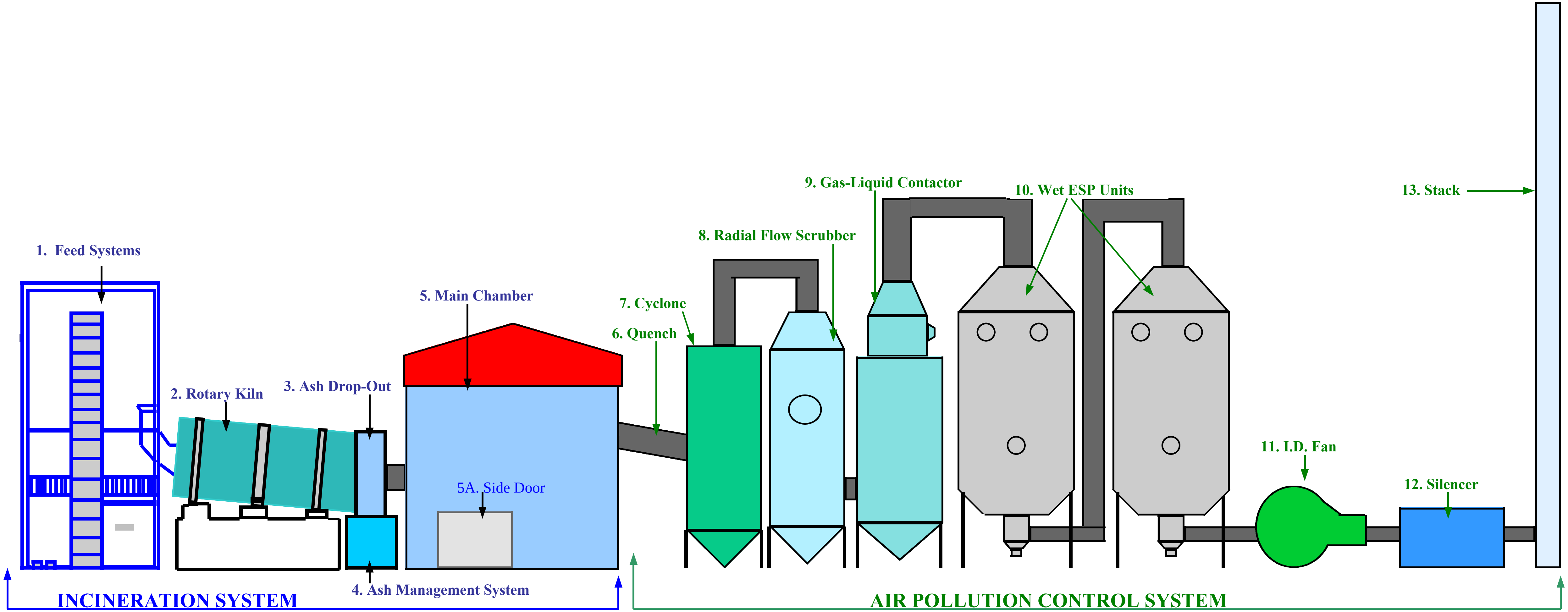
[7] Fuel costs not representative in the case of a waste incinerator, however, efficiency decreases due to added moisture and can negatively impact the DRE.

[8] Ash costs ommited due the nature of the hazardous waste incinerator

[9] Capital Recover Cost assuming an equipment life of 20 years and an interest rate of 5%.

Appendix B
Incinerator Process Flow Diagram

Ross Incineration Services, Inc.
Waste Incineration & Air Pollution Control System



Appendix C

Facility General Layout

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Confidential Information has been Removed from this Page

RIS has claimed this drawing confidential because it reveals information pertaining to the size and configuration of its process equipment, treatment, and/or storage areas.

Appendix D
TCI Calculations, Cost Control 7th Edition

The Total Cost Installed (TCI) of the SNCR system is estimated by the following expression:

$$TCI = 1.3 * (SNCR_{cost} + APH_{cost} + BOP_{cost})$$

Where:

$$SCNR_{cost} = \quad * (B_{MW} * HRF)^{0.42} * CoalF * BTF * ELEVF * RF$$

$APH_{cost} = 1$, only required for SO_3 control.

$$BOP_{cost} = \quad * (B_{MW})^{0.33} * \quad \left(\frac{NO_{x\_removed}}{hr}\right)^{0.12} * BTF * RF$$

The Total Cost Installed (TCI) of the SCR system is estimated by the following expression:

$$TCI = 1.3 * (SCR_{cost} + RPC + APHC + BPC)$$

Where:

$$SCR_{cost} = \quad * (NRF)^{0.2} * (0.1 * Q_B * CoalF)^{0.92} * ELEVF * RF$$

$$RPC = \quad * \ (NO_{x_{in}})^{0.25} * RF$$

$$APHC = \quad * (0.1 * Q_B * CoalF)^{0.78} * AHF * RF\ BPC$$

$$= \quad * (0.1 * Q_B * CoalF)^{0.42} * ELEVF * RF$$

Appendix E
TCI Calculations, Cost Control 6th Edition

The Direct Installed Cost (DC) of the SNCR system is estimated by the following expression:

$$DC(\$) = \frac{\$}{MMBtu} * Q_B\left(\frac{MMBtu}{hr}\right) * \left(\frac{\frac{MMBtu}{\left(\quad hr \right)}}{Q_B\left(\frac{MMBtu}{hr}\right)}\right)^{0.577} * (+ \; * \eta_{NO_x})$$

The Direct Installed Cost (DC) of the SCR system is estimated by the following expression:

$$DC(\$) = Q_B * \left(\frac{\$}{\frac{MMBtu}{hr}} + f(h_{SCR}) + f(NH_{3rate}) + f(new) + f(bypass)\right) * \left(\frac{Q_B}{\quad}\right)^{0.35} + f(Vol_{catalyst})$$

Where:

$$f(h_{SCR}) = \left(\frac{\$}{ft - \frac{MMBtu}{hr}} * h_{SCR}\right) - \frac{\$}{\frac{MMBtu}{hr}}$$

$$f(NH_{3rate}) = \left(\frac{\$}{\frac{lb}{hr}} * \frac{\dot{m}_{reagent}}{Q_B}\right) - \frac{\$}{\frac{MMBtu}{hr}}$$

$$f(new) = \frac{\$0}{\frac{MMBtu}{hr}} \; (for\, a\, retrofit)$$

$$f(bypass) = \frac{\$0}{\frac{MMBtu}{hr}} \; (no\ bypass)$$

$$f\left(VOL_{Catalyst}\right) = Vol_{Catalyst} * CC_{initial}$$