Attachment 1

Municipal Waste Combustor Workgroup Report

Prepared by the Ozone Transport Commission Stationary and Area Sources Committee

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Contents

Acronyms and Units

ASNCR	Advanced selective non-catalytic reduction
BACT	Best available control technology
CEM	Continuous emission monitor
CFD	Computational fluid dynamics
CFR	U.S. Code of Federal Regulations
EGU	Electric generating units
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
FGR	Flue gas recirculation
lb	Pounds
LN™	Low NOx technology
MMBtu	Million British thermal units
MWC	Municipal waste combustors
NOx	Nitrogen oxides
NSR	Normalized stoichiometric ratio
OTC	Ozone Transport Commission
OTR	Ozone Transport Region
PM	Particulate matter
ppm	Parts per million
ppmvd	Parts per million dry volume
RACT	Reasonably available control technology
RDF	Refuse derived fuel
SAS	Stationary and Area Sources Committee
SCR	Selective catalytic reduction
SNCR	Selective non-catalytic reduction
SOx	Sulfur oxides
VLN™	Very low NOx technology

Introduction

This report summarizes results from a municipal waste combustor (MWC) pilot project conducted by the Ozone Transport Commission (OTC) Stationary and Area Sources (SAS) Committee. The report provides an estimate of oxides of nitrogen (NOx) emissions from Ozone Transport Region (OTR) MWCs, identifies opportunities for additional NOx reductions from the units, and provides example costs for installing additional NOx controls on OTR MWCs. The report has five sections, including background information, an overview of methods used in the pilot study, findings, policy implications, and conclusions. There are seven appendices to the report, three of which detail emissions and operating characteristics of the approximately 100 MWCs in the OTR, one that provides information on MWCs outside of the OTR, two that provide calculations for converting NOx concentrations to mass emissions and costs for urea use, and one which describes MWC emission reduction technologies.

Background

During the development of the 2020 Stationary and Area Sources Committee Charge, SAS Committee members identified a number of sectors, including MWCs, small electric generating units, and others, as significant sources of NOx emissions in the OTR. In the 2020 Charge, the SAS Committee prioritized MWCs for a pilot project as the first sector for evaluation. The pilot was intended to provide a template for evaluation of other sectors in the region. The SAS Committee formed an MWC workgroup to conduct an evaluation of MWCs in the region and the results of that effort are described in this report.

In 2018, MWCs emitted approximately 22,000 tons of NOx in the OTR. Nine states in the OTR have MWCs and have established Reasonably Available Control Technology (RACT) regulatory or permit limits for the MWC NOx emissions. These states are: Connecticut, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, and Virginia. Some OTC states have initiated a process to update NOx RACT for MWCs and this potentially provides an opportunity to strengthen emissions limits.

Method

The pilot study was directed by the members of the SAS MWC workgroup. The sub-sections that follow in this section describe each basic step of the analysis method. In brief, these steps consisted of:

1) Developing a state-by-state OTR MWC unit inventory;
2) Estimating tons of NOx emitted annually from each MWC;
3) Conducting a literature review to identify additional control technologies;
4) Estimating tons per year of NOx that could be reduced with further controls; and
5) Researching and estimating the potential costs of further MWC NOx controls.

Developing a state-by-state MWC Inventory

In this step, MWC workgroup members compiled information in an Excel spreadsheet for each of the MWCs in their states. The information included the MWC unit ID, plant name, location, type of MWC, capacity (in tons of refuse processed per day), permit or RACT limits, existing control technology, and other information. In addition, using the federal definition, the workgroup segmented MWCs into “large” or “small” MWCs. A large unit has the capacity to process greater than 250 tons per day of refuse, and a small unit has the capacity to process no more than 250 tons of refuse per day. Small units referred to in this report includes a "very small" category of MWCs defined in 40 CFR Part 60 as units that process less than 35 tons of refuse per day. MWCs were also categorized by technology type based on 40 CFR part 60 classifications.[1] The purpose of categorizing the MWCs was to identify characteristics of the MWCs that would either lend themselves to further emission controls or preclude further emission control. Appendix A provides NOx emissions for large MWCs and an estimate of potential reductions, Appendix B provides characteristics of the large MWCs, and Appendix C details characteristics of small MWCs in the OTR. The workgroup performed some preliminary work to identify non-OTR MWC EGUs in the 48 contiguous states. The Results section provides an overview of findings, and Appendix D lists the MWCs outside of the OTR.

Developing an Emissions Inventory for the OTR MWCs

To develop inputs for the OTC Modeling Committee to use in air quality modeling, individual MWC permit limit NOx emission concentrations in parts per million (ppmvd) were collected.[2] These permit limits were used to estimate NOx mass emissions rates in pounds per million British thermal units (lb/MMBtu) using the provisions of 40 CFR Part 60 Appendix A Method 19 to convert from ppmvd to pounds per standard cubic foot (lb/scf). The workgroup subsequently used the provided F-factors to convert from lb/scf to lb/MMBtu. Method 19 provides conversion factors using F-factors for determining particulate matter (PM), sulfur dioxide (SO_2), and NOx emission rates in mass per unit calorific value, i.e., lb/ MMBtu.[3] Once inputs to the Method 19 calculation were gathered, the design capacity of the emission unit in MMBtu/hr was multiplied by the estimated lb/MMBtu emission rate to convert to a mass emission rate in pounds per hour (lb/hr).

Because these MWC units run practically all the time except for routine maintenance, the workgroup assumed these units operate continuously and used a consistent estimate of hours of operation per year across all emission units. The assumption of nearly constant operating levels of the MWCs was confirmed by examination of Energy Information Administration (EIA) fuel consumption data indicating nearly constant month-to-month fuel consumption over a year's time. By converting lb/hr to tons per year, the workgroup was able to compare the actual tons of NOx emitted per year relative to the permitted levels by using the same formula but inserting the permitted emission concentration in ppmvd. Appendix E provides a detailed description of the method used.

In addition to estimating tons per year of NOx for air quality modeling, the estimated mass emissions were used by the MWC workgroup to develop a ballpark estimate of the potential tons of NOx that could be reduced with the application of additional emissions controls.

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[1] *See* The Energy Recovery Council, "2018 Directory of Waste to Energy Facilities" accessed at: http://energyrecoverycouncil.org/wp-content/uploads/2019/10/ERC-2018-directory.pdf.

[2] Throughout this report, the term ppmvd is used in reference to NOx emissions concentrations. As background, ppm can be shown on a mass (ug/g, or ug/cubic meter) or volume (ul/l) basis. The unit "ppmvd" means that the concentration is on a volume basis. The ppmvd designation indicates that the associated values are on a dry basis (e.g. water vapor is not part of the sample), which provides consistency for comparing any two values, by ensuring that the value is corrected on a dry basis which eliminates the variability introduced by moisture content in the sample gas. This process is similar to correcting a measured value for O_2 content of the sample gas, such as x ppmvd @12% O_2.

[3] EPA, "Method 19 - Sulfur Dioxide Removal and Particulate, Sulfur Dioxide and Nitrogen Oxides from Electric Utility Steam Generators," see: Method 19 - Sulfur Dioxide Removal and Particulate, Sulfur Dioxide and Nitrogen Oxides from Electric Utility Steam Generators | Air Emission Measurement Center (EMC) | US EPA.

Conducting a Literature Review to Identify Additional NOx Control Technologies

The MWC workgroup identified and reviewed engineering analyses that evaluated the technical potential to reduce NOx emission from MWCs. The workgroup first found studies that evaluated NOx reductions from large MWCs with similar configurations to those in the OTR. A pair of studies conducted by Trinity Consultants for two Covanta facilities in Virginia were evaluated.[4] The studies used similar methodologies for both facilities. Another study conducted by Babcock Power Environmental for a Wheelabrator facility in Baltimore, Maryland was reviewed.[5] Like many large MWCs in the region, all three facilities use selective non-catalytic reduction (SNCR) as their baseline NOx control technology. A brief summary of these studies is provided below and more detail on the studies can be found in the Results section.

Trinity Consultants Studies

The Trinity Consultants studies evaluated two Covanta facilities, one in Alexandria/Arlington, VA and the other in Fairfax, VA, that are subject to RACT requirements for the 2008 ozone standard. Four technologies were evaluated for these MWCs: 1) optimized SNCR; 2) a proprietary low NOx combustion system (LN^{TM}) developed by Covanta for its own facilities; 3) selective catalytic reduction (SCR); and 4) Very Low NOx (VLN)/SNCR combination.

Babcock Power Environmental

The Babcock Power Environmental Study was conducted for a Wheelabrator facility in Baltimore, Maryland. The purpose of this study was to provide a feasibility analysis for additional control of NOx emissions from the waste-to-energy facility. As with the Covanta facilities evaluated in the Trinity Consultants' studies, the Baltimore MWCs were equipped with SNCR systems. The study analyzed seven technologies: 1) advanced SNCR (ASNCR), 2) flue gas recirculation SNCR (FGR-SNCR), 3) FGR-ASNCR, 4) hybrid SNCR-SCR, 5) DeNOx catalytic filter bags, 6) optimized SNCR, and 7) tail end SCR systems. A technology vendor (Fuel Tech, Inc.) was hired to provide a more comprehensive analysis of SNCR and ASNCR system capabilities to augment Babcock Power Environmental's analysis.

Findings from the Trinity and Babcock Power studies are excerpted in the Results section of this report.

Other Resources

Additional papers, correspondence, and studies were evaluated for this report. They include:

- A North American Waste to Energy paper which evaluated the feasibility of a 100 ppmvd 24-hour NOx limit[6]
- Information from a Montgomery County Resource Recovery NOx optimization study[7]

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[4] Trinity Consultants, "Project Report Covanta Alexandria/Arlington, Inc., Reasonably Available Control Technology Determination for NOx," September 2017, and "Project Report Covanta Fairfax, Inc., Reasonably Available Control Technology Determination for NOx," September 2017.

[5] Babcock Power Environmental, "Waste to Energy NOx Feasibility Study," Prepared for: Wheelabrator Technologies Baltimore Waste to Energy Facility Baltimore, MD, February 20, 2020.

[6] White, M.; Goff, S.; Deduck, S.; Gohlke, O., "New Process for Achieving Very Low NOx," Proceedings of the 17th Annual North American Waste-to-Energy Conference, NAWTEC17, May 18-20, 2009.

[7] Letter from the State of New Jersey to Michael Klein, dated March 14, 2019 in reference to Covanta Energy Group, Inc. Essex County Resource Recovery Facility – Newark Annual Stack Test Program

- Recent stack test data from the Covanta Essex facility in New Jersey where LN™ technology was working in conjunction with a conventional SNCR system[8]

Small MWCs

No studies were found of small MWCs in the OTR, which are characterized by limited space for NOx reduction technology installation. One study from South Korea was reviewed by the MWC workgroup. The study discusses computational fluid dynamics (CFD) modeling and actual test data for the application of SNCR on a small (50 ton per day) MWC.[9] More information on the configuration of small MWCs and space limitations is provided in the following section.

Estimating Tons per Year of NOx that Could Be Reduced with Further Controls

Using the classifications of MWCs in the region (Part 60 classifications) and the results of engineering studies found in the literature, the MWC workgroup estimated the potential for additional NOx reductions at MWCs. As described in the literature review section above, several studies were identified and reviewed. The approach used in this estimation is described below.

Large MWCs:

Most of the large MWCs in the OTR are equipped with SNCR, which was the baseline technology in both the Trinity and Babcock studies. Improvements to these units could include enhancing or modifying the existing SNCR system as installed with better monitoring or better spray nozzles. Another approach that was described in a Babcock study involved retrofitting the entire system. Additional approaches were described in detail in the Babcock study.

Using the OTR MWC inventory Excel worksheet, the workgroup applied two control levels to the large MWCs in the region: 130 ppmvd and 105 ppmvd. These two levels were both assumed to be 30-day averages. It is important to note that the Trinity studies used for this analysis assumed 24-hour averaging periods, but not a 30-day averaging period. The Babcock study assumed a 30-day averaging period, though the report also concluded that a 24-hour limit of 110-125 ppmvd could be met as well through the utilization of ASNCR. In addition, one unit in operation in the region at the Covanta Montgomery facility in Maryland which utilizes LN™ has a permit limit of 105 ppmvd for a 30-day rolling average.

The workgroup identified 105 ppmvd NOx on a 30-day averaging period as technically feasible for the large MWC units, based on the engineering analyses reviewed. The workgroup decided to use the same emission limit of 105 ppmvd over a 30-day average for nearly all large MWCs in the region, assuming that the control technologies evaluated in the studies can achieve this limit among nearly all large MWCs. This is the 30-day average value for ASNCR from the Babcock study. Like ASNCR, Covanta's Low NOx Technology is also able to meet a 30-day average of 105 ppmvd (e.g. the Covanta Montgomery facility in Maryland). This provides a consistent 30-day limit that is obtainable for the Covanta and Wheelabrator facilities. To the extent that the estimated emission reduction potential for some units is based on the permit limit values with 24-hour average periods, there is not a 1-to-1 comparison with the

[8] Letter from the State of New Jersey to Michael Klein, dated March 14, 2019 in reference to Covanta Energy Group, Inc. Essex County Resource Recovery Facility – Newark Annual Stack Test Program.

[9] Nguyen, T.D.B., *et al*., "Application of urea-based SNCR to a municipal incinerator: On-site test and CFD simulation," Chemical Engineering Journal 152 (2009) 36-43.

recommended limit of 105 ppmvd on a 30-day average unless the averaging time differences are accounted for.

In addition to researching the potential for a 30-day averaging period NOx limit, the workgroup evaluated the potential for a 24-hour averaging period NOx limit. The workgroup researched existing facilities permitted to a 110 ppmvd standard, read literature on technical feasibility and capital costs, and evaluated potential operating and maintenance costs associated with a more stringent 24-hour standard.

For both a 30-day and 24-hour NOx ppmvd averaging period, the workgroup researched and compiled implementation examples of MWCs that have been retrofitted with technologies to achieve the lower NOx limits.

Excluded Large MWCs:

There were large MWCs in the region that were also equipped with SNCR but were excluded from the estimation of NOx reductions. Two examples are the Wheelabrator Saugus units in Massachusetts. Due to the physical constraints of the two existing MWC units at this facility, the 105 ppmvd 30-day average NOx limit was not assumed to be achieved without major modifications of the existing MWCs. The Saugus MWCs are a vintage European design that incorporates a low profile "tail-end boiler" configuration with a single pass short waterwall furnace. The older tail end design and short furnace limits the ability to install additional cost-effective NOx controls.

Small MWCs

Small MWCs located in the OTR tend to utilize rotary combustors or modular combustors of either the starved air or excess air configurations. While some small MWCs of these configurations incorporate some NOx control provision in their original design, little recent information was located discussing the technical or economic feasibility of retrofitting additional or more modern NOx controls on such units. The exception was the study conducted in South Korea (see footnote 9). For the MWC in the South Korean study, a NOx reduction of 70 percent was found to be feasible. This percentage reduction is similar to that found in the literature for large MWCs with the installation of ASNCR. However, due to the limited number of small MWCs in the OTR and the sparsity of public information regarding the technological and economic feasibility of advanced controls, the MWC workgroup was unable to recommend NOx emission rate limitations more stringent than the values already permitted.

The possibility of additional control for these small MWCs, as demonstrated in non-US applications, should be considered in the event additional sources of NOx reductions become necessary. Conducting additional research on small MWCs is a potential area for additional research since further review of the literature may yield more information on the potential to reduce emissions from these units. A list of these units is provided in Appendix C.

The MWC workgroup attempted to collect available actual measured flow rates captured by continuous emission monitors (CEM) in the OTR. However, very little CEM data was found to use in a comparison with permit or RACT emission levels to determine the extent to which MWCs in the region are over-complying with regulated emissions limits and to determine opportunities for lowering emissions limits.

Researching the Potential Costs of Further MWC NOx Controls

The MWC workgroup relied on the Trinity and Babcock studies described above for example NOx control technology costs in this pilot study. In addition, the workgroup used costs found in an EPA document: Chapter 2 - Cost Estimation: Concepts and Methodology[10] to fill in gaps in cost data. Last, the workgroup used information from EPA's NSR Guidance document to estimate urea consumption-related operating costs.[11]

The pair of studies by Trinity Consultants (described in previous sections) for the Covanta MWCs located in Alexandria/Arlington and Fairfax, VA were first evaluated. The Covanta facilities were equipped with SNCR at the time of the RACT analysis and costs were evaluated for adding three additional potential technologies: 1) the proprietary low NOx combustion system (LN™) developed by Covanta for its own facilities; 2) selective catalytic reduction (SCR); and Very Low NOx (VLN)/SNCR combination.

In the analysis for the SCR costs, Covanta solicited bids from engineering, procurement, and construction companies to determine system costs. The SCR system included the SCR reactor; gas-to-gas recuperative heat exchanger; steam coil heater; reagent feed injection and mixing system; and all associated support steel, piping, and controls. The consultants were instructed to design the SCR to receive NOx at 90-180 ppmvd (24-hour average) and control it to 50 ppmvd (24-hour average). Direct and indirect annual operating costs were obtained from a BACT analysis of an MWC in West Palm Beach, Florida.[12]

Capital costs for installation of the LN™ process were estimated by examining each of the boilers at the facility and costs were developed on a per-boiler basis. The installation cost, which includes items such as fans, dampers, ducting, and process controls, was estimated based on actual expenses from another Covanta facility (Montgomery County, MD). The annual costs were scaled linearly from the Montgomery County project costs to the Covanta facilities in Virginia.

Total capital investment costs were provided in both Covanta studies, including direct costs (purchased equipment) and indirect costs (installation costs and lost production due to extended downtime for installation). Direct and indirect costs were also presented for annual operating costs.

The third study was the Babcock Power Environmental analysis conducted for the Wheelabrator facility in Baltimore. Capital and operating costs were evaluated for each technology. At the Baltimore facility, each of the three MWCs is equipped with SNCR. As mentioned above, the study analyzed advanced SNCR (ASNCR), FGR-SNCR that incorporates flue gas recirculation into the SNCR design, FGR-ASNCR, hybrid SNCR-SCR, DeNOx catalytic filter bags, and tail end SCR systems. Because Covanta's Low NOx combustion system is proprietary technology, it was not considered for the Wheelabrator facility in Baltimore. For each of these technologies, Babcock Power Environmental estimated costs for materials, equipment, and installation. A technology vendor (Fuel Tech, Inc.) was hired to provide a more comprehensive analysis of SNCR and Advanced SNCR (ASNCR) system capabilities to augment Babcock's analysis. In this study, annualized capital costs were not provided and so the MWC workgroup estimated

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[10] EPA, "Economic and Cost Analysis for Air Pollution Regulations," Chapter 2 - Cost Estimation: Concepts and Methodology, last updated in February 2018.
[11] EPA NSR Guidance Document, 2019, https://www.epa.gov/sites/production/files/2017-12/documents/sncrcostmanualchapter7thedition20162017revisions.pdf.
[12] Florida Department of Environmental Protection "Written Notice of Intent to Issue a Permit," "Public Notice of Intent to Issue Air Permit," "Technical Evaluation and Preliminary Determination," "Draft Permit with Appendices" November 2010.

these costs from a formula in the EPA document: Chapter 2 - Cost Estimation: Concepts and Methodology (see footnote 10).

To estimate the costs per ton of NOx reduced assuming a 24-hour NOx limit, the workgroup relied on the Trinity and Babcock Power studies. The workgroup made some adjustments to these costs. First, the workgroup estimated tons of NOx reduced each year using the 110 ppmvd limit. Operating cost adjustments were made to account for the fact that the Trinity study evaluated a 90 ppmvd annual NOx limit and the workgroup was estimating costs for a 110 ppmvd 24-hour limit. To adjust operating costs, the workgroup estimated the difference in cost for urea between the 90 ppmvd NOx annual limit and a 110 ppmvd 24-hour averaging period. The cost for urea consumption for NOx removal was performed in two ways. First, the cost estimate on a per lb of NOx reduction was developed using information in the Wheelabrator Baltimore study. The differences between the optimized SNCR and advanced SNCR control options were evaluated. The second estimation method was based on simple chemical reaction estimates available in guidance from EPA, and urea cost values from the Wheelabrator Baltimore study. Details of the utilized estimation methodologies are found in Appendix G. Additional information on how costs were developed in the RACT studies that the MWC workgroup relied on is provided in the next section.

The MWC workgroup anticipates the control technologies and associated costs found in the literature would apply to most of the MWCs throughout the OTR. However, additional analyses may be needed to further refine these estimates for specific MWCs.

Findings

In this section, an inventory of MWC units and NOx emissions in tons per year, a summary of technologies to reduce NOx from MWCs, an estimate of the NOx emission reduction potential for OTR MWCs, and estimated costs for installing and operating additional technologies are provided.

OTR MWC Inventory of Units and NOx Emissions

The inventory of MWC units in the OTR is summarized in Table 1. A total of 103 large and small units are operating in the nine OTR states with MWCs. In 2018, large units emitted over 21,000 tons of NOx annually and small units emitted approximately 900 tons of NOx. Missing from this analysis are a few MWCs in the region for which the MWC workgroup could not calculate annual NOx emissions. This is a minor portion of the inventory and could be estimated in a follow-on analysis.

Table 1: Summary of OTR MWCs and NOx Emissions by State

State	Number of Large Units	Number of Small Units	Annual Tons of NOx Emissions - Large Units (2018)	Annual Tons of NOx Emissions - Small Units (2018)
Connecticut	12	0	2,226	0
Maine	4	2	670	278
Maryland	6	0	1,435	0
Massachusetts	11	6	4,754	173
New Hampshire	2	0	344	0
New Jersey	11	0	2,044	0
New York	13	5	3,998	456
Pennsylvania	19	0	3,531	0
Virginia	7	0	2,276	0
Total	**90**	**13**	**21,278**	**906**

As can be seen from Table 1, large MWCs emit most of the NOx pollution from MWCs in the OTR. As mentioned above, information was found in the literature on additional NOx control technologies for the types of MWCs in the "large" category. For these reasons, the MWC workgroup focused its attention on technologies to reduce NOx emissions from large MWCs.

Technologies to Reduce NOx from MWCs in the OTR

Information is provided below on the potential to reduce NOx emissions from MWCs in the OTR. First, excerpts from the Trinity Consultants' report describing the technologies and the potential NOx reductions that can be achieved using each of the technologies on Covanta facilities are provided, followed by information from the Babcock Power study on a Wheelabrator facility. Additional information on the technologies is available in Appendix F.

Covanta patented low NOx technology (LN™)

Covanta has developed a proprietary low NOx combustion system that involves staging of combustion air. The system is a trademarked system and Covanta has received a patent for the technology. Secondary air (also called overfire air) is injected through nozzles located in the furnace side walls immediately above the grate creating turbulent mixing to complete the combustion process. The Covanta LN™ process modifies the secondary air stream. A new series of air nozzles are installed higher in the furnace (tertiary air) and a portion of the secondary air is diverted to these new nozzles. The distribution of air between the primary, secondary, and tertiary streams is then controlled to yield the optimal gas composition and temperature to minimize NOx formation and control combustion. The tertiary air achieves complete coverage of the furnace cross-section to ensure good mixing with the combustion gases. Note that the total air flow to the MWC is not changed, only the distribution of air is changed. The LN™ combustion system works in concert with an optimized SNCR system to achieve lower NOx emissions. The LN™ process can be retrofitted to an existing unit, and Covanta has installed the LN™ process at approximately 20 units worldwide. The LN™ process can appreciably increase annual maintenance costs due to increased refractory wear and boiler fouling.

The Trinity report found that implementation of LN™ can reasonably achieve an annual NOx emission limit of 90 parts per million volume dry (ppmvd) (7% O_2) and a daily NOx limit of 110 ppmvd (7% O_2). LN™ is used in combination with SNCR and is thus presented considering usage of the combustion technology plus SNCR.

SCR

Trinity Consultants instructed its subcontractors to design a SCR system that included the SCR reactor; gas-to-gas recuperative heat exchanger; steam coil heater; reagent feed injection, and mixing system; and all associated support steel, piping, and controls. The consultants were instructed to design the SCR to receive NOx at 90-180 ppmvd (24-hour average) and control it to 50 ppmvd (24-hour average). The study concluded there are significant space considerations with SCR system installation which can be managed in a cost-effective way in a new development, but which make retrofit installation very costly and complex. Specifically, the piping, wiring, supports, and other hardware require substantial space which may not be available in an existing facility.

VLN Technology

The Very Low NOx (VLN) system employs a unique combustion air system design, which in addition to the conventional primary and secondary air systems, features an internal gas recirculation injection system. Recirculation of the flue gas reduces the need for combustion air for complete combustion in the furnace. The combination of the internal gas recirculation and reduced secondary air extends the combustion zone in the furnace, which in turn inhibits the formation of NOx. A NOx limit of 110 ppmvd NOx on a 24-hour average basis and 90 ppmvd on an annual basis was found to be feasible. The study concluded that VLN remains a viable technology for new MWC units but is not technically feasible for an existing unit.

Babcock Power Environmental Study

The Babcock Power Environmental Study was conducted for a Wheelabrator facility in Baltimore, Maryland. The purpose of this study was to provide a feasibility analysis for additional control of NOx emissions from the waste-to-energy facility. The Baltimore MWCs were equipped with an SNCR system. Results from the analysis conducted for the study are provided below for each of the technologies evaluated.

Optimized SNCR

The study analyzed CFD model outputs and found that through adjustments to residence time, NOx emissions levels of 135 ppmvd @7% O_2 on a 24-hour block average and 130 ppmvd @7% O_2 on a 30-day rolling average are achievable.

Advanced-SNCR (ASNCR)

The Babcock Power Environmental study evaluated optimized injector locations. It concluded this option is technically feasible with future CFD and chemical spray modeling where particular attention is paid to injector placement so that there is no risk of chemical impingement on the superheater and boiler surfaces. The study concluded that a reduction of 25 ppmvd @7% O_2 on a 30-day rolling average (i.e., 105 ppmvd) can be realized over the optimized existing SNCR. In discussing the potential retrofit of ASNCR, the report states “based on experience … a 5% improvement in chemical coverage is feasible, leading to a target NOx of 110 ppmvd @7% O_2 on a 24-hour block average and 105 ppmvd @7% O_2 on a 30-day rolling average while the ammonia slip is kept at the 5 ppm range.”

ASNCR NOx control technology may be considered for retrofit on existing MWCs as either a new retrofit technology or a significant upgrade to an existing SNCR. ASNCR is like SNCR in that it utilizes the injection of reagents into the proper temperature zones of the furnace to reduce the flue gas NOx concentration. ASNCR designs may utilize advanced computer modeling techniques to specify SNCR nozzle locations and elevations so that their operation may be optimized across varying furnace conditions. The primary difference between a well-designed SNCR and ASNCR system is that ASNCR would utilize advanced furnace temperature monitoring instrumentation to provide near real time operating furnace temperature profiles. This information allows the control system to modulate which ASNCR injectors are in operation and to automatically adjust the individual injector flow rate in order to optimize the overall NOx emission rate. This advanced system optimizes the NOx reduction chemical reaction across the furnace to achieve high levels of overall NOx reduction while maintaining low ammonia slip.

ASNCR is an effective NOx reduction technology capably of achieving a 70% reduction. Industry literature discusses that for most large MWC EGUs, uncontrolled NOx emission rates are in the range of 300 ppmvd to 350 ppmvd @7% O_2. Based on these values, it would appear that a general range of NOx emissions utilizing ASNCR would be 90 ppmvd to 105 ppmvd.

The Babcock Power Environmental information suggests that ASNCR may be applicable to many MWCs as a retrofit technology, although furnace configuration or other factors could affect the NOx reduction potential.

FGR-SNCR

With this option, Flue Gas Recirculation is incorporated into the SNCR design. The FGR-SNCR option was evaluated using a boiler heat transfer model. In this option, a portion of the flue gas from combustion is recirculated from the fan inlet duct and re-injected back into the furnace through the over-fire air system. FGR is used to replace a portion of the secondary air flow. This reduces use of ambient air, and therefore provides additional NOx emission reduction by reducing O_2 concentration or excess ambient air and combustion temperature, while still maintaining the secondary air gas flow needed for mixing in the furnace.

FGR-ASNCR

It is also possible to combine the FGR technology with the ASNCR technology. The implementation of ASNCR by adding additional independent zones of injection and an acoustic pyrometer can provide additional NOx reduction while controlling the ammonia slip. The FGR-ASNCR system was evaluated using a boiler heat transfer model. The study concluded that FGR-ASNCR is technically feasible from both an arrangement and performance perspective with future CFD modeling.

Hybrid SNCR-SCR

The Hybrid SNCR-SCR option utilizes two treatment stages: a SNCR treatment stage followed by a SCR treatment stage. In a stand-alone SNCR application, the reducing agent is released at higher temperatures to minimize ammonia slip formation. In hybrid applications, the ammonia slip becomes the reducing agent over the catalyst. The hybrid system was not considered to be technically feasible for the Baltimore facility.

DeNOx Catalytic Filter Bags

DeNOx catalytic filter bags can be utilized with ammonia injection to reduce NOx in a similar fashion to traditional SCR catalyst. These combination bags remove both dust and gaseous compounds simultaneously. The DeNOx catalyst was not considered to be technically feasible at the Baltimore facility due to operating temperature requirements.

Tail end SCR Systems

A tail end system positions the SCR downstream of all other air pollution control equipment installed on a unit. A major benefit of this installation location is that many of the flue gas constituents that would be damaging to the catalyst have been removed prior to the SCR reactor inlet. However, the installation location results in flue gas temperatures below the acceptable range for catalytic reduction, and the flue gas consequently must be reheated via natural gas or oil burners or steam coil heaters. Tail end SCR was not found to be technically feasible for a retrofit application in this study. While it is potentially technically feasible, it would require additional detailed evaluations to be performed to confirm feasibility for retrofits.

Implementation Examples of LN™ and ASNCR

The Covanta LN**™** technology was installed at the Montgomery County, Maryland facility in 2009 and has been operational since then. The Montgomery County Resource Recovery Facility in Maryland is currently operating under a NOx RACT requirement which limits NOx emissions to 140 ppmvd @7% O_2 for a 24-hour block average. In 2009 Covanta, under an Agreement with the Northeast Maryland Waste Disposal Authority and the County, completed work on the installation of Covanta's LN™ combustion system upgrade to the SNCR system. Operational data (since the May 1, 2019 NOx RACT effective date) at the facility demonstrate that the units on average are able to achieve a daily average of around 84 ppmvd @7% O_2.

Maryland's NOx RACT also required a NOx 30-day rolling average emission rate of 105 ppmvd @7% O_2 to be met beginning on May 1, 2020. Since that time, the peak 24-hour average recorded has been on the order of 103 ppmvd @7% O_2. The facility is capable, and further demonstrates, meeting a 110 ppmvd 24-hour limit. Information from a Montgomery County Resource Recovery NOx optimization study found that ammonia slip is below 5 ppm for all units with LN™ technology with SNCR and with NOx emissions of 66 ppm and higher.

The Covanta LN**™** is being installed at Covanta Alexandria/Arlington, Virginia and Covanta Fairfax, Virginia. For Covanta Alexandria/Arlington, the permit requires the facility to install the low NOx combustion system on the first unit by the end of the 4th quarter of 2019, the second unit by the end of the 4th quarter of 2020, and the third unit by the end of the 4th quarter of 2021.[13] For Covanta Fairfax, the permit requires the facility to install the low NOx combustion system on the first unit by the end of the 2nd quarter of 2019, the second unit by the end of the 4th quarter of 2019, the third unit by the end of the 4th quarter of 2020, and the fourth unit by the end of the 4th quarter of 2021.[14] Thus, both facilities will be completely utilizing the low NOx technology by the start of 2022.

[13] Permit issued by the Commonwealth of Virginia to operate a municipal solid waste combustor at Alexandria, Virginia, dated February 2019.
[14] Permit issued by the Commonwealth of Virginia to operate a municipal solid waste combustor at Fairfax, Virginia, dated February 2019.

The Virginia Department of Environmental Quality has determined that Covanta's proprietary Low NOx technology is RACT for Covanta MWCs. The Virginia facilities are permitted to emit 110 ppmvd of NOx on a 24-hour average basis @7% O_2, and 90 ppmvd of NOx on an annual average basis @7% O_2.[15] In addition, the limits of 110 ppmvd @7% O_2 on a daily average and 90 ppmvd @7% O_2 on an annual average have been adopted into The Commonwealth of Virginia's SIP as RACT for the 2008 ozone NAAQS for both of these facilities.[16]

Table 2 lists details for facilities that have permitted NOx emission rate limits of 110 ppmvd @7% O_2, 24-hour average. Public information indicates all have been retrofit with the proprietary Covanta Low NOx (LN™) modifications in conjunction with SNCR. The boiler/combustion units are of three different manufacturers and range in rating from 325 tons/hr to 750 tons/hr.

Table 2: List of Facilities with Retrofit NOx Controls Permitted at 110 ppmvd 24-hour Average

Plant Name	State	Combustor Manufacturer	Rating (tons/day)	NOx Control	Permit Short Term NOx Limit*,**	Permit Long Term NOx Limit*,***
Covanta Alexandria/Arlington Energy	VA	Keeler/Dorr-Oliver	325	Covanta LN, SNCR	110	90
Covanta Alexandria/Arlington Energy	VA	Keeler/Dorr-Oliver	325	Covanta LN, SNCR	110	90
Covanta Alexandria/Arlington Energy	VA	Keeler/Dorr-Oliver	325	Covanta LN, SNCR	110	90
Covanta Fairfax Energy	VA	Ogden Martin	750	Covanta LN, SNCR	110	90
Covanta Fairfax Energy	VA	Ogden Martin	750	Covanta LN, SNCR	110	90
Covanta Fairfax Energy	VA	Ogden Martin	750	Covanta LN, SNCR	110	90
Covanta Fairfax Energy	VA	Ogden Martin	750	Covanta LN, SNCR	110	90
Hillsborough County Resource Recovery	FL	Riley w/Martin GMBH Grates	690	Covanta LN, SNCR, FGR	110	90

* ppmvd @7% O_2

** Permit short term limit averaging period is 24 hours.
*** Permit long term limit averaging period is annual.

The information in Table 2 indicates that many of the Covanta run facilities, across a wide range of sizes and manufacturers, can be retrofitted with the proprietary Covanta LN™ technology and achieve

[15] See footnotes 16 and 17 for sources.
[16] Submittal to EPA Region III for a SIP revision by the Commonwealth of Virginia entitled, "Statement of Legal and Factual Basis, Covanta Alexandria/Arlington, Permit No. NRO-RACT 71895," February 2019 and "Statement of Legal and Factual Basis, Covanta Fairfax, Permit No. NRO-RACT 71920," February 2019.

significant NOx reductions. That a number of these units have been retrofitted with the LN™ technology and have been permitted at 110 ppmvd @7% O_2 24-hr average supports a proposed 110 ppmvd 24-hr avg NOx rate limit. Furthermore, data on Covanta Fairfax's website (https://www.covanta.com/where-we-are/our-facilities/fairfax) shows the facility is consistently able to achieve a daily average of around 90 ppmvd @7% O_2 for Units 2 and 4.

A number of additional facilities are retrofitted with LN™ but not permitted to 110 ppmvd. These include:

- The Montgomery County facility described previously.
- The Covanta Essex facility in New Jersey has achieved values around 100 ppmvd @7% O_2.[17] This is based on recent stack test data.
- There is limited information available that technology similar to LN™ has been installed on a Covanta operated MWC in the mid-west that is said to be operating at 90 ppmvd @7% O_2 annual average (similar to the annual limits for the units that are now permitted at 110 ppmvd 24-hr). However, the publicly available information indicates that the unit is operating at the low NOx level by contract, not by permit limit.

A North American Waste to Energy paper discussing the retrofit potential of Covanta's proprietary VLN and LN technologies on an existing Covanta operated MWC found that a 100 ppmvd 24-hour limit is feasible. The paper provided an overview of a MWC development and demonstration project and provided NOx and ammonia (NH_3) slip data. The paper discussed the extended operating experience that has been established on the system.

ASNCR technology is being installed at a Baltimore City, MD facility. The schedule for implementing the technology is as follows: permits must be in place by the end of 2021 for the three units, followed by construction in 2022, and the facilities must be on-line in 2023.

Potential NOx Reductions Resulting from Installing Additional Control Technologies

Using the methods described in previous sections, the MWC workgroup estimated that approximately 7,200 tons of NOx could be reduced in the OTR with a 105 ppmvd 30-day average NOx requirement for MWCs. The results are summarized in Table 3. The workgroup also evaluated a 130 ppmvd 30-day average NOx requirement. Not shown in the table, a 130 ppmvd 30-day average limit was estimated to reduce NOx by 3,600 tons per year.

Table 3: Summary of Potential NOx Reductions from MWCs in the OTR

Type of unit	2023 Projected NOx Emissions (tons/yr)	Potential 2023 NOx Reduction (tons/yr) Assuming 105 ppmvd	Percent Reduction from 2023 Projected NOx Emissions
Large MWC	22,992	7,290	32%
Small MWC	1,006	Not estimated	Not estimated
Total	23,998	7,290	30%

[17] Letter from the State of New Jersey to Michael Klein, dated March 14, 2019 in reference to Covanta Energy Group, Inc. Essex County Resource Recovery Facility – Newark Annual Stack Test Program.

An OTR-wide estimate of potential tons of NOx reduced assuming a 24-hour NOx limit of 110 ppmvd was not estimated in this study, however, tons of NOx reduced on an annual basis would be in the range of the reductions shown in column three of Table 3.

Control Costs

As discussed in the Method section, the MWC workgroup researched studies to identify costs associated with the installation and operation of additional NOx control technologies on MWCs in the region. Three studies were found with detailed cost information for MWCs that are similar in configuration to a significant number of large MWCs in the region. The results of cost analyses from these studies are provided in this section.

Results from the Trinity Consultants analysis of installation of a proprietary Covanta Low NOx technology and SCR at Covanta facilities are shown in Table 4. SCR was estimated to be very costly ($31,000 per ton of NOx reduced), therefore the results for that technology are not presented here. The left column lists types of costs (such as capital or operating costs) and NOx emissions information for the Alexandria/Arlington VA facility. The middle column provides emission information for the baseline technology (SNCR). No costs are provided in this column since SNCR is already in operation at the facility. The right column provides costs associated with installing the Low NOx technology to the MWC and the resulting NOx emissions changes.

Table 4: Cost of Installing Low NOx Technology on an MWC with SNCR (Alexandria/Arlington, VA)

	SNCR (Base)	Low NOx
Capital Costs ($)	-	$1,018,705
Annual Operating Costs ($)	-	$213,773
Annualized Capital Costs ($)	-	$116,533
Projected Lifetime (yr)	-	20
Interest Rates (%)	-	7%
Total Yearly Costs ($)	-	$330,306
Base Case NOx (ppmvd)*	180	180
Controlled NOx (ppmvd)	180	90
Estimated NOx Reduction (%)	0	50
NOx Emission (ton/yr)	165	82.5
Emission Reduction (ton/yr)	0	82.5
Cost Effectiveness ($/ton)	**$0.00**	**$4,004**

*This is an "equivalent" NOx emissions rate, rather than a permit level.

The analysis shows that equipping the Covanta unit with Low NOx technology resulted in a 50 percent NOx reduction at a cost of approximately $4,000 per ton of NOx reduced.

The row labeled "Base Case NOx (ppmvd)" shows the permit limit before installation of Covanta's Low NOx Technology and the "Controlled NOx (ppmvd)" is the new annual permit limit after installation of the Low NOx technology. The table shows that NOx emissions were reduced from 180 ppmvd to 90 ppmvd with the installation of the Low NOx technology.[18] The row labeled "NOx Emission (ton/yr)" shows NOx emissions before and after installation of Covanta's Low NOx technology. The NOx emission

[18] Unless stated otherwise, all concentrations listed in this report assume 7% O_2.

reduction in tons per year is calculated to be 82.5 tons per year as shown in the next row. The "Cost Effectiveness" value assumes that SNCR was already installed at the facility and thus assigns zero additional cost to the facility.

The total capital investment or "Capital Costs" includes direct and indirect costs. Direct costs are purchased equipment costs and indirect costs are costs associated with installation of equipment and lost revenue due to extended downtime for installation.

The study also estimated direct and indirect costs for annualized expenditures. Direct costs in this category include increased capital expenditures due to the Low NOx technology and increased annual expenses from operating the equipment. Indirect operating costs are annualized capital costs such as administrative charges plus capital recovery (loan interest). Note that control costs are facility-specific, so any costs specified here are examples only.

Table 5 shows a similar analysis for the Covanta Fairfax, Virginia facility. In the Trinity Consultants analysis for the Fairfax facility, capital costs ($1,564,242) were approximately 50 percent higher than for the Alexandria/Arlington facility. Operating costs ($493,322) were 130 percent higher than those for the Alexandria/Arlington facility. The cost effectiveness ($/ton of NOx reduced) for Fairfax was lower than in the Alexandria/Arlington MWC at $2,888 per ton of NOx reduced. This is because the NOx emissions from the Fairfax MWC are considerably higher than in the example shown in Table 4. While both facilities realized a 50 percent reduction in NOx emissions from the installation of Low NOx technology, the MWC in Fairfax had a 230 ton annual NOx reduction while the Alexandria/Arlington facility realized an 83 ton NOx reduction annually for a capital cost that was 50 percent lower.

Table 5: Cost of Installing Low NOx Technology on an MWC with SNCR (Fairfax, VA)

	SNCR (Base)	**Low NOx**
Capital Costs ($)	-	$1,564,242
Annual Operating Costs ($)	-	$493,322
Annualized Capital Costs ($)	-	$178,938
Projected Lifetime (yr)	-	20
Interest Rates (%)	-	7%
Total Yearly Costs ($)	-	$672,260
Base Case NOx (ppmvd)	180	180
Controlled NOx (ppmvd)	180	90*
Estimated NOx Reduction Factor	0	0.5
Estimated NOx Reduction (%)	0	50
NOx Emission (ton/yr)	465.6	465.6
Projected Controlled NOx Emissions (ton/yr)	465.6	232.8
Emission Reduction (ton/yr)	0	232.8
Cost Effectiveness ($/ton)	**$0.00**	**$2,888**

*Annual average.

Cost Estimate for a 24-Hour NOx Limit of 110 ppmvd using LN™

In this section, the workgroup's estimate of capital and operating costs for using LN technology to achieve a 24-hour NOx limit of 110 ppmvd is presented. Tables 6 and 7 show estimates for the cost of installing and operating LN™ at Covanta facilities. In the far-right columns in the tables, labeled "Low

NOx Trinity Consultants Study," costs and cost effectiveness numbers are taken from the Trinity Consulting study of the Alexandria/Arlington and Fairfax, VA Covanta facilities. The analysis evaluated an annual limit of 90 ppmvd for the facilities. The third column labeled "Low NOx Workgroup" provides an estimate developed by the MWC workgroup of dollars per ton of NOx reduced assuming a 24-hour limit using the costs from the Trinity study.

Table 6: Cost of Installing Low NOx Technology on an MWC with SNCR (Alexandria/Arlington, VA)

	SNCR (Base)[1]	**Low NOx – Workgroup**[2]	**Low NOx**[3]
Capital Costs ($)[3]	-	$1,018,705	$1,018,705
Cost Reduction for Assuming 110 ppmvd ($)[4]		$32,627	
Annual Operating Costs ($)	-	$181,146	$213,773[3]
Annualized Capital Costs ($)[3]	-	$116,533	$116,533
Projected Lifetime (yr)	-	20	20
Interest Rates (%)	-	7%	7%
Total Yearly Costs ($)	-	$297,679	$330,306
Base Case NOx (ppmvd)[5]	180	180	180
Controlled NOx (ppmvd)[6]	180	110	90
Estimated NOx Reduction Factor	0.0	0.389	0.5
Estimated NOx Reduction (%)	0	38.89	50
NOx Emission (ton/yr)[5]	165	165	165
Projected Controlled NOx Emissions (tons/yr)	165	100.83	82.5
Emission Reduction (ton/yr)	0	64.17	82.5
Cost Effectiveness ($/ton)[7]	**$0.00**	**$4,639**	**$4,004**

[1] SNCR was already installed at both facilities; assume $0 additional cost to facilities.
[2] The Workgroup's recommendation and cost estimate.
[3] Based on Covanta's "Reasonably Available Control Technology Determination for NOx" for Covanta Alexandria/Arlington, VA.
[4] Savings based on $0.89 per pound of NOx reduced (from Babcock report for Wheelabrator Baltimore).
[5] NOx emissions before installation of Covanta's Low NOx Technology.
[6] New annual permit limit (@7% O_2).
[7] The Commonwealth of VA has determined that Low NOx Technology is RACT for the Alexandria and Arlington facilities.

The O&M costs from the Trinity study assume use of reagent and other substances required to meet the 90 ppmvd annual average limit, as well as maintenance costs. Using these costs to calculate cost effectiveness values ($/ton) for an assumed 110 ppmvd NOx 24-hour average limit could result in higher costs than would be incurred in actual use for the 110 ppmvd limit. This is because reagent and other substances required to meet the 90 ppmvd limit may be higher than that of O&M costs to achieve the 110 ppmvd 24-hour limit. Thus, using the method previously described, the workgroup adjusted the O&M costs and this is reflected in the "Annual Operating Costs" row in Tables 6 and 7.

The workgroup's estimate of a 110 ppmvd 24-hour NOx limit cost effectiveness is $4,639 per ton of NOx reduced. This is approximately $600 per ton higher than the 90 ppmvd annual NOx limit in the Trinity study. The difference in cost effectiveness (in $/ton of NOx removed) is primarily due to a lower estimated number of tons of NOx removed with the recommended NOx emission rate limit while assuming similar capital expenses associated with both rate limits. Note however that the estimated annual O&M expenses would be somewhat lower for the recommended 110 ppmvd limit primarily due to a reduction in reagent consumption.

Table 7 provides a similar calculation using the Fairfax, VA Covanta cost evaluation from the Trinity study.

Table 7: Cost of Installing Low NOx Technology on an MWC with SNCR (Fairfax, VA)

	SNCR (Base)[1]	**Low NOx – Workgroup[2]**	**Low NOx[3]**
Capital Costs ($)[3]	-	$1,564,242	$1,564,242
Cost Reduction for Assuming 110 ppmvd ($)[4]		$92,079	
Annual Operating Costs ($)	-	$401,243	$493,322[3]
Annualized Capital Costs ($)[3]	-	$178,938	$178,938
Projected Lifetime (yr)	-	20	20
Interest Rates (%)	-	7%	7%
Total Yearly Costs ($)	-	$580,181	$672,260
Base Case NOx (ppmvd)[5]	180	180	180
Controlled NOx (ppmvd)[6]	180	110	90
Estimated NOx Reduction Factor	0.0	0.389	0.5
Estimated NOx Reduction (%)	0	38.89	50
NOx Emission (ton/yr)[5]	465.6	465.6	465.6
Projected Controlled NOx Emissions (tons/yr)	465.6	284.53	232.8
Emission Reduction (ton/yr)	0	181.07	232.8
Cost Effectiveness ($/ton)[7]	**$0.00**	**$3,204**	**$2,888**

[1] SNCR was already installed at both facilities; assume $0 additional cost to facilities.
[2] The Workgroup's recommendation and cost estimate.
[3] Based on Covanta's "Reasonably Available Control Technology Determination for NOx" for Covanta Alexandria/Arlington, VA.
[4] Savings based on $0.89 per pound of NOx reduced (from Babcock report for Wheelabrator Baltimore).
[5] NOx emissions before installation of Covanta's Low NOx Technology.
[6] New annual permit limit (@7% O_2).
[7] The Commonwealth of VA has determined that Low NOx Technology is RACT for the Alexandria and Arlington facilities.

The cost per ton of NOx reduced in the 110 ppmvd 24-hour limit case (third column) is $3,204. The method used to develop this estimate is the same as used in Table 6 for the Covanta Alexandria/Arlington facility.

As mentioned previously, the Babcock Power Environmental study for Wheelabrator evaluated four technologies: optimized SNCR, ASNCR, FGR-SNCR, and FGR-ASNCR. The baseline technology in this Wheelabrator facility was SNCR. Costs for converting this Wheelabrator facility to the different technology configurations are provided in Table 8.

The capital costs shown in Table 8 were taken from the Babcock study for the Wheelabrator Baltimore facility. "Annualized Capital Costs" are based on a formula from the EPA document: Chapter 2 - Cost Estimation: Concepts and Methodology. "Interest Rates" and "Projected Lifetime" are based on

Covanta's NOx RACT Analysis in Virginia for Covanta Fairfax and Covanta Alexandria/Arlington. "Current NOx Emissions" are based on 2023 estimates for NOx emissions from Wheelabrator Baltimore.

Table 8: Costs for Converting a Wheelabrator MWC with SNCR to Lower NOx Technology Configurations

	Optimized SNCR	**ASNCR**	**FGR-SNCR**	**FGR-ASNCR**
Capital Costs ($)[1]	$85,200	$8,665,162	$5,829,591	$12,993,524
Annual Operating Costs ($)	$695,000	$995,000	$815,000	$1,035,000
Annualized Capital Costs ($)	$8,042	$817,930	$550,272	$1,226,497
Projected Lifetime (yr)	20	20	20	20
Interest Rates (%)	7%	7%	7%	7%
Total Yearly Costs ($)	$703,042	$1,812,9300	$1,365,272	$2,261,497
Base Case NOx (ppmvd)	150	150	150	150
Controlled NOx (ppmvd)	135	110	120	105
Estimated NOx Reduction Factor	0.100	0.267	0.20	0.30
Estimated NOx Reduction (%)	10.000	26.7	20	30
Current NOx Emission (tons/yr)	1,104	1,104	1,104	1,104
Projected Controlled NOx Emissions (tons/yr)	993.38	809.42	883.01	772.63
Emission Reduction (tons/yr)	110.38	294.34	220.75	331.13
Cost Effectiveness ($/ton)	**$6,370**	**$6,159**	**$6,185**	**$6,830**

In Table 8, the "Base Case NOx" 24-hour permit limit is 150 ppmvd and the "Controlled NOx" limits for technologies are based on 24-hour block averages from Babcock Power Environmental study for Wheelabrator Baltimore.

Cost Summary

Cost evaluated for additional NOx controls ranged from $2,888 to $6,159 per ton of NOx reduced, depending on the technology and averaging period considered. While the costs presented in this section may be generally representative of the costs of upgrading other MWCs in the region with additional technology, further analysis would be required to determine an estimate for specific units. Nonetheless, the workgroup believes the costs reported in this section represent a reasonable estimate for further reducing NOx emissions from MWCs in the OTR.

Non-OTR MWCs

Available public data indicate there are 63 MWC EGU units in non-OTR contiguous states. Most of these 63 non-OTR MWCs would be categorized as large MWCs. The majority of these MWC EGUs are located in Florida (33 units), and the state with the next highest number of MWCs is Minnesota (nine units). Of the 63 non-OTR MWC EGUs, 12 are located in states linked to OTR state air quality. Permit NOx emission rate limits for these non-OTR MWCs (including those in linked states) are predominately within the range of the existing limits for OTR MWCs. While the non-OTR states were not contacted to obtain additional information from regulatory personnel most familiar with the non-OTR MWC, the publicly available information appeared to indicate that the range of configuration and operating characteristics of these non-OTR MWCs were not dissimilar from the range of OTR MWCs. This suggests that these non-OTR MWCs would have emission reduction potentials, on an average MWC unit basis, similar to those estimated for the OTR MWC units. Because of the apparent low impact potential of the non-OTR MWCs due to number and geographic location, the workgroup did not quantify the emission reduction potential associated with the non-OTR MWCs. However, the fact that NOx emission reductions appear to be technically and economically feasible from this class of sources in upwind states should not be forgotten if more detailed analysis of upwind source impact is undertaken. See Additional Research (below) for recommendations on additional actions.

Policy Implications

This pilot study of MWCs in the OTR finds a NOx limit of 105 ppmvd (30-day average) could be achieved with the technologies described in this report in a cost-effective manner. In addition, the pilot concludes almost all large MWC facilities can be held to a 110 ppmvd @7% O_2 24-hour NOx limit. Thus, states that are updating RACT or NOx permit limits for MWCs in the OTR should consider increasing the stringency of those emissions limits. At the federal level, the workgroup recommends SAS initiate a conversation with EPA on the introduction of similar requirements nationwide.

Additional Research

The Workgroup identified several areas for potential additional research. These are as follows:

- Conduct further research to determine whether any controls can be used on small MWCs. Since the workgroup had limited time to conduct its analysis, the group prioritized large MWCs. Some additional research could yield recommendations for these small units.
- Evaluate how peak day emissions could be reduced with either a 30-day averaging limit or a 24-hour limit.
- Conduct additional work to evaluate emissions from non-OTR MWCs.
- Initiate a dialogue with EPA on establishing nationwide MWC standards similar to the ones recommended in this pilot and to the extent possible conduct additional research to support this goal.

Conclusions

MWCs in the OTR are a significant source of NOx emissions: in 2018, MWCs in the region emitted over 22,000 tons of NOx. Significant annual NOx reductions could be achieved from MWCs in the OTR using several different technologies as described in this report. The MWC workgroup concludes that a control level of 105 ppmvd on a 30-day average basis and a 110 ppmvd on a 24-hour averaging period are likely achievable for most large MWCs in the region. This conclusion is based on a review of engineering studies of similar MWCs in the OTR. Based on a projected 2023 NOx inventory for the large MWCs in the region of approximately 23,000 tons, NOx emissions from MWCs could be reduced by approximately 7,300 tons annually with additional controls achieving a 105 ppmvd level on a 30-day average. Approximately 4,000 tons of NOx could be reduced with a permit limit of 130 ppmvd on a 30-day average. Studies evaluating MWCs similar in design to the large MWCs in the OTR found NOx reductions could be achieved at a cost ranging from $2,900 to $6,600 per ton of NOx reduced.

Appendix A: OTR Large MWC Actual and Proposed Emissions

Facility Name	State	Projected 2023 NOx Emissions (tons/yr)	Permit NOx Limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Covanta Bristol Energy	CT	97	120	130 ppmvd is higher than permit	0	0	-12	97	84
Covanta Bristol Energy	CT	113	150	-13%	-15	-30%	-34	98	79
Covanta Southeastern Connecticut Company	CT	167	150	-13%	-22	-30%	-50	144	117
Covanta Southeastern Connecticut Company	CT	171	150	-13%	-23	-30%	-51	148	120
MIRA	CT	260	146	-11%	-28	-28%	-73	231	187
MIRA	CT	134	146	-11%	-15	-28%	-38	119	96
MIRA	CT	276	146	-11%	-30	-28%	-78	246	199
Wheelabrator Bridgeport	CT	301	150	-13%	-40	-30%	-90	261	211
Wheelabrator Bridgeport	CT	305	150	-13%	-41	-30%	-91	264	213
Wheelabrator Bridgeport	CT	310	150	-13%	-41	-30%	-93	269	217
Wheelabrator Lisbon	CT	117	150	-13%	-16	-30%	-35	101	82
Wheelabrator Lisbon	CT	126	150	-13%	-17	-30%	-38	109	88
Covanta Haverhill	MA	553	150	-13%	-74	-30%	-166	479	387
Covanta Haverhill	MA	586	150	-13%	-78	-30%	-176	508	410
SEMASS Resource Recovery	MA	426	146	-11%	-47	-28%	-120	379	306

Facility Name	State	Projected 2023 NOx Emissions (tons/yr)	Permit NOx Limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
SEMASS Resource Recovery	MA	486	146	-11%	-53	-28%	-136	432	349
SEMASS Resource Recovery	MA	498	146	-11%	-55	-28%	-140	443	358
Wheelabrator Millbury Facility	MA	500	150	-13%	-67	-30%	-150	433	350
Wheelabrator Millbury Facility	MA	472	150	-13%	-63	-30%	-142	409	331
Wheelabrator North Andover	MA	417	150	-13%	-56	-30%	-125	361	292
Wheelabrator North Andover	MA	447	150	-13%	-60	-30%	-134	387	313
Wheelabrator Saugus	MA	405	150	--	--	--	--	405	405
Wheelabrator Saugus	MA	388	150	--	--	--	--	388	388
Montgomery County Resource Recovery	MD	147	140	-7%		-25%	-37	147	110
Montgomery County Resource Recovery	MD	147	140	-7%		-25%	-37	147	110
Montgomery County Resource Recovery	MD	147	140	-7%		-25%	-37	147	110
Wheelabrator Baltimore Refuse	MD	367	150	-13%		-30%	-110	367	257
Wheelabrator Baltimore Refuse	MD	367	150	-13%		-30%	-110	367	257
Wheelabrator Baltimore Refuse	MD	367	150	-13%		-30%	-110	367	257

Facility Name	State	Projected 2023 NOx emissions (ton/yr)	Permit NOx limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Penobscot Energy Recovery	ME	69.12	230	-43%	-30	-54%	-38	39	32
Penobscot Energy Recovery	ME	103.32	230	-43%	-45	-54%	-56	58	47
Ecomaine	ME	231.9	180	-28%	-64	-42%	-97	167	135
Ecomaine	ME	250.35	180	-28%	-70	-42%	-104	181	146
Wheelabrator Concord Facility	NH	218.09	205	-37%	-80	-49%	-106	138	112
Wheelabrator Concord Facility	NH	205.45	205	-37%	-75	-49%	-100	130	105
Camden Resource Recovery Facility	NJ	84.75	150	-13%	-11	-30%	-25	73	59
Camden Resource Recovery Facility	NJ	110.62	150	-13%	-15	-30%	-33	96	77
Camden Resource Recovery Facility	NJ	112.13	150	-13%	-15	-30%	-34	97	78
Covanta Essex Company	NJ	226.26	150	-13%	-30	-30%	-68	196	158
Covanta Essex Company	NJ	260.01	150	-13%	-35	-30%	-78	225	182
Covanta Essex Company	NJ	300.78	150	-13%	-40	-30%	-90	261	211
Union County Resource Recovery	NJ	204.55	150	-13%	-27	-30%	-61	177	143

Facility Name	State	Projected 2023 NOx emissions (ton/yr)	Permit NOx limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Union County Resource Recovery	NJ	209.09	150	-13%	-28	-30%	-63	181	146
Union County Resource Recovery	NJ	216.8	150	-13%	-29	-30%	-65	188	152
Wheelabrator Gloucester LP	NJ	137.78	150	-13%	-18	-30%	-41	119	96
Wheelabrator Gloucester LP	NJ	126.77	150	-13%	-17	-30%	-38	110	89
Covanta Babylon Inc	NY	110.79	150	-13%	-15	-30%	-33	96	78
Covanta Babylon Inc	NY	111.78	150	-13%	-15	-30%	-34	97	78
Covanta Hempstead	NY	357.31	145.7 (lb/hr)	-29.7%	-106	43%	-155	357	203
Covanta Hempstead	NY	380.28	145.7 (lb/hr)	29.7%	-113	43%	-164	251	216
Covanta Hempstead	NY	465.8	145.7 (lb/hr)	29.7%	-138	43%	-201	267	264
Covanta Niagara I, LLC	NY	341.73	150	-13%	-46	-30%	-103	327	239
Covanta Niagara I, LLC	NY	378.41	150	-13%	-50	-30%	-114	328	265
Huntington Resource Recovery	NY	443 for all 3 units	185	185	-30%	-35	-43%	-50	82
Huntington Resource Recovery	NY	443 for all 3 units	185	185	-30%	-35	-43%	-50	82

Facility Name	State	Projected 2023 NOx emissions (ton/yr)	Permit NOx limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Huntington Resource Recovery	NY	443 for all 3 units	185	-30%	-35	-43%	-50	82	66
Onondaga County Resource Recovery	NY	684.18	200	-35%	-239	-48%	-325	445	359
Onondaga County Resource Recovery	NY		200	-35%	0	-48%	0		0
Onondaga County Resource Recovery	NY		200	-35%	0	-48%	0		0
Wheelabrator Hudson Falls	NY	145.81	205	-37%	-53	-49%	-71	92	75
Wheelabrator Hudson Falls	NY	153	205	-37%	-56	-49%	-75	97	78
Wheelabrator Westchester	NY	411.93	184	-29%	-121	-43%	-177	291	235
Wheelabrator Westchester	NY	417.23	184	-29%	-122	-43%	-179	295	238
Wheelabrator Westchester	NY	459.57	184	-29%	-135	-43%	-197	325	262
Covanta Delaware Valley	PA	228.29	180	-28%	-63	-42%	-95	165	133
Covanta Delaware Valley	PA	240.23	180	-28%	-67	-42%	-100	173	140
Covanta Delaware Valley	PA	247.59	180	-28%	-69	-42%	-103	179	144
Covanta Delaware Valley	PA	253.87	180	-28%	-71	-42%	-106	183	148

Facility Name	State	Projected 2023 NOx emissions (ton/yr)	Permit NOx limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Covanta Delaware Valley	PA	274.62	180	-28%	-76	-42%	-114	198	160
Covanta Delaware Valley	PA	275.95	180	-28%	-77	-42%	-115	199	161
Covanta Plymouth Renewable Energy	PA	440.65	180	-28%	-122	-42%	-184	318	257
Covanta Plymouth Renewable Energy	PA	445.72	180	-28%	-124	-42%	-186	322	260
Harrisburg Facility	PA	83.74	135	-4%	-3	-22%	-19	81	65
Harrisburg Facility	PA	84.22	135	-4%	-3	-22%	-19	81	66
Harrisburg Facility	PA	84.58	135	-4%	-3	-22%	-19	81	66
Lancaster County Resource Recovery	PA	231.02	180	-28%	-64	-42%	-96	167	135
Lancaster County Resource Recovery	PA	232.04	180	-28%	-64	-42%	-97	168	135
Lancaster County Resource Recovery	PA	233.49	180	-28%	-65	-42%	-97	169	136
Wheelabrator Falls	PA	430.12	150	-13%	-57	-30%	-129	373	301
Wheelabrator Falls	PA	451.76	150	-13%	-60	-30%	-136	392	316
York County Resource Recovery	PA	187.75	135	-4%	-7	-22%	-42	181	146
York County Resource Recovery	PA	206.45	135	-4%	-8	-22%	-46	199	161
York County Resource Recovery	PA	207.17	135	-4%	-8	-22%	-46	199	161

Facility Name	State	Projected 2023 NOx emissions (ton/yr)	Permit NOx limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Covanta Alexandria/Arlington Energy	VA	75	110	130 ppmvd is higher than permit		-5%	-3	75	72
Covanta Alexandria/Arlington Energy	VA	77	110	130 ppmvd is higher than permit		-5%	-4	77	74
Covanta Alexandria/Arlington Energy	VA	75	110	130 ppmvd is higher than permit		-5%	-3	75	72
Covanta Fairfax Energy	VA	250	110	130 ppmvd is higher than permit		-5%	-11	250	239
Covanta Fairfax Energy	VA	250	110	130 ppmvd is higher than permit		-5%	-11	250	239

Facility Name	State	Projected 2023 NOx emissions (ton/yr)	Permit NOx limit (ppmvd)*	130 ppmvd control level estimated NOx reduction (%)	130 ppmvd control level estimated NOx reduction (ton/yr)	105 ppmvd estimated control level NOx reduction (%)	105 ppmvd control level NOx estimated reduction (ton/yr)	2023 projected NOx (ton/yr) at 130 ppmvd	2023 projected NOx (ton/yr) at 105 ppmvd
Covanta Fairfax Energy	VA	250	110	130 ppmvd is higher than permit		-5%	-11	250	239
Covanta Fairfax Energy	VA	250	110	130 ppmvd is higher than permit		-5%	-11	250	239
Total		**22,992**			**(3,971)**		**(7,290)**	**19,021**	**15,702**

* The majority of these limits reflect 7% O_2.

Appendix B: OTR Large MWC Characteristics

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Covanta Bristol Energy	CT	Hartford	Zurn	0.332	Mass burn waterwall	358	SNCR
Covanta Bristol Energy	CT	Hartford	Zurn	0.414	Mass burn waterwall	358	SNCR
Covanta Southeastern Connecticut Company	CT	New London	Deutsche Babcock Anlagen	0.444	Mass burn waterwall	344.5	SNCR
Covanta Southeastern Connecticut Company	CT	New London	Deutsche Babcock Anlagen	0.444	Mass burn waterwall	344.5	SNCR
CT Resource Rec Authority Facility	CT	Hartford	CE	0.981	Refuse-derived fuel combustor	675.6 RDF; 236.4 coal	SNCR
CT Resource Rec Authority Facility	CT	Hartford	CE	0.981	Refuse-derived fuel combustor	675.6 RDF; 236.4 coal	SNCR
CT Resource Rec Authority Facility	CT	Hartford	CE	0.981	Refuse-derived fuel combustor	675.6 RDF; 236.4 coal	SNCR
Wheelabrator Bridgeport	CT	Fairfield	B&W	1.005	Mass burn waterwall	750	SNCR
Wheelabrator Bridgeport	CT	Fairfield	B&W	1.005	Mass burn waterwall	750	SNCR
Wheelabrator Bridgeport	CT	Fairfield	B&W	1.005	Mass burn waterwall	750	SNCR
Wheelabrator Lisbon	CT	New London	B&W	0.377	Mass burn waterwall	281.4	SNCR
Wheelabrator Lisbon	CT	New London	B&W	0.377	Mass burn waterwall	281.4	SNCR

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Covanta Haverhill	MA	Essex	Ogden Martin	1.180	Mass burn waterwall	825	SNCR
Covanta Haverhill	MA	Essex	Ogden Martin	1.180	Mass burn waterwall	825	SNCR
SEMASS Resource Recovery	MA	Plymouth	Riley Stoker	1.190	Refuse-derived fuel combustor	995	
SEMASS Resource Recovery	MA	Plymouth	Riley Stoker	1.190	Refuse-derived fuel combustor	995	
SEMASS Resource Recovery	MA	Plymouth	Riley Stoker	1.129	Refuse-derived fuel combustor	995	SNCR
Wheelabrator Millbury Facility	MA	Worcester	B&W	0.999	Mass burn waterwall	864	SNCR
Wheelabrator Millbury Facility	MA	Worcester	B&W	0.999	Mass burn waterwall	864	SNCR
Wheelabrator North Andover	MA	Essex	Riley Stoker	0.892	Mass burn waterwall	750	SNCR
Wheelabrator North Andover	MA	Essex	Riley Stoker	0.892	Mass burn waterwall	750	SNCR
Wheelabrator Saugus	MA	Essex	Von Roll	1.005	Mass burn waterwall	750	SNCR
Wheelabrator Saugus	MA	Essex	Von Roll	1.005	Mass burn waterwall	750	SNCR
Montgomery County Resource Recovery	MD	Montgomery	Martin	0.794	Mass burn waterwall	600	LoNOx Mod & SNCR
Montgomery County Resource Recovery	MD	Montgomery	Martin	0.794	Mass burn waterwall	600	LoNOx Mod & SNCR
Montgomery County Resource Recovery	MD	Montgomery	Martin	0.794	Mass burn waterwall	600	LoNOx Mod & SNCR
Wheelabrator Baltimore Refuse	MD	Baltimore City	Wheelabrator Frye	1.005	Mass burn waterwall	750	SNCR - Optimized
Wheelabrator Baltimore Refuse	MD	Baltimore City	Wheelabrator Frye	1.005	Mass burn waterwall	750	SNCR - Optimized

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Wheelabrator Baltimore Refuse	MD	Baltimore City	Wheelabrator Frye	1.005	Mass burn waterwall	750	SNCR - Optimized
Penobscot Energy Recovery	ME	Penobscot		0.854	Refuse-derived fuel combustor	360.5	
Penobscot Energy Recovery	ME	Penobscot		0.854	Refuse-derived fuel combustor	360.5	
Comaine	ME	Cumberland	Steinmüller	0.453	Mass burn waterwall	275	SNCR
Regional Waste Systems	ME	Cumberland	Steinmüller	0.453	Mass burn waterwall	275	SNCR
Wheelabrator Concord Facility	NH	Merrimack	B&W	0.456	Mass burn waterwall	287.5	SNCR
Wheelabrator Concord Facility	NH	Merrimack	B&W	0.456	Mass burn waterwall	287.5	SNCR
Camden Resource Recovery Facility	NJ	Camden		0.478	Mass burn waterwall	350	SNCR
Camden Resource Recovery Facility	NJ	Camden		0.478	Mass burn waterwall	350	SNCR
Camden Resource Recovery Facility	NJ	Camden		0.478	Mass burn waterwall	350	SNCR
Covanta Essex Company	NJ	Essex	Foster Wheeler	1.308	Mass burn waterwall	933	SNCR and Low NOx
Covanta Essex Company	NJ	Essex	Foster Wheeler	1.308	Mass burn waterwall	933	SNCR and Low NOx
Covanta Essex Company	NJ	Essex	Foster Wheeler	1.308	Mass burn waterwall	933	SNCR and Low NOx
Union County Resource Recovery	NJ	Union		0.667	Mass burn waterwall	480	SNCR and Low NOx
Union County Resource Recovery	NJ	Union		0.667	Mass burn waterwall	480	SNCR and Low NOx

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Union County Resource Recovery	NJ	Union		0.667	Mass burn waterwall	480	SNCR and Low NOx
Wheelabrator Gloucester LP	NJ	Gloucester		0.334	Mass burn waterwall	287.5	SNCR
Wheelabrator Gloucester LP	NJ	Gloucester		0.334	Mass burn waterwall	287.5	SNCR
Covanta Babylon Inc	NY	Suffolk		0.453	Mass burn waterwall	375	SNCR
Covanta Babylon Inc	NY	Suffolk		0.453	Mass burn waterwall	375	SNCR
Covanta Hempstead	NY	Nassau	Deutsche Babcock Anlagen	1.748	Mass burn waterwall	890	SNCR
Covanta Hempstead	NY	Nassau	Deutsche Babcock Anlagen	1.748	Mass burn waterwall	890	SNCR
Covanta Hempstead	NY	Nassau	Deutsche Babcock Anlagen	1.748	Mass burn waterwall	890	SNCR
Covanta Niagara I, LLC	NY	Niagara	Deutsche Babcock Anlagen	1.683	Mass burn waterwall	1125	SNCR
Covanta Niagara I, LLC	NY	Niagara	Deutsche Babcock Anlagen	1.683	Mass burn waterwall	1125	SNCR
Huntington Resource Recovery	NY	Suffolk			Mass burn waterwall	250	SNCR
Huntington Resource Recovery	NY	Suffolk			Mass burn waterwall	250	SNCR
Huntington Resource Recovery	NY	Suffolk			Mass burn waterwall	250	SNCR

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Onondaga County Resource Recovery	NY	Onondaga		0.680	Mass burn waterwall	330	SNCR
Onondaga County Resource Recovery	NY	Onondaga		0.680	Mass burn waterwall	330	SNCR
Onondaga County Resource Recovery	NY	Onondaga		0.680	Mass burn waterwall	330	SNCR
Wheelabrator Hudson Falls	NY	Washington			Mass burn waterwall	275	
Wheelabrator Hudson Falls	NY	Washington			Mass burn waterwall	275	
Wheelabrator Westchester	NY	Westchester		1.233	Mass burn waterwall	750	SNCR
Wheelabrator Westchester	NY	Westchester		1.233	Mass burn waterwall	750	SNCR
Wheelabrator Westchester	NY	Westchester		1.233	Mass burn waterwall	750	SNCR
Covanta Delaware Valley	PA	Delaware		0.665	Mass burn rotary waterwall		
Covanta Delaware Valley	PA	Delaware		0.665	Mass burn rotary waterwall		
Covanta Delaware Valley	PA	Delaware		0.665	Mass burn rotary waterwall		
Covanta Delaware Valley	PA	Delaware		0.665	Mass burn rotary waterwall		
Covanta Delaware Valley	PA	Delaware		0.665	Mass burn rotary waterwall		
Covanta Delaware Valley	PA	Delaware		0.665	Mass burn rotary waterwall		
Covanta Plymouth Renewable Energy	PA	Montgomery		0.965	Mass burn waterwall	608	

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Covanta Plymouth Renewable Energy	PA	Montgomery		0.965	Mass burn waterwall	608	
Harrisburg Facility	PA	Dauphin		0.322	Mass burn waterwall	266	SNCR
Harrisburg Facility	PA	Dauphin		0.322	Mass burn waterwall	266	SNCR
Harrisburg Facility	PA	Dauphin		0.322	Mass burn waterwall	266	SNCR
Lancaster County Resource Recovery	PA	Lancaster		0.619	Mass burn waterwall	400	
Lancaster County Resource Recovery	PA	Lancaster		0.619	Mass burn waterwall	400	
Lancaster County Resource Recovery	PA	Lancaster		0.619	Mass burn waterwall	400	
Wheelabrator Falls	PA	Bucks		1.005	Mass burn waterwall	800	SNCR
Wheelabrator Falls	PA	Bucks		1.005	Mass burn waterwall	800	SNCR
York County Resource Recovery	PA	York	Deltak Blr w/O'Connor Rot Comb	0.468	Mass burn waterwall	449	
York County Resource Recovery	PA	York	Deltak Blr w/O'Connor Rot Comb	0.468	Mass burn waterwall	449	
York County Resource Recovery	PA	York	Deltak Blr w/O'Connor Rot Comb	0.468	Mass burn waterwall	449	
Covanta Alexandria/Arlington Energy	VA	Alexandria City	Keeler/Dorr-Oliver	0.276	Mass burn waterwall	325	
Covanta Alexandria/Arlington Energy	VA	Alexandria City	Keeler/Dorr-Oliver	0.276	Mass burn waterwall	325	

Plant Name	State	County	Manufacturer	Est Daily PTE (tons)	Amended Unit Type, based on part 60 classifications, ERC directory & permits	Tons MSW/day	Permit NOx Control
Covanta Alexandria/Arlington Energy	VA	Alexandria City	Keeler/Dorr-Oliver	0.276	Mass burn waterwall	325	
Covanta Fairfax Energy	VA	Fairfax	Ogden Martin	0.780	Mass burn waterwall	750	SNCR
Covanta Fairfax Energy	VA	Fairfax	Ogden Martin	0.780	Mass burn waterwall	750	SNCR
Covanta Fairfax Energy	VA	Fairfax	Ogden Martin	0.780		750	SNCR
Covanta Fairfax Energy	VA	Fairfax	Ogden Martin	0.780		750	SNCR

Appendix C: OTR Small MWCs

Plant Name	State	Permit NOx Limit ppmvd (24-hour limit)	Unit Type (Part 60 classifications)	Tons MSW/day	2023 Projected NOx Emissions (ton/yr)
Pioneer Valley Resource Recovery	MA	167	Modular Excess Air	136	40.91
Pioneer Valley Resource Recovery	MA	167	Modular Excess Air	136	45.41
Pioneer Valley Resource Recovery	MA	167	Modular Excess Air	136	40.51
Pittsfield Resource Recovery Facility	MA	192	Modular Excess Air	120	17.9
Pittsfield Resource Recovery Facility	MA	192	Modular Excess Air	120	18.8
Pittsfield Resource Recovery Facility	MA	192	Modular Excess Air	120	18.97
MMWAC Resource Recovery Facility	ME	315	Mass burn rotary waterwall*	125	211.28
MMWAC Resource Recovery Facility	ME	315	Mass burn rotary waterwall*	125	202.71
Dutchess Cnty Resource Recovery Facility	NY	170	Mass burn rotary waterwall	228	Missing
Dutchess Cnty Resource Recovery Facility	NY	170	Mass burn rotary waterwall	228	Missing
MacArthur Waste to Energy Facility	NY	170	Mass burn rotary waterwall	242.5	Missing
MacArthur Waste to Energy Facility	NY	170	Mass burn rotary waterwall	242.5	Missing
Oswego County Energy Recovery	NY		Modular starved air	50	199.79

Appendix D: Non-OTR MWCs

State	Configuration	Rating (tons/day)	NOx Control	Permit NOx Limit 1*	Est NOx Rate*** (lb/MMBtu)
CA	Mass burn waterwall	400	Ammonia Injection	165	0.2835
CA	Mass burn waterwall	400	Ammonia Injection	165	0.2835
CA	Mass burn waterwall w/reciprocating grate		SNCR	205	0.3522
CA	Mass burn waterwall w/reciprocating grate		SNCR	205	0.3522
CA	Mass burn waterwall w/reciprocating grate		SNCR	205	0.3522
FL	Mass burn rotary waterwall	255		170	0.2921
FL	Mass burn rotary waterwall	255		170	0.2921
FL	Mass burn waterwall	250	SNCR	205	0.3522
FL	Mass burn waterwall	250	SNCR	205	0.3522
FL	Mass burn waterwall	460	SNCR	205	0.3522
FL	Mass burn waterwall	460	SNCR	205	0.3522
FL	Mass burn waterwall	460	SNCR	205	0.3522
FL	Mass burn waterwall	690	Covanta LN™, SNCR, FGR	110	0.1890
FL	Mass burn waterwall	660	SNCR	180	0.3093

State	Configuration	Rating (tons/day)	NOx Control	Permit NOx Limit 1*	Est NOx Rate*** (lb/MMBtu)
FL	Mass burn waterwall	660	SNCR	180	0.3093
FL	Mass burn waterwall	660	SNCR & FGR	150	0.2577
FL	Mass burn waterwall	288	SNCR	205	0.3522
FL	Mass burn waterwall	288	SNCR	205	0.3522
FL	Mass burn waterwall	288	SNCR	205	0.3522
FL	Mass burn waterwall	288	SNCR	205	0.3522
FL	RDF Spreader Stoker	648	SNCR	250	0.4295
FL	RDF Spreader Stoker	648	SNCR	250	0.4295
FL	RDF Spreader Stoker	648	SNCR	250	0.4295
FL	RDF Spreader Stoker	648	SNCR	250	0.4295
FL	RDF	900	SNCR	250	0.4295
FL	RDF	900	SNCR	250	0.4295
FL	Stoker Mass Burn waterwall	1000	SCR	50	0.0859
FL	Stoker Mass Burn waterwall	1000	SCR	50	0.0859
FL	Stoker Mass Burn waterwall	1000	SCR	50	0.0859
FL	Mass burn waterwall	350	SNCR	205	0.3522
FL	Mass burn waterwall	350	SNCR	205	0.3522

State	Configuration	Rating (tons/day)	NOx Control	Permit NOx Limit 1*	Est NOx Rate*** (lb/MMBtu)
FL	Mass burn waterwall	350	SNCR	205	0.3522
FL	Mass burn waterwall	1050	SNCR	205	0.3522
FL	Mass burn waterwall	1050	SNCR	205	0.3522
FL	Mass burn waterwall	1050	SNCR	205	0.3522
FL	Mass burn waterwall	836	SNCR	205	0.3522
FL	Mass burn waterwall	836	SNCR	205	0.3522
FL	Mass burn waterwall	836	SNCR	205	0.3522
IN	Mass burn waterwall	726	SNCR	205	0.3522
IN	Mass burn waterwall	726	SNCR	205	0.3522
IN	Mass burn waterwall	726	SNCR	205	0.3522
MI	Mass burn waterwall	312.5	SNCR	205	0.3522
MI	Mass burn waterwall	312.5	SNCR	205	0.3522
MN	Mass burn waterwall	606	Ammonia Injection	205	0.3522
MN	Mass burn waterwall	606	Ammonia Injection	205	0.3522
MN	Stoker mass burn waterwall	100		500	0.8590
MN	Stoker mass burn waterwall	200	SNCR	150	0.2577
MN	Stoker mass burn waterwall	100		500	0.8590

State	Configuration	Rating (tons/day)	NOx Control	Permit NOx Limit 1*	Est NOx Rate*** (lb/MMBtu)
MN	Starved air modular	48		500	0.8590
MN	Starved air modular	48		500	0.8590
MN	RDF air swept, traveling grate	393.6		250	0.4295
MN	RDF air swept, traveling grate	393.6		250	0.4295
OK	Mass burn waterwall	375	SNCR	205	0.3522
OK	Mass burn waterwall	375	SNCR	205	0.3522
OK	Mass burn waterwall	375	SNCR & Tertiary Air	205	0.3522
OR	Mass burn waterwall	275	SNCR	200	0.3436
OR	Mass burn waterwall	275	SNCR	200	0.3436
VA	RDF Spreader Stoker	593		250	0.4295
VA	RDF Spreader Stoker	593		250	0.4295
VA	RDF Spreader Stoker	593		250	0.4295
VA	RDF Spreader Stoker	593		250	0.4295
WA**	Mass burn waterwall	475		165	0.2835
WA**	Mass burn waterwall	475		165	0.2835

* ppmvd @12% CO_2.

** 8-hour average, all others are 24-hour average.

*** From permit NOx rate and EPA Method 19.

Appendix E: Conversion of NOx Concentration to Mass

Below is an example of the calculation for conversion of NOx from concentration in ppm to lb/MMBtu and then ultimately from lb/MMBtu to lb/hr.

9.3 OTHER CEMS/CERMS CALCULATIONS

9.3.1 Calculation of Emissions in lb/MMBtu

Pollutant emission in units of lb/MMBtu are calculated as follows (see 40 CFR 60 Appendix A, Reference Method 19):

$$E = C_d * R * F_d * \left[\frac{20.9}{(20.0 - \%O_{2d})} \right]$$

Where:

E	=	Pollutant emission rate in pounds of pollutant per million Btu (lb/MMBtu).
C_d	=	Average pollutant concentration (ppm SO_2, NO_x or CO) recorded by the CEM Data Logger Subsystem, dry and calibration corrected, for a given hour.
R	=	Conversion factor - ppm to lb/scf ($SO_2 = 1.660E^{-7}$, $NO_x = 1.194E^{-7}$, $CO = 7.267E^{-8}$).
F_d	=	O_2 based F-factor (9570 dscf/MMBtu).
$\%O_{2d}$	=	Average dilutent concentration (% O_2) recorded by the CEM data logger subsystem, for a given hour, dry and calibration corrected.

In addition to the above example, more detail on the conversion calculations are provided below. In this example, an MWC with a NOx concentration emission limit of 150 ppm, and design capacity of 382 MMBtu/hr is used:.

lb/MMBtu = (1.37*10^-6/460+Ts)*MWp*F-factor/MMBtu*20.9/(20.9-%Oxygen)*(ppm)

Where Ts = 68: Ts = stack gas T

MWp = Molecular weight (of NOx)

MWp NOx = 46

F-factor/MMBtu = 9570 for municipal solid waste in Appendix A EPA test method 19

%Oxygen = 7

0.00000137/528 x 46 x 9570 x (20.9/13.9) x 150 = 0.257 lb/MMBtu

0.257 lb/MMBtu x 382 MMBtu/hr = 98.2 lb/hr NOx

98.2 lb/hr x 24 hr/day x 1 ton/2,000 lb = 1.2 tons per day (tons per summer day)

Ts = stack gas T

T2 = standard T (32F)

1 mole = 22.4 L

ug/m^3 = (moles of pollutant/10^6 moles)*(460+T2)/(460+Ts)

ug/m^3 = 44.64*MWp*(460+T2)/(460+Ts) for 1 ppm

ug/m^3 = (21,962.88*MWp)/(460+Ts)*(ppm) for more than 1 ppm

lb/ft^3 = (21,962.88/460+Ts)*MWp*(m^3/35.31ft^3) *(g/10^6 ug)*(lb/454 g) for 1 ppm

lb/ft^3 = 1.37*10^-6*MWp/(460+Ts)*(ppm) for more than 1 ppm

Td = default T = 68 degrees F

Rankin scale where (degrees F + 460 = degrees Rankin) which is used in thermodynamics

lb/MMBtu = (1.37*10^-6/460+Td)*MWp*F-factor/MMBtu*20.9/(20.9-%Oxygen) for 1 ppm

lb/MMBtu = (1.37*10^-6/460+Ts)*MWp*F-factor/MMBtu*20.9/(20.9-%Oxygen)*(ppm) for more than 1 ppm

Appendix F: MWC Technology Descriptions

Municipal waste combustors are intended to reduce the volume of municipal solid waste through combustion of that solid waste. Municipal solid waste is a fuel that tends to be a heterogeneous mixture of heavy and light materials of various combustibility. Most MWCs are designed to recover some of the heat generated from the MSW combustion process through heat absorption by radiant and convective water-cooled and steam-cooled tubing surfaces. MWCs may incorporate the steam generator within the MWC as an integral component, or the steam generator is a separate entity acting as a waste heat recovery device attached to the MWC. The are many designs and configurations of MWC units, often depending upon the intended volume of MSW throughput, characteristics of the design “municipal waste fuel”, and the experience and preferences of the owner/operator and engineering/design organization.

The majority of the OTR MWCs can be generalized into three major categories based on their individual municipal solid waste combustion process characteristics. One type of MWC is often referred to as mass burn, where the MSW is combusted in an as-received condition with only the removal of large objects prior to its introduction to the MWC. Most mass burn MWCs are essentially steam generators with MSW as the primary fuel.

The second type of MWC utilizes refuse derived fuel (RDF), a type of municipal solid waste produced by processing municipal solid waste through shredding and size classification to produce low-density fluff RDF (in the OTR), densified RDF or pelletized RDF. The majority of RDF MWCs are essentially steam generators using RDF as the primary fuel.

The third type of MWC is sometimes referred to as a modular MWCs. These units are mass burn (unprepared MSW, other than removal of large objects). However, modular MWCs are generally smaller units that are shop-built rather than field-erected and utilize two combustion chambers. There are generally two types of modular controlled air MWCs, one that utilizes sub-stoichiometric air combustion conditions in the primary chamber (modular starved air MWC) and the other that utilizes excess air combustion conditions in the primary chamber (modular excess air MWC). This type of MWC generally features a secondary combustion chamber with supplemental fuel burners and combustion air supply. The modular MWC combustor does not generally incorporate heat recovery in the combustion chambers themselves, but in many cases the flue gases from the modular MWC are exhausted to a heat recovery steam generator for energy recovery.

Mass Burn MWCs

In the OTR, there are two major sub-categories of mass burn MWCs: mass burn waterwall MWCs and rotary waterwall MWCs.

- Mass Burn Waterwall MWCs

  Mass burn waterwall MWCs have lower furnace primary combustion zones made of waterwall tubes for heat transfer in the combustion zone. For mass burn water wall MWCs, the MSW fuel is typically loaded into charging hoppers and fed to hydraulic rams that push the MSW fuel onto the stoker grate in the furnace for combustion. Most stokers utilize a reciprocating grate action, utilizing either forward or reverse acting grate movement, that moves the combusting MSW fuel across the furnace to allow time for drying and complete combustion. Generally, there will be a large volume of fuel at the front end of the grate that burns down to a small amount of ash at the back of the grate. The grate may have a slightly downward angle from fuel introduction to the ash drop off to help move the MSW fuel through the furnace. The reciprocating action of the grates also tends agitate the MSW fuel, generally causing the MSW fuel to roll and mix. This agitation helps ensure all of the MSW fuel is exposed to the high temperatures in the bed of combusting MSW fuel and helps provide contact with combustion air, resulting in more complete combustion of the MSW fuel as it travels across the furnace. Combustion ash that does not leave the stoker grate as fly ash is dropped off at the end of the stoker through a discharge chute for disposal or further processing.

  Mass burn waterwall MWCs may also incorporate auxiliary fuel burners to help bring the MWCs to temperature to begin combustion of the MSW fuel, to supplement the heat input necessary to attain the steam generator output rating with varying MSW fuel quality, or to ensure sufficient flue gas temperatures are attained for proper emissions control.

  Combustion air is generally introduced to the combustion zone utilizing pressurized air as underfire (primary) air or overfire (secondary) air. At least one proprietary design, however, splits the overfire air into two distinct zones, effectively creating three combustion air introduction zones.

  Underfire air is introduced under the stoker grate, sometimes through a series of plenums that allow for the amount of underfire air introduced to various portions of the grate area to be controlled to enhance combustion based on MSW fuel characteristics. The underfire air travels from the plenums to the combustion zone through holes in the grate to assure good distribution across the grate. Underfire air systems are generally designed to be able to provide up to 70% of the total combustion air requirement, with typical underfire air operating requirements utilizing 50% to 60% of the total combustion air.

  Overfire air is introduced into the furnace above the grate level through multiple ports in the furnace walls. The primary purpose of the overfire air is to provide the amount of air necessary to mix the furnace gasses leaving the grate combustion zone and provide the oxygen required to complete the combustion process. Proper control of the overfire air may also be utilized to provide some control of the NOx emission rate leaving the high temperature zone of the furnace. The amount of overfire air is typically 40% to 50% of the total required combustion air, and is somewhat dependent upon MSW fuel quality and NOx emission control requirements.

- Rotary Waterwall MWCs

  A rotary waterwall MWC utilizes a water cooled, tilted, rotating cylindrical combustion chamber. The MSW fuel is typically loaded into charging hoppers and fed to hydraulic rams that push the MSW fuel into the slowly rotating combustion chamber. The rotation of the tilted cylindrical combustion chamber causes the MSW fuel to tumble and advance the length of the cylindrical combustion chamber, ensuring all of the MSW fuel is exposed to high temperatures and combustion air for a sufficient amount of time for drying and complete combustion of the MSW fuel. Combustion ash that does not leave the rotary burner as fly ash is dropped off at the end of the rotary burner through a discharge chute for disposal or further processing.

  Rotary burner MWCs may also incorporate auxiliary fuel burners to help bring the MWCs to temperature to begin combustion of the MSW fuel, to supplement the heat input necessary to attain the steam generator output rating with varying MSW fuel quality, or to ensure sufficient flue gas temperatures are attained for proper emissions control.

  Combustion air for rotary burner MWCs is introduced to the rotating combustion chamber by a pressurized plenum surrounding the rotating combustion chamber. The combustion air enters the rotating combustion chamber through the walls of the chamber, generally through spaces between waterwall tubes. Underfire air is introduced at the bottom of the rotating combustion chamber and through the bed of combusting MSW. Overfire air is introduced into the rotating combustion chamber over the bed of combusting MSW. Dampers are utilized to proportion the total air flow and control the overfire air/underfire air split.

RDF MWCs

In contrast to mass burn MWCs, RDF MWCs employ a more complex feeder/spreader system and different combustion bed characteristics. The prepared RDF is ram fed to a feeder hopper, where a conveying device further mixes and fluffs the RDF into a more uniform density as it transports the RDF to fuel/air spreader spouts. Multiple fuel/air spreader spouts located across the furnace and above the stoker grate distribute the RDF evenly across the width of a traveling grate, while the air pressure may be continuously varied to help provide a more uniform fuel bed over the depth of the grate. The traveling grate typically travels from the rear of the furnace to the front in the direction of the fuel distribution. Combustion of the RDF takes place in suspension for the lower density fraction and on the stoker grate for the higher density fraction. The underfire combustion air passing through the traveling grate provides some agitation to the fuel bed to help ensure all the RDF is exposed to high temperatures and sufficient combustion air to ensure more complete combustion as it travels across the furnace. Like the mass burn combustion system, ash from the combustion process that does not leave the grate as fly ash will be dropped off at the end of the stoker through a discharge chute for disposal or further processing.

For RDF burning MWCs, combustion air is generally introduced to the combustion zone utilizing pressurized air as underfire (primary) air or overfire (secondary) air.

Underfire air (sometimes referred to as undergrate air) is introduced under the stoke grate. The underfire air is generally introduced into the steam generator through a single undergrate plenum and relies on enough pressure drop to supply combustion air evenly through all portions of the grate. Underfire air systems are generally designed to be able to provide up to 70% of the total combustion air requirement, with typical underfire air operating requirements utilizing 50% to 60% of the total combustion air.

Overfire air is introduced into the furnace above the grate level through multiple ports in the furnace walls. The primary purpose of the overfire air is to provide enough air to mix the furnace gasses leaving the grate combustion zone to provide the oxygen required to complete the combustion process. Proper control of the overfire air may provide some control of the NOx emission rate leaving the high temperature zone of the furnace. The amount of overfire air is typically 40% to 50% of the total required combustion air, being somewhat dependent upon the RDF fuel quality and NOx emission control requirements.

The fuel/air spreaders generally require approximately 5% of the total air flow requirement at any given load to properly distribute the RDF fuel in the furnace over the grate.

RDF MWCs may also incorporate auxiliary fuel burners to help bring the MWCs to temperature to begin combustion of the RDF, to supplement the heat input necessary to attain the steam generator output rating with varying RDF quality, or to ensure sufficient flue gas temperatures are attained for proper emissions control.

Modular MWCs

Modular MWCs are generally of smaller capacity than mass burn and RDF MWCs and utilize two combustion zones rather than one. The MSW fuel is typically introduced to the MWC without preparation other than removing large objects. MSW fuel is dropped into a chute and is pushed by rams into the first, or primary, combustion chamber and on to a reciprocating grate(s) or moving hearth. Instead of traveling grates or hearths, some modular MWCs may utilize a series of stepped rams to move the combusting MSW fuel across the combustion chamber. The MSW fuel is dried and combusted as it travels across the primary combustion chamber, and any ash not leaving the primary chamber as fly ash is dropped off at the end of the primary combustion chamber into a discharge chute for disposal or further processing.

The combustion zones of modular MWCs generally do not incorporate any heat recovery water or steam walls. Instead the combustion zones generally consist of refractory lined walls. Heat recovery, if any, occurs in a heat recovery steam generator that is connected to the exhaust of the secondary combustion chamber. The distribution of combustion air is the primary distinction between the designs of modular starved air MWCs and modular excess air MWCs.

Combustion air for modular starved air MWCs is proportioned to provide combustion air to the primary combustion chamber and to the secondary combustion zone, with the amount of air supplied to the primary combustion chamber controlled such that combustion in the primary chamber is sub-stoichiometric (i.e. less oxygen than is necessary to achieve complete combustion). This results in flue gases exiting the primary chamber with high levels of combustibles. The flue gases enter the secondary chamber, where additional air (secondary air) is injected to complete the combustion process. The relatively high amount of secondary air injection also provides a high amount of turbulence to ensure mixing with the combustible portions of the primary combustion chamber flue gases. One of the intended results of the primary chamber sub-stoichiometric combustion is reduced air/flue gas velocity causing less turbulence in the combustion bed, less flue gas particulate carried out from the primary chamber, and lower peak combustion temperatures. However, the modular starved air MWC may reasonably be expected to have higher levels of unburned fuel than other types of MWCs.

Combustion air for modular excess air MWCs is also proportioned between the primary and secondary combustion chambers, but the amount of combustion air suppled to the primary chamber is proportioned to provide combustion conditions at greater than stoichiometric conditions (i.e. more oxygen than is necessary to achieve complete combustion). This may lead to higher levels of particulate carry-out from the primary combustion chamber and a higher degree of MSW fuel burnout.

Modular air MWCs may also incorporate auxiliary fuel burners to help the MWC operate with varying MSW fuel characteristics or to ensure appropriate flue gas temperatures are attained for proper emissions control.

MWC Retrofit NOx Control Technologies

MWCs are intended to combust a municipal waste fuel that tends to be a heterogeneous mixture of heavy and light materials of variable combustibility. Both fuel and thermal NOx is generated by the combustion process, with some limited degree of control possible through variation of the primary/secondary air ratio. The variation in MWC unit design and fuel quality leads to a range of expected uncontrolled NOx emissions, sometimes given as a range of 250 ppmvd @7% O_2 to 300 ppmvd @7% O_2. There are several NOx control options that can be retrofitted to existing MWCs, with applicability and effectiveness dependent upon unit configuration. Not all NOx reduction technologies are applicable to all MWC configurations, and not all technologies are reasonably feasible from an economic standpoint even if they are technologically feasible. Assessments of individual MWCs are necessary to evaluate the technical and economic feasibility of any NOx reduction technology for that MWC. However, the following information provides a limited indication of general applicability and cost effectiveness of various control equipment types.

Combustion Air Control

For the purposes of this document, combustion air control technology for NOx control on MWCs means utilization of low excess air operation or staged combustion, either separately or in combination. For low excess air operation, the overall amount of combustion air in the system is reduced generally through reduction of both underfire and overfire air. For staged combustion, the amount of underfire air is reduced to reduce the air available during the initial stages of combustion, while the amount of overfire air is increased to provide enough air to complete the combustion process. The generally high excess air requirements needed to achieve complete combustion of the non-homogenous MSW fuel provides only limited ability to attain NOx reductions through excess air reduction while still maintaining acceptable MSW fuel burnout, although some NOx rate reduction may be possible at some MWCs. By design, the majority of MWCs incorporate some level of control to proportion underfire and overfire air to optimize combustion quality with NOx generation rate so this technology is more of an operational tuning control technology. Industry information indicates that combustion air optimization for NOx control has the potential to reduce NOx emission rates by up to 10% while still maintaining acceptable fuel burnout on many MWCs. Because this "technology" control is already part of most OTR MWCs, it is assumed that optimizing combustion air control is already part of good operating practices.

Selective Non-Catalytic Reduction

Selective non-catalytic reduction (SNCR) is a retrofit-capable NOx control technology that is widely utilized for existing MWC units, including those located in the OTR. For SNCR, reagents (urea or ammonia) are injected into the MWC furnace at locations in the proper temperature range to drive chemical reactions between the reagents and NOx, resulting in the nitrogen in NOx being reduced to elemental nitrogen (N2) and water vapor. SNCR systems generally include reagent storage facilities, supply of demineralized water, electric power supply, pumps, mixing components, a heated structure to protect the pump skid and mixing/flow control components from colder ambient temperatures, pressurized air supply, pipes and tubing, flow control valves, a control system, communication with steam generator control and instrumentation systems, and penetrations into the steam generator at the proper locations to install SNCR injection nozzles. The effectiveness of NOx control using SNCR will be a function of the MWC's characteristics (such as furnace configuration, combustion excess air requirements, flue gas temperature gradients, etc.) to attain the proper orientation and location of SNCR injector nozzles and the ability to achieve proper reagent atomization and sufficient time for reagent contact and mixing with the flue gas in the proper temperature range. SNCR effectiveness will also be affected by the ability to consistently introduce the appropriate amount of reagents across the MWC's load range and in reaction to changes in MSW fuel characteristics. Literature suggests that SNCR is a technologically feasible NOx control system applicable to many MWCs.

The use of properly designed and well-tuned SNCR technology has been demonstrated to achieve approximate 40% to 50% reductions in NOx emission rates with low ammonia slip values at many facilities, including retrofit applications. Compliance with 150 ppmvd @7% O_2 24-hr average NOx emission rate limitations has been demonstrated at many OTR MWC facilities utilizing SNCR as the primary NOx control.

Some historic non-OTR NOx RACT evaluations and cost effectiveness estimates have been identified in EPA's RACT/BACT/LAER Clearinghouse regarding the use of SNCR on MWC units. Two are described below.

- The Lee County Waste to Energy facility (Florida) indicated an estimated cost effectiveness of $2,000/ton (approximately $2,880/ton in 2020 dollars) of NOx reduced utilizing SNCR for control on a 660 ton/day MWC. The permit NOx rate limits were 110 ppmvd 12-month average and 150 ppmvd 24-hour average.
- The Hillsborough County Resource Recovery facility (Florida) indicated an estimated cost effectiveness of $1,000/ton (approximately $1,500/ton in 2020 dollars) of NOx reduced utilizing SNCR for control on a 600 ton/day MWC. The permit NOx rate limits were 90 ppmvd 12-month average and 110 ppmvd 24-hour average.

Some historic industry information suggests a very wide range of NOx reduction cost effectiveness values as a function of the size (input capacity) of MWCs. This information suggests that estimated cost effectiveness values may range from approximately $7,400/ton for small MWCs (100 ton/day and smaller) to approximately $1,900/ton for large MWCs (750 ton/day and larger), based on a 50% NOx reduction and 80% annual capacity factor. Variations in capacity factor, required level of NOx reduction, and other factors would shift the estimated cost effectiveness range. As portions of SNCR can be shared among multiple MWCs at a single facility (reagent preparation, reagent storage, demineralized water supply, pumping/forwarding skids, etc.), the per MWC NOx reduction estimated cost at a multi-MWC facility may be lower.

Flue Gas Recirculation

Flue gas recirculation (FGR) technology can be a stand-alone NOx reduction technology, but as SNCR is already being utilized for many OTR MWCs, for this discussion it will be assumed that a retrofit FGR system would be utilized in combination with the continued use of existing SNCR technology. The equipment and function of the existing SNCR portion of this option is assumed to be unchanged from that of properly tuned existing SNCR technology.

FGR helps reduce NOx emission rates by slightly reducing the average oxygen content in the combustion zone and also by reducing the peak temperatures in the combustion zone. An FGR retrofit would generally require the installation new ductwork, fan, control dampers and damper operators, electric power supply, flue gas injection/mixing nozzles, system controls, and integration with the steam generator controls and instrumentation. Retrofit FGR would generally be designed to extract a portion of the flue gases from ductwork downstream of the steam generator convective passes. Utilizing a fan, the extracted flue gases would be mixed with the secondary air prior to introduction into the combustion zone. As indicated above, by diluting the secondary air with the flue gases, the average amount of excess air available for combustion and average flame temperature are reduced resulting in lower levels of NOx formation. The amount of gas recirculated would be controlled to ensure complete combustion of the MSW fuel.

FGR is listed as an installed equipment at a couple of MWC facilities in the OTR. FGR is potentially a technically feasible retrofit technology for many MWCs. An exception might be a modular MWC not incorporating any heat recovery as that would hamper the ability to reduce flue gas temperatures to a range useful for recirculation to the combustion zone.

Babcock Power Environmental prepared an analysis for potential installation of FGR-SNCR at the Wheelabrator Baltimore MWC facility, which includes three MWCs each with a rating of 625 ton/day. The evaluation predicted the ability to maintain a 120 ppmvd @7% O_2 24-hr NOx rate limit and a 115 ppmvd @7% O_2 30-day NOx rate limit with ammonia slip of approximately 5 ppmvd.

A cost effectiveness estimate was performed using the data provided in the Babcock Power document. Using the cost assumptions for this particular facility (as discussed in the Babcock Power document with a 20-year control life with 6% interest rate), the incremental cost effectiveness was estimated at $3,470/ton of NOx reduced. There could be a significant range in estimated cost effectiveness due to MWC input capacity (and the need for the corresponding difference in amount of recirculated gas). For similar types of MWCs, the range of sizes would require the same level of engineering and design, and the same type of components (potentially varying in size), therefore many of the associated costs are similar. Because the ton/year of NOx mass reduction would vary with the input range of the MWCs, this could lead to a large range in the estimated cost effectiveness. Using the Babcock and Wilcox Wheelabrator Baltimore evaluation as a base input, the estimated FGR cost effectiveness could range from approximately $3,200/ton to $11,000/ton.

Advanced SNCR

Advanced SNCR (ASNCR) NOx control technology may be considered for retrofit on existing MWCs as either a new retrofit technology or a significant upgrade to an existing SNCR. ASNCR is like SNCR in that it utilizes the injection of reagents into the proper temperature zones of the furnace to reduce the flue gas NOx concentration. Both SNCR and ASNCR designs may utilize advanced computer modeling techniques to specify SNCR nozzle locations and elevations so that their operation may be optimized across varying furnace conditions. The primary difference between a well-designed SNCR and ASNCR system is that ASNCR would utilize advanced furnace temperature monitoring instrumentation to provide near real time operating furnace temperature profiles. This information allows the control system to modulate which ASNCR injectors are in operation and to automatically adjust the individual injector flow rate in order to optimize the overall NOx emission rate. This advanced system optimizes the NOx reduction chemical reaction across the furnace to achieve high levels of overall NOx reduction while maintaining low ammonia slip. Babcock and Wilcox (B&W) prepared an analysis for the Wheelabrator Baltimore facility that included the potential use of ASNCR technology for NOx control. The B&W information suggests that ASNCR may be applicable to many MWCs as a retrofit technology, although furnace configuration or other factors could affect the NOx reduction potential.

Babcock Power prepared an analysis for potential installation of ASNCR at the Wheelabrator Baltimore MWC facility. The evaluation predicted the ability to maintain a 110-125 ppmvd @7% O_2 24-hr NOx rate limit and a 105-110 ppmvd @7% O_2 30-day NOx rate limit with ammonia slip of approximately 5 ppmvd.

A cost effectiveness estimate was performed using the data provided in the Babcock Power document. Using the cost assumptions for this particular facility (as discussed in the Babcock Power document and assuming a 20-year control life with 6% interest rate), the incremental cost effectiveness was estimated at $3,883/ton of NOx reduced.

Some industry information indicates that while it is likely that most MWCs could successfully retrofit ASNCR and expect NOx reductions, its ability to achieve significant amounts of NOx reduction in small MWCs is limited due to the reduced space and contact time. These factors are influenced by individual unit design. An insufficient amount of information is available to provide an estimate of the range of cost effectiveness for small MWCs.

Another control option combines ASNCR with FGR. The equipment and function of the ASNCR portion of this option is identical to that of the ASNCR-only technology described above. The FGR part would be identical to the above FGR discussion, where a portion of the flue gases is extracted downstream of the convective passes of the steam generator and those flue gases are injected into the secondary air system using an FGR fan. By diluting the secondary air with flue gases, the average amount of excess air available for combustion is reduced and the average flame temperature is reduced, resulting in lower levels of NOx formation. The lower levels of NOx formed are further reduced by the reaction of the flue gas NOx with the ASNCR reagents, which are enhanced by the high flow rate of the secondary air and recirculated flue gas mixture.

Babcock Power Environmental prepared an analysis for potential installation of FGR-SNCR at the Wheelabrator Baltimore MWC facility. The evaluation predicted the ability to maintain a 105 ppmvd @7% O_2 24-hr NOx rate limit and a 100 ppmvd @7% O_2 30-day NOx rate limit with ammonia slip of approximately 5 ppmvd.

A cost effectiveness estimate was performed using the data provided in the Babcock Power document. Using the cost assumptions for this particular facility (as discussed in the Babcock Power document with a 20-year control life with 6% interest rate), the incremental cost effectiveness was estimated at $4,695/ton of NOx reduced.

Covanta Proprietary Low-NOx

The Covanta Low-NOx (LN™) is a proprietary NOx reduction technology. The LN™ process modifies the combustion process by diverting a portion of the secondary air and injecting it (tertiary air) at a higher elevation in the furnace. The distribution of combustion air between the primary, secondary, and tertiary levels is controlled to optimize combustion control and reduce NOx emissions by providing additional fuel/air staging for NOx control while still providing enough air for complete combustion. The installation of the LN™ system on a combustion unit already incorporating SNCR may require modifications to the SNCR system to optimize the combined NOx reduction effect of the LN and SNCR technologies. Covanta's website indicates that the propriety LNTM technology has already been installed on many of the MWCs operated by Covanta, with plans to install it on many more. The proprietary aspects of this technology suggest it is unlikely that it can be installed on non-Covanta MWCs.[19]

The Covanta LNTM technology was permitted as RACT for retrofit installation and operation in conjunction with SNCR at the Covanta Fairfax facility in Virginia. The permit NOx emission limits are 110 ppmvd @7% O_2 24-hr, and 90 ppmvd @7% O_2 annual. Prior to the LNTM retrofit, the

[19] See footnote 3 for reference.

facility's MWCs typically operated with NOx emission rate set-points ranging from 160 ppmvd to 180 ppmvd (dependent upon furnace conditions) in compliance with the permitted 205 ppmvd emission rate limits. Information provided in the RACT analysis for Covanta Fairfax indicated that at that time, the Covanta LNTM technology had been installed in approximately 20 units. The calculated incremental cost effectiveness for Covanta Fairfax was $2,888/ton of NOx removed.

The Covanta LNTM technology was also permitted as RACT for retrofit installation and operation in conjunction with SNCR at the Covanta Alexandria/Arlington facility in Virginia. The permit NOx emission limits are 110 ppmvd @7% O_2 24-hr, and 90 ppmvd @7% O_2 annually. Prior to LNTM retrofit, the facility's MWCs typically operated with NOx emission rate set-points ranging from 160 ppmvd to 180 ppmvd (dependent upon furnace conditions) in compliance with permitted 205 ppmvd emission rate limits. The calculated incremental cost effectiveness for Covanta Alexandria/Arlington was $4,005/ton of NOx removed.

The proprietary Covanta LNTM technology with SNCR technology has been in operation on the Montgomery County Resource Recovery unit in Maryland for several years. A recent study was performed at the request of MDE to address the potential for any additional NOx rate reduction capability that could be considered RACT. The evaluation noted that the facility has been able to typically control its average 24-hour NOx rate to less than 100 ppm, but that there are some periodic spikes in excess of those values caused by process variations that are outside operator control. The document concludes that an emissions limitation of 140 ppmvd @7% O_2, 24-hr average, is reasonable and can be met with good ammonia slip control.[20]

Covanta Bristol in Connecticut has incorporated the proprietary Covanta LNTM technology on one of its combustion units, and has been permitted with a 120 ppmvd @7% O_2 NOx, 24-hr average, emission rate limit.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) is a retrofit-capable NOx reduction technology where ammonia is injected into the flue gases ahead of a catalyst. In the proper temperature range, the nitrogen in the flue gas NOx is reduced to elemental nitrogen by the catalyst. Incorporation of SCR on an existing unit requires installation of a catalyst module in the flue gas ductwork, the installation of an ammonia storage and injection piping and control system, instrumentation, and coordination with steam generator controls to ensure the appropriate amount of ammonia is injected into the flue gas ahead of the catalyst. Since the temperature of the flue gases downstream of the steam generator convective passes may be too low to enough chemical reaction in the catalyst, most MWC units also require a means of reheating the flue gas to acceptable levels. This could be accomplished through installation of burners or other heat exchangers in the ductwork ahead of the catalyst module. In some installations, it may also be necessary to upgrade the existing induced draft fan(s) to overcome the draft loss through the catalyst. While this

[20] See footnote 4.

technology is applicable and effective to most MWCs, the space availability and configuration of a given facility may make it infeasible. SCR is also very costly from a capital expense standpoint.

Babcock Power prepared an analysis for potential installation of SCR at the Wheelabrator Baltimore MWC facility. While the analysis did not provide a site-specific prediction for the achievable NOx emission rate, the evaluation discussed BACT rates for a new MWC facility that incorporated SCR. The discussed NOx emission rates were 50 ppmvd @7% O_2 24-hr NOx rate limit and 45 ppmvd @7% O_2 30-day NOx rate limit, with ammonia slip of approximately 10 ppmvd.

A cost effectiveness estimate was performed using the data provided in the Babcock Power document. Using the cost assumptions for the Wheelabrator Baltimore facility (as discussed in the Babcock Power document with a 20-year control life with 6% interest rate), the incremental cost effectiveness was estimated from $10,296/ton to $12,779/ton of NOx reduced, depending upon which flue gas reheating mechanism was chosen.

The RACT evaluation for the Covanta Alexandria/Arlington facility addressed the potential for installing SCR at that site. This evaluation also cited the same new MWC facility SCR installation as Babcock Power did in their Wheelabrator Baltimore facility evaluation, along with the 50 ppmvd @7% O_2 24-hr NOx rate limit and 45 ppmvd @7% O_2 30-day NOx rate limit. The Covanta Alexandria/Arlington evaluation estimated a cost effectiveness of $31,445/ton of NOx removed.

The RACT evaluation for the Covanta Fairfax facility addressed the potential for installing SCR at that site. This evaluation also cited the same new MWC facility SCR installation as Babcock Power used in their Wheelabrator Baltimore facility evaluation, along with the 50 ppmvd @7% O_2 24-hr NOx rate limit and 45 ppmvd @7% O_2 30-day NOx rate limit. The Covanta Alexandria/Arlington evaluation estimated a cost effectiveness of $15,898/ton of NOx removed.

For Florida's Palm Beach Renewable Energy Facility, which was a new MWC facility, the use of SCR and a 50 ppmvd @7% O_2 NOx (24-hr average) emission rate were considered BACT when the facility was permitted in 2010.

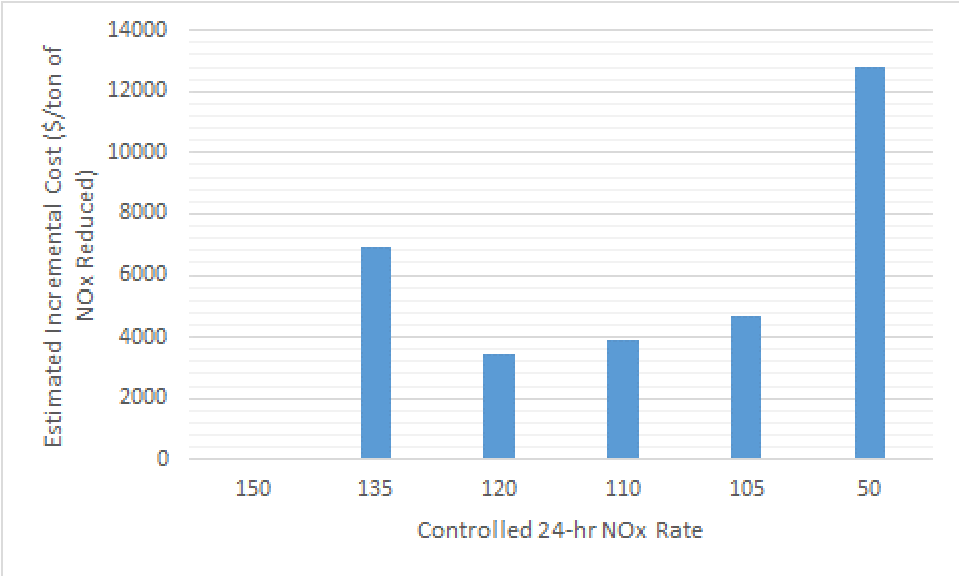
Based on these NOx reduction technology retrofit cost effectiveness estimations for the few existing MWC facilities discussed above, all technologies except SCR could potentially be considered in a revised RACT review for some of the OTR MWC facilities, from a technical standpoint, depending on unit specific design and operating conditions. However, the estimated cost effectiveness of the options may not be considered reasonable for any revised RACT.

The only cost effectiveness information associated with potential NOx reduction technologies that provides the consistency of same design and same operating characteristics is presented in the Babcock Power NOx control evaluation for the Wheelabrator Baltimore facility. The evaluation provided estimated costs and NOx control capability of several NOx reduction technologies, allowing a reasonable comparison of the impact of the control technologies. The incremental cost effectiveness values in the below chart were estimated from the data provided in the Babcock

Power document, by assuming a 20-year control life with 6% interest rate. For this facility and group of potential NOx reduction technologies, NOx reduction cost effectiveness is optimized when the control technology reduces NOx emissions to approximately 120 ppmvd @7% O_2. Note that the baseline comparison for this estimate is compliance with a 150 ppmvd @7% O_2 24-hr average NOx emission rate.

Estimated NOx Control Cost Effectiveness

Estimates based on Babcock Power Wheelabrator Baltimore Study



The NOx reduction technologies associated with the controlled NOx rate values in the above chart are in shown in the following table.

Information from Babcock Power Study of Wheelabrator Baltimore

Control Technology	Estimated 24-hr Avg NOx Rate (ppmvd @7%O2)
Estimate Base	150
Optimize Existing SNCR	135
FGR & Existing SNCR	120
ASNCR	110
FGR & ASNCR	105
SCR	50

The above information suggests that for this facility with these NOx control technologies, the most cost-effective options are FGR&SNCR and ASNCR. The associated controlled NOx emission rates are between 110 ppmvd @7% O_2 and 120 ppmvd @7% O_2, 24-hr average. The range of NOx control estimated cost effectiveness is $3,470/ton to $3,883/ton.

These indications are somewhat in agreement with the RACT analysis conducted by Virginia and Covanta for the Covanta Fairfax and Covanta Alexandria/Arlington facilities. For these Covanta facilities, RACT was selected as Covanta's proprietary LNTM technology and SNCR with predicted NOx emission rate values of 110 ppmvd @7% O2, 24-hr average. The analysis indicated a NOx control cost effectiveness of $2,888/ton for Covanta Fairfax and $4,005/ton for Covanta Alexandria/Arlington. These values are comparable to the range of controlled NOx rate and cost effectiveness estimated for the Wheelabrator Baltimore facility. While cost effectiveness values would vary across MWCs, the control technologies would likely maintain the same relative cost effectiveness positioning.

While any revised RACT is unit-specific based on technical and economic feasibility of marketed control technologies, the limited information above suggests that a revised NOx RACT rate of between 110 ppmvd @7% O_2 and 120 ppmvd @7% O_2, 24-hr average, may be a reasonably achievable target emission rate for many MWCs. The limited information also suggests that NOx reduction cost effectiveness values of $3,000/ton to $4,000/ton may be reasonably representative of the range of related costs to achieve a revised NOx RACT emission rate. Within this cost range, several NOx reduction technologies may be available for consideration to comply with a revised RACT for MWCs.

The following table shows the estimated NOx reductions on a PTE basis for the fleet of OTR MWCs. The estimates assume no backsliding for MWCs that are already subject to NOx rate limitations lower than the assumed NOx RACT rates discussed in this analysis and that all subject units are able to attain the assumed NOx RACT rates. The estimated reductions also assume all the MWCs can technically and economically attain the assumed NOx rate values. As indicated in the table, the estimated NOx PTE reduction for the OTR MWC fleet associated with a NOx rate of 120 ppmvd @7% O_2 is approximately 25%.

Estimated OTR MWC Fleet NOx Emission Reductions Using Assumed NOx RACT Emission Rate Targets

Assumed NOx RACT Value (ppmvd@ 7%O2)	Est Hourly PTE (lb)	Est Daily PTE (tons)	% Reduction
Existing Rates	6395.4	76.4	
150	5778.8	69.3	9.3
140	5471.8	65.7	14.0
130	5091.7	61.6	19.4
120	4724.7	56.7	25.8

Appendix G: Method for Estimating Costs for Urea Consumption

The cost estimation for urea consumption for NOx removal was performed in two ways. First, the cost estimate on a per lb of NOx reduction was performed using information presented in the Wheelabrator Baltimore study and specifically the differences between the optimized SNCR and advanced SNCR control options. Using this Wheelabrator Baltimore study information, the incremental NOx reduction cost effectiveness was estimated to be $0.89 per pound of NOx reduced. The second estimation method was based on simple chemical reaction estimates, high efficiency NSR guidance from EPA, and urea cost values from the Wheelabrator Baltimore study. Using this second estimation methodology, the cost effectiveness was estimated to be $1.01 per pound of NOx reduced. Details of the utilized estimation methodologies are included below.

Using the estimated cost effectiveness values and the mass reduction values shown in the workgroup summary document, the estimated annual O&M cost reductions for the two facilities are shown in the following table:

Facility	Workgroup Paper Identified Change In NOx Mass Reduction (tons/yr)	Workgroup Paper Existing Estimated O&M Cost ($/yr)	Estimated O&M Cost Reduction Due To Urea Consumption Based On Wheelabrator Baltimore Study ($/yr)	Estimated O&M Cost Reduction Due To Urea Consumption Based On Chemistry/EPA NSR ($/yr)
Alexandria/Arlington	18.33	213773	32627	37027
Fairfax	51.73	493322	92079	104495

As can be seen in the cost per pound of NOx reduction estimates, there is a $0.12/lb difference between the two methodologies. One possible explanation is that in reality there is no need to have an NSR as high as 2.0 (as was assumed for the chemistry based estimate) to achieve the target 110 ppmvd @7% O_2 limit when there is improved reagent furnace penetration and mixing with ASNCR. The workgroup has used the Wheelabrator study information for adjusting the estimated O&M costs for the workgroup document.

Incremental Cost Estimation for Urea Consumption Using Wheelabrator Baltimore Study*

From EPA Method 19, eq 19-1: $E = CdFd(20.9/(20.9 - \%O_2))$

where: E = pollutant emission rate lb/MMBtu

Cd = pollutant sample concentration dry basis lb/scf

Fd = fuel specific factor volume of dry combustion products per fuel heat content 9570 dscf/MMBtu for municipal waste

Incremental NOx rate reduction: From 135 ppmvd limit to 110 ppmvd limit = 25 ppmvd Cd NOx = 25 ppmvd x (1.194 x 10^-7 (lb/ft^3)/ppm) = 29.9 x 10^-7 lb/ft^3

E = (29.9 x 10^-7 lb/ft^3)(9570 dscf/MMBtu)(20.9/(20.9 – 7)) = 0.0430 lb/MMBtu

Incremental annual NOx mass reduction: 0.0430 lb/MMBtu x 3 boilers x 325 MMBtu/hr/boiler * 8760 hr/yr * 0.92 availability = 337882 lb/yr 168.9 tons/yr

Annual average change in cost per incremental reduction = (995,000$/yr – 695,000$/yr) / (337,882 lb/yr) = 0.8879 $/lb or 1776.20 $/ton

*Ref: WASTE TO ENERGY NOX FEASIBILITY STUDY; PREPARED FOR: WHEELABRATOR TECHNOLOGIES BALTIMORE WASTE TO ENERGY FACILITY BALTIMORE, MARYLAND; BPE PROJECT NO. : 100825; BPE DOCUMENT NO.: 100825-0908400100; FINAL REVISION FEBRUARY 20, 2020

*Study operating assumptions: Three Stirling boilers of 750 tpd capacity each (municipal solid waste at 5200 BTU/lb) ~ 325 MMBtu/hr/boiler

92% annual operating factor

Urea mixture cost $1.19/gal, 50% urea by weight

*Study Control Option – Optimize Existing SNCR: 135 ppmvd 24-hr avg @7% O_2, estimated annual urea consumption cost ~ $695,000/yr, estimated urea consumption 72 gal/hr

*Study Control Option – Advanced SNCR: 110 ppmvd 24-hr avg @7% O_2, estimated urea consumption cost ~ $995,000/yr, estimated urea consumption 105 gal/hr

Incremental Cost Estimation Using Basics

Assumption NOx – 95% NO, 5% NO_2

$2NO + CO(CH_2)_2 + 1/2O_2 >>> 2N_2 + CO_2 + 2H_2O$

$2NO_2 + 2CO(NH_2)_2 + O_2 >>> 3N_2 + 2CO_2 + 4H_2O$

Estimated mix MW (95% NO, 5% NO_2) >>> 30.8 lb

Estimated urea requirement (per lb/mole NOx) >>>31.54 lb (theoretical NSR)

Theoretical NSR for urea/NOx = 0.5

Hi-efficiency removal operating NSR for urea/NOx - 2.0 (ref Fig 1.7, https://www.epa.gov/sites/production/files/2017-12/documents/sncrcostmanualchapter7thedition20162017revisions.pdf)

Estimated required urea for high efficiency NSR=2 (per lb/mole of NOx) >>> 126.16 lb urea / 30.8 lb NOx = 4.09 lb

Weight of 50% by weight water/urea – 9.57 lb/gal urea = 4.79 lb urea/lb mixture

Urea/water mixture consumption @ 2.0 NSR – 4.09 lb urea / (4.79 lb urea/gal mixture) = 0.85 gal urea/lb NOx removed

Estimated water/urea mixture cost range (@ 1.19$/gal from Wheelabrator Baltimore report, 2020 value) 0.85 gal/lb NOx x $1.19/gal = $1.01/lb NOx removed

Attachment 2

Commonwealth of Virginia

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

NORTHERN REGIONAL OFFICE
13901 Crown Court, Woodbridge, Virginia 22193
(703)583-3800 FAX (703) 583-3821
www.deq.virginia.gov

Matthew J. Strickler
Secretary of Natural Resources

David K. Paylor
Director
(804) 698-4000

Thomas A. Faha
Regional Director

February 8, 2019

Mr. Frank Capobianco
Facility Manager
Covanta Fairfax, Inc.
9898 Furnace Road
Lorton, Virginia 22079

Location: Fairfax County
Registration No.: 71920

Dear Mr. Capobianco:

Attached is a permit to operate a solid waste combustor facility in accordance with the provisions of the Commonwealth of Virginia State Air Pollution Control Board Regulations for the Control and Abatement of Air Pollution. This permit is for the purpose of implementing the "reasonably available control technology" (RACT) requirements of 9 VAC 5-40-7400, 9 VAC 5-40-7420 and 9 VAC 5-40-7430 of the Regulations of the Board. Except to the extent that conditions in this permit may be more stringent, this permit does not supersede or replace any other valid permit. Furthermore, this approval to operate shall not relieve Covanta Fairfax, Inc. (CFI) to comply with all other local, state, and federal permit regulations.

This permit contains legally enforceable conditions. Failure to comply may result in a Notice of Violation and civil penalty. Please read all conditions carefully.

At any time in the future, should CFI plan any modifications (within the context of the new source review program) of the facility covered by this permit, CFI shall have the right to apply to the Board for a new source review permit and the Board may consent to such modifications provided such modifications will meet all of the new source review permit program regulatory requirements in existence at that time.

Issuance of this permit is a case decision. The Regulations, at 9 VAC 5-170-200, provide that you may request a formal hearing from this case decision by filing a petition with the Board within 30 days after this permit is mailed or delivered to you. Please consult that and other relevant provisions for additional requirements for such requests.

Additionally, as provided by Rule 2A:2 of the Supreme Court of Virginia, you have 30 days from the date you actually received this permit or the date on which it was mailed to you, whichever occurred first, within which to initiate an appeal to court by filing a Notice of Appeal with:

Mr. David K. Paylor, Director
Department of Environmental Quality
P. O. Box 1105
Richmond, VA 23218

In the event that you receive this permit by mail, three days are added to the period in which to file an appeal. Please refer to Part Two A of the Rules of the Supreme Court of Virginia for additional information including filing dates and the required content of the Notice of Appeal.

If you have any questions concerning this permit, please contact the Northern Regional Office at (703) 583-3800.

Sincerely,

Thomas A. Faha

Thomas A. Faha
Regional Director

TAF/JBL/HGB/71920-RACT SOP (2-8-2019)

Attachment: Permit

cc: Joseph Walsh, Covanta (electronic file submission)
Riley Burger, EPA Region III
Manager/Inspector, Air Compliance Manager (electronic file submission)

Commonwealth of Virginia

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Secretary of Natural Resources

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Director
(804) 698-4000

Thomas A. Faha
Regional Director

STATIONARY SOURCE PERMIT TO OPERATE

In compliance with the Federal Clean Air Act and the Commonwealth of Virginia Regulations for the Control and Abatement of Air Pollution,

Covanta Fairfax, Inc.
9898 Furnace Road
Lorton, Virginia 22079
Registration No.: 71920

is authorized to operate

a municipal solid waste combustor facility

located at

9898 Furnace Road
Lorton, Virginia 22079
(Fairfax County)

in accordance with the Conditions of this permit.

Approved on February 8, 2019.

Thomas A. Faha

Thomas A. Faha
Regional Director

Permit consists of 9 pages.
Permit Conditions 1 to 26.

INTRODUCTION/PURPOSE

This permit is, (i) for the purpose of implementing the "reasonably available control technology" (RACT) requirements of 9VAC5-40-7420 of the State Air Pollution Control Board Regulations for the Control and Abatement of Air Pollution ("Regulations"), and (ii) establishes control technology and other requirements for the control of nitrogen oxides (NO_X) emissions from Covanta Fairfax, Inc. (CFI) in the Northern Virginia Ozone Non-Attainment Area and the Ozone Transport Region in Virginia. These RACT requirements shall be the legal and regulatory basis for control of NO_X emissions from this facility. In addition, this facility may be subject to additional applicable requirements not listed in this permit.

Words or terms used in this permit shall have meanings as provided in 9VAC5-10-20 of the Regulations. The regulatory reference or authority for each condition is listed in parentheses () after each condition.

The availability of information submitted to the Department of Environmental Quality (DEQ) or the Board will be governed by applicable provisions of the Freedom of Information Act, §§ 2.2-3700 through 2.2-3714 of the Code of Virginia, § 10.1-1314 (addressing information provided to the Board) of the Code of Virginia, and 9VAC5-170-60 of the State Air Pollution Control Board Regulations. Information provided to federal officials is subject to appropriate federal law and regulations governing confidentiality of such information.

EQUIPMENT LIST

Equipment at this facility subject to RACT requirements consist of the following:

Emission Unit ID	Equipment Description	Rated Capacity	Pollutant(s)*
001-01	Ogden-Martin MSW Combustor with Martin-Stoker boiler system (Began commercial operation in June 1990)	343.75 MMBtu/hr (heat input)	NO_X
002-01	Ogden-Martin MSW Combustor with Martin-Stoker boiler system (Began commercial operation in June 1990)	343.75 MMBtu/hr (heat input)	NO_X
003-01	Ogden-Martin MSW Combustor with Martin-Stoker boiler system (Began commercial operation in June 1990)	343.75 MMBtu/hr (heat input)	NO_X
004-01	Ogden-Martin MSW Combustor with Martin-Stoker boiler system (Began commercial operation in June 1990)	343.75 MMBtu/hr (heat input)	NO_X

* Pollutant(s) listed for each specified emission unit is only as 9VAC5-40-7420 applies.

PROCESS REQUIREMENTS

1. **Emission Control** – Upon completion of the installation and optimization period per Conditions 2 and 3, respectively, nitrogen oxides (NO_X) emissions from each municipal waste combustor (MWC) (Ref. 001-01 through 004-01) shall be controlled by furnace design, proper operation, ammonia injection (selective non-catalytic reduction (SNCR)), and the Covanta proprietary low NO_X combustion system (LN™). Until that time, the NO_X emissions shall be controlled by furnace design, proper operation, and ammonia injection (SNCR). The SNCR and LN™ system shall be provided with adequate access for inspection and shall be in operation when each municipal waste combustor (Ref. 001-01 through 004-01) is operating.
(9VAC5-80-850 and 9VAC5-40-7420)

2. **Emission Controls** – The permittee shall install the Covanta proprietary low NO_X combustion system (LN™) on the MWCs (Ref. 001-01 through 004-01) on a staged basis. The installation shall be completed according to the following schedule;

   a. The LN™ system installed on the first MWC no later than the end of the 2nd quarter 2019,

   b. The LN™ system installed on the second MWC no later than the end of the 4th quarter 2019,

   c. The LN™ system installed on the third MWC no later than the end of the 4th quarter 2020, and

   d. The LN™ system installed on the fourth MWC no later than the end of the 4th quarter 2021.

   (9VAC5-80-850 and 9VAC5-40-7420)

3. **Emission Controls** – Following the installation of each LN™ system on the MWCs, (Ref. 001-01 through 004-01) there shall be no more than a 180-day testing and optimization period for the respective unit. Completion of the testing/optimization period would mark the start of the revised NO_X emission limits as specified in Condition 4.
(9VAC5-80-850 and 9VAC5-40-7420)

EMISSION LIMITS

4. **Process Emission Limits** – No later than the testing and optimization of the LN™ system on each of the MWCs (Ref. 001-01 through 004-01), as referenced in Condition 3 above, NO_X emissions from such MWC shall not exceed the following:

   a. Daily Average Nitrogen Oxides
   110 ppmvd @ 7% O_2.

   b. Annual Average Nitrogen Oxides
   90 ppmvd @ 7% O_2.

   c. The daily average is defined as the hourly rolling average of all hourly average emission concentrations (i.e. 24 hourly averages in a 24-hour period). The 24-hour average calculation should exclude those periods in which no waste was being combusted, when the MWC was not on-line or during periods of startup, shutdown or malfunction.

d. The annual average emissions shall be calculated on a daily basis using the daily average comprising all operating days in the year. Compliance for the annual average period shall be demonstrated daily by averaging the most recently completed daily average with the preceding yearly daily average emissions. The 24-hour average used for the annual average calculation shall begin at 12:00 midnight and continue to the following 12:00 midnight.

Compliance with these emission standards shall be determined by continuous emissions monitors (CEMS) or performance tests.

Compliance with the annual average nitrogen oxide emission limit for each MWC shall begin upon completion of 12 calendar months after the date of this permit, or 12 calendar months following the installation, testing and optimization of the LN™ system on the respective MWC, whichever is later for that unit.
(9VAC5-80-850 and 9VAC5-40-7420)

MONITORING

5. **CEMS** – A continuous emission monitoring system (CEMS) consisting of a nitrogen oxides (NO_X) pollutant concentration monitor, an oxygen (O_2) diluent monitor, and an automated data acquisition and handling system meeting the applicable design specifications of 40 CFR Part 60, Appendix B shall be installed to measure and record the emissions of NO_X from each MWC (Ref. 001-01 through 004-01) exhaust stack as ppmvd, corrected to 7% O_2. The CEMS shall be installed, calibrated, maintained, audited and operated in accordance with the requirements of 40 CFR 60.13, 40 CFR 60, Appendices B and F, as applicable, or DEQ approved procedures which are equivalent to the requirements of 40 CFR §60.13 and 40 CFR 60, Appendices B and F, as applicable. Data shall be reduced to one-hour averages and 24-hour rolling averages using procedures approved by the Air Compliance Manager of the DEQ's Northern Regional Office (NRO). The span value for the NO_X monitor shall be 125 percent of the maximum estimated hourly potential NO_X emissions of the MWC unit and the O_2 monitor shall be 25 percent O_2. Each CEM shall be provided with adequate access for inspection and shall be in operation when the MWC (Ref. 001-01 through 004-01) is operating.
(9VAC5-80-850 and 9VAC5-40-7420)

6. **CEMS Quality Control Program** – A CEMS quality control program which meets the requirements of 40 CFR §60.13 and 40 CFR Part 60, Appendix F shall be implemented for all continuous monitoring systems, except that Relative Accuracy Test Audits (RATAs) may be required less frequently if approved by DEQ.
(9VAC5-80-850 and 9VAC5-40-7420)

7. **CEMS Valid Data Collection** – At a minimum, valid NO_X CEMS hourly averages shall be obtained as specified below for 75 percent of the operating hours per day for 90 percent of the operating days per calendar quarter that each MWC unit is combusting MSW.

   a. At least 2 data points per hour shall be used to calculate each 1-hour arithmetic average.

b. Each NO_X 1-hour arithmetic average shall be corrected to 7 percent O_2 on an hourly basis using the 1-hour arithmetic average of the O_2 CEMS data.

(9 VAC 5-80-890 and 9VAC5-40-8140 G)

8. **CEMS Data** – All valid NO_X CEMS data shall be used in calculating emission averages even if the minimum CEMS data requirements of Condition 7 are not met.
(9VAC5-80-890 and 9VAC5-40-8140 G)

TESTING

9. **Emission Testing** – Each municipal waste combustor (Ref. 001-01 through 004-01) shall be constructed/modified/installed to allow for emissions testing upon reasonable notice at any time, using appropriate methods. This includes constructing the facility/equipment such that volumetric flow rates and pollutant emission rates are accurately determined by applicable test methods. The permittee shall provide sampling ports when requested at the appropriate locations and safe sampling platforms provided.
(9VAC5-80-850, 9VAC5-80-880, and 9VAC5-40-7490)

RECORDS

10. **On Site Records** – The permittee shall maintain records of emission data and operating parameters as necessary to demonstrate compliance with this permit. The content and format of such records shall be arranged with the Air Compliance Manager of the DEQ's NRO. These records shall include, but are not limited to;

    a. All 1-hour average NO_X emission concentrations as specified in Conditions 4 and 7.

    b. All 24-hour daily arithmetic average NO_X emission concentrations as specified in Condition 4.

    c. All annual NO_X emission concentrations as specified in Condition 4.

    d. Each calendar date for which the minimum number of hours of any of the NO_X data have not been obtained including reasons for not obtaining sufficient data and a description of corrective actions taken.

    e. The NO_X emission data, or operational data that have been excluded from the calculation of average emission concentrations or parameters, and the reasons for excluding the data.

    f. The permittee shall record the results of daily drift tests, quarterly accuracy determinations, percent operating time, and RATA for NO_X and O_2 CEMS, as applicable, as required under 40 CFR Part 60, Appendix F, Procedure 1.

    g. Scheduled and unscheduled maintenance and operator training.

The records shall be maintained onsite in either paper copy or computer-readable format, unless the Air Compliance Manager of the DEQ's NRO approves an alternative format and shall be available on-site for inspection by DEQ for a period of at least five years.
(9VAC5-80-850, 9VAC5-80-900, and 9VAC5-40-7510)

NOTIFICATIONS

11. **Emission Controls** – The permittee shall submit to the Regional Air Compliance Manager of DEQ's NRO, a notification of the dates of the commencement and completion of the installation of the LN™ systems on each MWC (Ref. 001-01 through 004-01), postmarked no later than 30 days after such dates, or no later than 30 days after the date of this permit, whichever is later.
(9VAC5-80-850, 9VAC5-80-900 and 9VAC5-7510)

12. **Emission Controls** – The permittee shall submit to the Regional Air Compliance Manager of DEQ's NRO the date of the completion of the testing/optimization period for each MWC, postmarked no later than 30 days after such date, or no later than 30 days after the date of this permit, whichever is later.
(9VAC5-80-850, 9VAC5-80-900 and 9VAC5-7510)

REPORTING

13. **CEMS Reports** – The permittee shall furnish written reports to the Air Compliance Manager of the DEQ's NRO of excess emissions from any process monitored by a CEMS on a quarterly basis, postmarked no later than the 30th day following the end of the calendar quarter. These reports shall include, but are not limited to the following information:

    a. The magnitude of excess emissions, any conversion factors used in the calculation of excess emissions, and the date and time of commencement and completion of each period of excess emissions;

    b. Specific identification of each period of excess emissions that occurs during startups, shutdowns, and malfunctions of the process, the nature and cause of the malfunction (if known), the corrective action taken or preventative measures adopted;

    c. The date and time identifying each period during which the continuous monitoring system was inoperative except for zero and span checks, other quality assurance (as required in 40 CFR 60, Appendix F) and the nature of the system repairs or adjustments; and

    d. When no excess emissions have occurred or the continuous monitoring systems have not been inoperative, repaired or adjusted, such information shall be stated in that report.

    (9VAC5-80-850 and 9VAC5-40-7420)

14. **NOx Emissions Reporting –** The permittee shall submit semi-annual reports to the Regional Air Compliance Manager of DEQ's NRO for each semi-annual period that emissions exceed the limits of Condition 4. The periods covering each semi-annual period shall be January 1 through June 30 and July 1 through December 31.
(9VAC5-80-900)

15. **NOx Emissions Reporting** – The permittee shall submit the data reports required in Condition 14 no later than March 1 and September 1 of each year following the semiannual period in which the data were collected, unless otherwise approved by the Air Compliance Manager of the DEQ's NRO.
(9VAC5-80-900)

GENERAL CONDITIONS

16. **Permit Limitations –** Except to the extent that conditions in this permit may be more stringent, this permit does not supersede or replace any other valid permit, regulatory or statutory requirement. Furthermore, this approval to operate shall not relieve Covanta Fairfax, Inc. (CFI) of the responsibility to comply with all other local, state and federal regulations, including permit regulations.
(9VAC5-80-850)

17. **Federal Enforceability** – Once the permit is approved by the U.S. Environmental Protection Agency into the Commonwealth of Virginia State Implementation Plan, the permit is enforceable by EPA and citizens under the federal Clean Air Act.
(9VAC5-80-850)

18. **Permit Revision/Repeal** – The Board may revise (modify, rewrite, change or amend) or repeal this permit with the consent of CFI, for good cause shown by CFI, or on its own motion provided approval of the revision or repeal is accomplished in accordance with Regulations of the Board and the Administrative Process Act (§ 2.2-4000 *et seq.*). Such revision or repeal shall not be effective until the revision or repeal is approved by the U.S. Environmental Protection Agency following the requirements of 40 CFR Part 51 (Requirements for Preparation, Adoption, and Submittal of Implementation Plans).
(9VAC5-80-850)

19. **Failure to Comply –** Failure by CFI to comply with any of the conditions of this permit shall constitute a violation of a Permit of the Board. Failure to comply may result in a Notice of Violation and civil penalty. Nothing herein shall waive the initiation of appropriate enforcement actions or the issuance of orders as appropriate by the Board as a result of such violations. Nothing herein shall affect appropriate enforcement actions by any other federal, state, or local regulatory authority.
(9VAC5-80-850)

20. **Right of Entry –** The permittee shall allow authorized local, state, and federal representatives, upon the presentation of credentials:

    a. To enter upon the permittee's premises on which the facility is located or in which any records are required to be kept under the terms and conditions of this permit;

b. To have access to and copy at reasonable times any records required to be kept under the terms and conditions of this permit or the State Air Pollution Control Board Regulations;

c. To inspect at reasonable times any facility, equipment, or process subject to the terms and conditions of this permit or the State Air Pollution Control Board Regulations; and

d. To sample or test at reasonable times.

For purposes of this condition, the time for inspection shall be deemed reasonable during regular business hours or whenever the facility is in operation. Nothing contained herein shall make an inspection time unreasonable during an emergency.
(9VAC5-170-130 and 9VAC5-80-850)

21. **Notification for Facility or Control Equipment Malfunction** – The permittee shall furnish notification to the Regional Air Compliance Manager of DEQ's NRO of malfunctions of the affected facility or related air pollution control equipment that may cause excess emissions for more than one hour. Such notification shall be made as soon as practicable but no later than four daytime business hours after the malfunction is discovered. The permittee shall provide a written statement giving all pertinent facts, including the estimated duration of the breakdown, within two weeks of discovery of the malfunction. When the condition causing the failure or malfunction has been corrected and the equipment is again in operation, the permittee shall notify the Regional Air Compliance Manager of DEQ's NRO in writing.
(9VAC5-20-180 C and 9VAC5-80-850)

22. **Violation of Ambient Air Quality Standard** – The permittee shall, upon reasonable request of the DEQ, reduce the level of operation or shut down a facility, as necessary to avoid violating any primary ambient air quality standard and shall not return to normal operation until such time as the ambient air quality standard will not be violated.
(9VAC5-20-180 I and 9VAC5-80-850)

23. **Maintenance/Operating Procedures** – At all times, including periods of start-up, shutdown, soot blowing, and malfunction, the permittee shall, to the extent practicable, maintain and operate the affected source, including associated air pollution control equipment, in a manner consistent with good air pollution control practices for minimizing emissions.

The permittee shall take the following measures in order to minimize the duration and frequency of excess emissions, with respect to each municipal waste combustor (Ref. 001-01 through 004-01) air pollution control equipment, and process equipment which affect such emissions:

a. Develop a maintenance schedule and maintain records of all scheduled and non-scheduled maintenance.

b. Maintain an inventory of spare parts.

c. Have available written operating procedures for equipment. These procedures shall be based on the manufacturer's recommendations, as available.

d. Train operators in the proper operation of all such equipment and familiarize the operators with the written operating procedures, prior to their first operation of such equipment. The permittee shall maintain records of the training provided including the names of trainees, the date of training and the nature of the training.

e. Records of maintenance and training shall be maintained on site for a period of five years and shall be made available to DEQ personnel upon request.

(9VAC5-50-20 E and 9VAC5-80-850)

24. **Permit Suspension/Revocation** – This permit may be revoked if the permittee:

a. Knowingly makes material misstatements in the permit application or any amendments to it;

b. Fails to comply with the terms or conditions of this permit;

c. Fails to comply with any emission standards applicable to a permitted emissions unit;

d. Causes emissions from this facility which result in violations of, or interferes with the attainment and maintenance of, any ambient air quality standard;

e. Fails to operate this facility in conformance with any applicable control strategy, including any emission standards or emission limitations, in the State Implementation Plan in effect at the time that an application for this permit is submitted;

f. Fails to comply with the applicable provisions of Articles 6, 8 and 9 of 9VAC5 Chapter 80.

(9VAC5-80-1010)

25. **Change of Ownership** – In the case of a transfer of ownership of a stationary source, the new owner shall abide by any current permit issued to the previous owner. The new owner shall notify the Regional Air Compliance Manager of DEQ's NRO of the change of ownership within 30 days of the transfer.
(9VAC5-80-940)

26. **Permit Copy** – The permittee shall keep a copy of this permit on the premises of the facility to which it applies.
(9VAC5-80-860 D)

Attachment 3

Commonwealth of Virginia

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

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Regional Director

February 8, 2019

Mr. Bryan Donnelly
Facility Manager
Covanta Alexandria/Arlington, Inc.
5301 Eisenhower Avenue
Alexandria, Virginia 22304

Location: City of Alexandria
Registration No.: 71895

Dear Mr. Donnelly:

Attached is a permit to operate a solid waste combustor facility in accordance with the provisions of the Commonwealth of Virginia State Air Pollution Control Board Regulations for the Control and Abatement of Air Pollution. This permit is for the purpose of implementing the "reasonably available control technology" (RACT) requirements of 9 VAC 5-40-7400, 9 VAC 5-40-7420 and 9 VAC 5-40-7430 of the Regulations of the Board. Except to the extent that conditions in this permit may be more stringent, this permit does not supersede or replace any other valid permit. Furthermore, this approval to operate shall not relieve Covanta Alexandria/Arlington, Inc. (CAAI) to comply with all other local, state, and federal permit regulations.

This permit contains legally enforceable conditions. Failure to comply may result in a Notice of Violation and civil penalty. Please read all conditions carefully.

At any time in the future, should CAAI plan any modifications (within the context of the new source review program) of the facility covered by this permit, CAAI shall have the right to apply to the Board for a new source review permit and the Board may consent to such modifications provided such modifications will meet all of the new source review permit program regulatory requirements in existence at that time.

Issuance of this permit is a case decision. The Regulations, at 9 VAC 5-170-200, provide that you may request a formal hearing from this case decision by filing a petition with the Board within 30 days after this permit is mailed or delivered to you. Please consult that and other relevant provisions for additional requirements for such requests.

Additionally, as provided by Rule 2A:2 of the Supreme Court of Virginia, you have 30 days from the date you actually received this permit or the date on which it was mailed to you, whichever occurred first, within which to initiate an appeal to court by filing a Notice of Appeal with:

Mr. David K. Paylor, Director
Department of Environmental Quality
P. O. Box 1105
Richmond, VA 23218

In the event that you receive this permit by mail, three days are added to the period in which to file an appeal. Please refer to Part Two A of the Rules of the Supreme Court of Virginia for additional information including filing dates and the required content of the Notice of Appeal.

If you have any questions concerning this permit, please contact the Northern Regional Office at (703) 583-3800.

Sincerely,

Thomas A. Faha
Regional Director

TAF/JBL/HGB/71895-RACT SOP (2-8-2019)

Attachment: Permit

cc: Joseph Walsh, Covanta (electronic file submission)
Riley Burger, EPA Region III
Manager/Inspector, Air Compliance Manager (electronic file submission)

Commonwealth of Virginia

VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

NORTHERN REGIONAL OFFICE
13901 Crown Court, Woodbridge, Virginia 22193
(703)583-3800 FAX (703) 583-3821
www.deq.virginia.gov

Matthew J. Strickler
Secretary of Natural Resources

David K. Paylor
Director
(804) 698-4000

Thomas A. Faha
Regional Director

STATIONARY SOURCE PERMIT TO OPERATE

In compliance with the Federal Clean Air Act and the Commonwealth of Virginia Regulations for the Control and Abatement of Air Pollution,

Covanta Alexandria/Arlington, Inc.
5301 Eisenhower Ave.
Alexandria, Virginia 22304
Registration No.: 71895

is authorized to operate

a municipal solid waste combustor facility

located at

5301 Eisenhower Ave.
Alexandria, VA 22304

in accordance with the Conditions of this permit.

Approved on February 8, 2019.

Thomas A. Faha
Regional Director

Permit consists of 9 pages.
Permit Conditions 1 to 26.

INTRODUCTION/PURPOSE

This permit is, (i) for the purpose of implementing the "reasonably available control technology" (RACT) requirements of 9VAC5-40-7420 of the State Air Pollution Control Board Regulations for the Control and Abatement of Air Pollution ("Regulations"), and (ii) establishes control technology and other requirements for the control of nitrogen oxides (NO_X) emissions from Covanta Alexandria/Arlington, Incorporated (CAAI) in the Northern Virginia Ozone Non-Attainment Area and the Ozone Transport Region in Virginia. These RACT requirements shall be the legal and regulatory basis for control of NO_X emissions from this facility.

Words or terms used in this permit shall have meanings as provided in 9VAC5-10-20 of the State Air Pollution Control Board Regulations for the Control and Abatement of Air Pollution. The regulatory reference or authority for each condition is listed in parentheses () after each condition.

The availability of information submitted to the Department of Environmental Quality (DEQ) or the Board will be governed by applicable provisions of the Freedom of Information Act, §§ 2.2-3700 through 2.2-3714 of the Code of Virginia, § 10.1-1314 (addressing information provided to the Board) of the Code of Virginia, and 9VAC5-170-60 of the State Air Pollution Control Board Regulations. Information provided to federal officials is subject to appropriate federal law and regulations governing confidentiality of such information.

EQUIPMENT LIST

Equipment List - Equipment at this facility consists of the following:

Emission Unit ID	Equipment Description	Rated Capacity	Pollutant(s)*
001-02	Keeler/Dorr-Oliver municipal waste combustor with Martin stokers Model # MK 325 (Construction Date Feb. 1988)	121.8 MMBtu	NO_X
002-02	Keeler/Dorr-Oliver municipal waste combustor with Martin stokers Model # MK 325 (Construction Date Feb. 1988)	121.8 MMBtu	NO_X
003-02	Keeler/Dorr-Oliver municipal waste combustor with Martin stokers Model # MK 325 (Construction Date Feb. 1988)	121.8 MMBtu	NO_X

*Pollutant(s) listed for each specified emission unit is only as 9VAC5-40-7420 applies.

PROCESS REQUIREMENTS

1. **Emission Controls** – Upon completion of the installation and optimization period per Conditions 2 and 3, respectively, nitrogen oxides (NO_X) emissions from each municipal waste combustor (MWC) (Ref. 001-02, 002-02, and 003-02) shall be controlled by furnace design, proper operation, good combustion practices, ammonia injection (selective non-catalytic reduction (SNCR)), and the Covanta proprietary low NO_X combustion system (LN™). Until that time, the NO_X emissions shall be controlled by furnace design, proper operation, and ammonia injection (SNCR). The SNCR and LN™ system shall be provided with adequate access for inspection and shall be in operation when each municipal waste combustor (Ref. 001-02, 002-02, and 003-02) is operating.
(9VAC5-80-850 and 9VAC5-40-7420)

2. **Emission Controls** – The permittee shall install the Covanta proprietary low NO_X combustion system (LN™) on the MWCs (Ref. 001-02, 002-02, and 003-02) on a staged basis. The installation shall be completed according to the following schedule;

   a. The LN™ system installed on the first MWC no later than the end of the 4th quarter 2019,

   b. The LN™ system installed on the second MWC no later than the end of the 4th quarter 2020, and

   c. The LN™ system installed on the third MWC no later than the end of the 4th quarter 2021.

   (9VAC5-80-850 and 9VAC5-40-7420)

3. **Emission Controls** – Following the installation of each LN™ systems on the MWCs (Ref. 001-02, 002-02, and 003-02) there shall be no more than a 180-day testing and optimization period, for the respective unit. Completion of the testing/optimization period would mark the start of the revised NO_X emission limits as specified in Condition 4.
(9VAC5-80-850 and 9VAC5-40-7420)

EMISSION LIMITS

4. **Process Emission Limits** – No later than the testing and optimization period of the LN™ system on each of the MWCs (Ref. 001-02, 002-02, and 003-02), as referenced in Condition 3 above, NO_X emissions from such MWC shall not exceed the following:

   a. Daily Average Nitrogen Oxides
      110 ppmvd @ 7% O_2.

   b. Annual Average Nitrogen Oxides
      90 ppmvd @ 7% O_2.

   c. The daily average is defined as the hourly rolling average of all hourly average emission concentrations (i.e. 24 hourly averages in a 24-hour period). The 24-hour average calculation should exclude those periods in which no waste was being combusted, when the MWC was not on-line or during periods of startup, shutdown or malfunction.

d. The annual average emissions shall be calculated on a daily basis using the daily average comprising all operating days in the year. Compliance for the annual average period shall be demonstrated daily by averaging the most recently completed daily average with the preceding yearly daily average emissions. The 24-hour average used for the annual average calculation shall begin at 12:00 midnight and continue to the following 12:00 midnight.

Compliance with these emission standards shall be determined by continuous emissions monitors (CEMS) or performance tests.

Compliance with the annual average nitrogen oxide emission limit for each MWC shall begin upon completion of 12 calendar months after the date of this permit, or 12 calendar months following the installation, testing and optimization of the LN™ system on the respective MWC, whichever is later for that unit.
(9VAC5-80-850 and 9VAC5-40-7420)

MONITORING

5. **CEMS –** A continuous emission monitoring system (CEMS) consisting of a nitrogen oxides (NO_X) pollutant concentration monitor, an oxygen (O_2) diluent monitor, and an automated data acquisition and handling system meeting the applicable design specifications of 40 CFR Part 60, Appendix B shall be installed to measure and record the emissions of NO_X from each MWC (Ref. 001-02, 002-02, and 003-02) exhaust stack as ppmvd corrected to 7% O_2. The CEMS shall be installed, calibrated, maintained, audited and operated in accordance with the requirements of 40 CFR 60.13, 40 CFR 60, Appendices B and F, as applicable, or DEQ approved procedures which are equivalent to the requirements of 40 CFR §60.13 and 40 CFR 60, Appendices B and F, as applicable. Data shall be reduced to one-hour averages and 24-hour rolling averages using procedures approved by the Air Compliance Manager of the DEQ's Northern Regional Office (NRO). The span value for the NO_X monitor shall be 125 percent of the maximum estimated hourly potential NO_X emissions of the MWC unit and the O_2 monitor shall be 25 percent O_2. Each CEM shall be provided with adequate access for inspection and shall be in operation when the MWC (Ref. 001-02, 002-02, and 003-02) is operating.
(9VAC5-80-850 and 9VAC5-40-7420)

6. **CEMS Quality Control Program –** A CEMS quality control program which meets the requirements of 40 CFR 60.13 and 40 CFR Part 60, Appendix F shall be implemented for all continuous monitoring systems, except that Relative Accuracy Test Audits (RATAs) may be required less frequently if approved by DEQ.
(9VAC5-80-850 and 9VAC5-40-7420)

7. **CEMS Valid Data Collection –** At a minimum, valid NO_X CEMS hourly averages shall be obtained as specified below for 75 percent of the operating hours per day for 90 percent of the operating days per calendar quarter that each MWC unit is combusting MSW.

   a. At least 2 data points per hour shall be used to calculate each 1-hour arithmetic average.

b. Each NO_X 1-hour arithmetic average shall be corrected to 7 percent O_2 on an hourly basis using the 1-hour arithmetic average of the O_2 CEMS data.

(9VAC5-80-890 and 9VAC5-40-8140 G)

8. **CEMS Data** – All valid NO_X CEMS data shall be used in calculating emission averages even if the minimum CEMS data requirements of Condition 7 are not met.
(9VAC5-80-890 and 9VAC5-40-8140 G)

TESTING

9. **Emission Testing** – Each municipal waste combustor (Ref. 001-02, 002-02, and 003-02) shall be constructed/modified/installed to allow for emissions testing upon reasonable notice at any time, using appropriate methods. This includes constructing the facility/equipment such that volumetric flow rates and pollutant emission rates are accurately determined by applicable test methods. The permittee shall provide sampling ports when requested at the appropriate locations and safe sampling platforms provided.
(9VAC5-80-850, 9VAC5-80-880, and 9VAC5-40-7490)

RECORDS

10. **On Site Records** – The permittee shall maintain records of emission data and operating parameters as necessary to demonstrate compliance with this permit. The content and format of such records shall be arranged with the Air Compliance Manager of the DEQ's NRO. These records shall include, but are not limited to;

    a. All 1-hour average NO_X emission concentrations as specified in Conditions 4 and 7.

    b. All 24-hour daily arithmetic average NO_X emission concentrations as specified in Condition 4.

    c. All annual NO_X emission concentrations as specified in Condition 4.

    d. Each calendar date for which the minimum number of hours of any of the NO_X data have not been obtained including reasons for not obtaining sufficient data and a description of corrective actions taken.

    e. The NO_X emission data, or operational data that have been excluded from the calculation of average emission concentrations or parameters, and the reasons for excluding the data.

    f. The permittee shall record the results of daily drift tests, quarterly accuracy determinations, percent operating time, and RATA for NO_X and O_2 CEMS, as required under 40 CFR Part 60, Appendix F, Procedure 1.

    g. Scheduled and unscheduled maintenance and operator training.

The records shall be maintained onsite in either paper copy or computer-readable format, unless the Air Compliance Manager of the DEQ's NRO approves an alternative format and shall be available on-site for inspection by DEQ for a period of at least five years.
(9VAC5-80-850, 9VAC5-80-900, and 9VAC5-40-7510)

NOTIFICATIONS

11. **Emission Controls** – The permittee shall submit to the Regional Air Compliance Manager of DEQ's NRO, a notification of the dates of the commencement and completion of the installation of the LN^{TM} systems on each MWC (Ref. 001-02, 002-02, and 003-02), postmarked no later than 30 days after such dates, or no later than 30 days after the date of this permit, whichever is later.
(9VAC5-80-850, 9VAC5-80-900 and 9VAC5-7510)

12. **Emission Controls** – The permittee shall submit to the Regional Air Compliance Manager of DEQ's NRO, the date of the completion of the testing/optimization period for each MWC, postmarked no later than 30 days after such date, or no later than 30 days after the date of this permit, whichever is later.
(9VAC5-80-850, 9VAC5-80-900 and 9VAC5-7510)

REPORTING

13. **CEMS Reports** – The permittee shall furnish written reports to the Air Compliance Manager of the DEQ's NRO of excess emissions from any process monitored by a CEMS on a quarterly basis, postmarked no later than the 30th day following the end of the calendar quarter. These reports shall include, but are not limited to the following information:

    a. The magnitude of excess emissions, any conversion factors used in the calculation of excess emissions, and the date and time of commencement and completion of each period of excess emissions;

    b. Specific identification of each period of excess emissions that occurs during startups, shutdowns, and malfunctions of the process, the nature and cause of the malfunction (if known), the corrective action taken or preventative measures adopted;

    c. The date and time identifying each period during which the continuous monitoring system was inoperative except for zero and span checks, other quality assurance (as required in 40 CFR 60, Appendix F) and the nature of the system repairs or adjustments; and

    d. When no excess emissions have occurred or the continuous monitoring systems have not been inoperative, repaired or adjusted, such information shall be stated in that report.

    (9VAC5-80-850 and 9VAC5-40-7420)

14. **NOx Emissions Reporting –** The permittee shall submit semi-annual reports to the Regional Air Compliance Manager of DEQ's NRO for each semi-annual period that emissions exceed the limits of Condition 4. The periods covering each semi-annual period shall be January 1 through June 30 and July 1 through December 31.
(9VAC5-80-900)

15. **NOx Emissions Reporting –** The permittee shall submit the data reports required in Condition 14 no later than March 1 and September 1 of each year following the semiannual period in which the data were collected, unless otherwise approved by the Air Compliance Manager of the DEQ's NRO.
(9VAC5-80-900)

GENERAL CONDITIONS

16. **Permit Limitations** – Except to the extent that conditions in this permit may be more stringent, this permit does not supersede or replace any other valid permit, regulatory or statutory requirement. Furthermore, this approval to operate shall not relieve Covanta Alexandria/Arlington, Inc. of the responsibility to comply with all other local, state and federal regulations, including permit regulations.
(9VAC5-80-850)

17. **Federal Enforceability** – Once the permit is approved by the U.S. Environmental Protection Agency into the Commonwealth of Virginia State Implementation Plan, the permit is enforceable by EPA and citizens under the federal Clean Air Act.
(9VAC5-80-850)

18. **Permit Revision/Repeal –** The Board may revise (modify, rewrite, change or amend) or repeal this permit with the consent of Covanta Alexandria/Arlington, Inc., for good cause shown by Covanta Alexandria/Arlington, Inc., or on its own motion provided approval of the revision or repeal is accomplished in accordance with Regulations of the Board and the Administrative Process Act (§ 2.2-4000 *et seq.*). Such revision or repeal shall not be effective until the revision or repeal is approved by the U.S. Environmental Protection Agency following the requirements of 40 CFR Part 51 (Requirements for Preparation, Adoption, and Submittal of Implementation Plans).
(9VAC5-80-850)

19. **Failure to Comply –** Failure by Covanta Alexandria/Arlington, Inc. to comply with any of the conditions of this permit shall constitute a violation of a Permit of the Board. Failure to comply may result in a Notice of Violation and civil penalty. Nothing herein shall waive the initiation of appropriate enforcement actions or the issuance of orders as appropriate by the Board as a result of such violations. Nothing herein shall affect appropriate enforcement actions by any other federal, state, or local regulatory authority.
(9VAC5-80-850)

20. **Right of Entry** – The permittee shall allow authorized local, state, and federal representatives, upon the presentation of credentials:

    a. To enter upon the permittee's premises on which the facility is located or in which any records are required to be kept under the terms and conditions of this permit;

    b. To have access to and copy at reasonable times any records required to be kept under the terms and conditions of this permit or the State Air Pollution Control Board Regulations;

    c. To inspect at reasonable times any facility, equipment, or process subject to the terms and conditions of this permit or the State Air Pollution Control Board Regulations; and

    d. To sample or test at reasonable times.

    For purposes of this condition, the time for inspection shall be deemed reasonable during regular business hours or whenever the facility is in operation. Nothing contained herein shall make an inspection time unreasonable during an emergency.
    (9VAC5-170-130 and 9VAC5-80-850)

21. **Notification for Facility or Control Equipment Malfunction** – The permittee shall furnish notification to the Regional Air Compliance Manager of DEQ's NRO of malfunctions of the affected facility or related air pollution control equipment that may cause excess emissions for more than one hour. Such notification shall be made as soon as practicable but no later than four daytime business hours after the malfunction is discovered. The permittee shall provide a written statement giving all pertinent facts, including the estimated duration of the breakdown, within two weeks of discovery of the malfunction. When the condition causing the failure or malfunction has been corrected and the equipment is again in operation, the permittee shall notify the Regional Air Compliance Manager of DEQ's NRO in writing.
    (9VAC5-20-180 C and 9VAC5-80-850)

22. **Violation of Ambient Air Quality Standard** – The permittee shall, upon reasonable request of the DEQ, reduce the level of operation or shut down a facility, as necessary to avoid violating any primary ambient air quality standard and shall not return to normal operation until such time as the ambient air quality standard will not be violated.
    (9VAC5-20-180 I and 9VAC5-80-850)

23. **Maintenance/Operating Procedures** – At all times, including periods of start-up, shutdown, soot blowing, and malfunction, the permittee shall, to the extent practicable, maintain and operate the affected source, including associated air pollution control equipment, in a manner consistent with good air pollution control practices for minimizing emissions.

    The permittee shall take the following measures in order to minimize the duration and frequency of excess emissions, with respect to municipal waste combustor (Ref. 001-02, 002-02, and 003-02) air pollution control equipment, and process equipment which affect such emissions:

    a. Develop a maintenance schedule and maintain records of all scheduled and non-scheduled maintenance.

    b. Maintain an inventory of spare parts.

c. Have available written operating procedures for equipment. These procedures shall be based on the manufacturer's recommendations, as available.

d. Train operators in the proper operation of all such equipment and familiarize the operators with the written operating procedures, prior to their first operation of such equipment. The permittee shall maintain records of the training provided including the names of trainees, the date of training and the nature of the training.

e. Records of maintenance and training shall be maintained on site for a period of five years and shall be made available to DEQ personnel upon request.

(9VAC5-50-20 E and 9VAC5-80-850)

24. **Permit Suspension/Revocation** – This permit may be revoked if the permittee:

a. Knowingly makes material misstatements in the permit application or any amendments to it;

b. Fails to comply with the terms or conditions of this permit;

c. Fails to comply with any emission standards applicable to a permitted emissions unit;

d. Causes emissions from this facility which result in violations of, or interferes with the attainment and maintenance of, any ambient air quality standard;

e. Fails to operate this facility in conformance with any applicable control strategy, including any emission standards or emission limitations, in the State Implementation Plan in effect at the time that an application for this permit is submitted;

f. Fails to comply with the applicable provisions of Articles 6, 8 and 9 of 9VAC5 Chapter 80.

(9VAC5-80-1010)

25. **Change of Ownership** – In the case of a transfer of ownership of a stationary source, the new owner shall abide by any current permit issued to the previous owner. The new owner shall notify the Regional Air Compliance Manager of DEQ's NRO of the change of ownership within 30 days of the transfer.
(9VAC5-80-940)

26. **Permit Copy** – The permittee shall keep a copy of this permit on the premises of the facility to which it applies.
(9VAC5-80-860 D)

Attachment 4

AIR POLLUTION EMISSION CONTROL
AND MONITORING AGREEMENT

THIS AIR POLLUTION EMISSION CONTROL AND MONITORING AGREEMENT (the "Agreement") is made and entered into this 4th day of November, 2020, by and among the Mayor and City Council of Baltimore ("City"), and Wheelabrator Baltimore, L.P. ("Wheelabrator" or the "Company") (together, the City and Wheelabrator are referred to herein as the "Parties" and individually as a "Party").

Recitals

WHEREAS, Wheelabrator operates a municipal waste combuster in the City of Baltimore, Maryland (the "Facility"); and

WHEREAS, in 2018, the City enacted the Baltimore Clean Air Act, Council Bill 18-0306, Ordinance 19-232 (the "BCAA"), which imposed air pollution emissions limits and monitoring requirements on Wheelabrator's Facility that were more stringent than those set forth in the Wheelabrator Facility's Title V/Part 70 Permit; and

WHEREAS, Wheelabrator filed a Complaint against the City in the U.S. District Court for the District of Maryland styled *Wheelabrator Baltimore, L.P., et al. v. Mayor and City Council of Baltimore*, Case No. 1:19-cv-01264-GLR (the "Litigation"), in which it alleged, *inter alia*, that the Baltimore Clean Air Act was preempted by federal and state law; and

WHEREAS, the City denies and disputes Wheelabrator's allegations in the Litigation; and

WHEREAS, the U.S. District Court for the District of Maryland granted partial summary judgment in favor of Wheelabrator on the preemption issue, finding that the BCAA was preempted; and

WHEREAS, the City noted an appeal to the U.S. Court of Appeals for the Fourth Circuit of the preemption ruling, and Wheelabrator cross-appealed on a separate issue (the "Appeal"); and

WHEREAS, the City and Wheelabrator now desire to fully compromise and settle finally and forever any now existing or future claims or disputes asserted or which could have been asserted in the Litigation, of whatever nature, including without limitation, any and all claims, causes of action, costs and demands of whatever name or nature, in any manner arising, growing out of, or on account of the Litigation.

Agreement

NOW THEREFORE, as an inducement to the City's agreement to the Settlement Agreement and Release dated November 4, 2020 and the Related Agreements set forth therein, and in consideration of the mutual promises and agreements set forth herein, and for other good and valuable consideration, the receipt and sufficiency of which is hereby acknowledged, Wheelabrator and the City agree as follows:

1. Definitions. Capitalized terms not otherwise defined in this Agreement shall have the respective meanings given in the Waste Disposal Agreement. The following are definitions of certain terms used in this Agreement.

"Acceptable Waste" means all household garbage, trash, rubbish, and refuse, but excluding all Unacceptable Waste. In no event shall Acceptable Waste include any materials defined herein as Unacceptable Waste. In addition, the Parties recognize that some substances which are not, as of the Effective Date, considered harmful or of a toxic nature or dangerous, may be determined by the EPA or any other federal, state or local Governmental Body subsequent to the Effective Date to be hazardous, toxic, dangerous, or harmful, and at the time of receipt of notice from the Company to the City following such determination, such substances shall cease to be Acceptable Waste and become Unacceptable Waste. If any Governmental Body having appropriate jurisdiction shall determine that any chemicals or other substances which are not, as of the Effective Date, included within this definition of Acceptable Waste because they are considered harmful or of a toxic nature or dangerous, are not harmful, toxic or dangerous, the Company, the Authority and the City may mutually agree that such chemicals or other substances shall be Acceptable Waste for the purposes of this Agreement.

"ASNCR" means an advanced selective non-catalytic reduction NOx control system incorporating real time furnace temperature monitoring, independent NOx reducing reagent injection levels and control algorithms.

"Air Emission Requirements" means the air emission limits set forth in Section 3.

"Applicable Law" means: (1) any federal, state or local law, code or regulation; (2) any formally adopted and generally applicable rule, requirement, determination, standard, policy, implementation schedule or other order of any Governmental Body having appropriate jurisdiction; (3) any established interpretation of law or regulation utilized by an appropriate Governmental Body if such interpretation is documented by such Governmental Body and generally applicable; and (4) any Governmental Approval, in each case having the force of law and applicable from time to time to: (a) the siting, design, acquisition, construction, equipping, financing, ownership, possession, start up, testing, operation, maintenance, repair, replacement or management of municipal solid waste resource recovery systems, including the Facility; (b) the air, noise, dust and odor emissions therefrom; (c) the transfer, handling, processing, transportation or disposal of Unacceptable Waste, Residue and other by-products produced thereby; (d) the performance by a Party of its obligations hereunder; or (e) any other transaction or matter contemplated hereby (including, without limitation, any of the foregoing which pertain to solid waste processing, waste disposal, health, safety, fire, environmental protection, labor relations, building codes and non-discrimination).

"Authority" means the Northeast Maryland Waste Disposal Authority, a body politic and corporate organized and existing under the laws of the State of Maryland.

"Completion" means (i) the completion of the Facility Improvements in all material respects except for any punchlist and similar items such that the Facility and the Facility Improvements are in good working order in all material respects and (ii) the Facility is meeting the Air Emission Requirements.

"Completion Date" means December 31, 2023, as such date may be extended as a result of a Facility Improvements Uncontrollable Circumstance as provided in this Agreement.

"Continuous Emissions Monitoring" or "CEM" means the continuous emissions monitoring system referred to in Wheelabrator's Title V/Part 70 Permit.

"Facility Improvements" means (i) an ASNCR and (ii) an FF Baghouse on each of the Facility's three boiler unit trains, and (for the avoidance of doubt) includes the Phase 1 Facility Improvements and the Phase 2 Facility Improvements

"Facility Improvements Uncontrollable Circumstance" means any act, event, or condition that is beyond the reasonable control of the Party relying thereon as justification for not performing an obligation, covenant or agreement or complying with any condition required of such Party under this Agreement, to the extent such act, event or condition is not the result of or does not arise from the willful or negligent act, error or omission, failure to exercise reasonable care or diligence, equipment failure or breach of this Agreement on the part of the Party. Such acts, conditions or events include, but are not limited to, the following (but only to the extent and for such duration as such act, condition or event reasonably affects a Party's performance under this Agreement):

(a) (i) an act of God, epidemic, landslide, lightning, earthquake, fire, explosion, storm, flood or similar occurrence, an act of the public enemy, war, blockade, insurrection, riot, general arrest or restraint of government and people, civil disturbance or similar occurrence, or (ii) a strike, lockout, or similar industrial or labor action;

(b) the order and/or judgment of any federal, state or local court or Governmental Body, if it is not also the result of willful or negligent action or a lack of reasonable diligence of the non-performing Party, provided that the contesting in good faith of any such order and/or judgment shall not constitute or be construed as a willful or negligent action or a lack of reasonable diligence of such non-performing Party;

(c) the failure to obtain, or suspension, termination, interruption or failure of renewal of any Governmental Approval essential to the operation, ownership or possession of the Facility or the design, construction, equipping or testing of the Facility Improvements as provided for herein or required with respect hereto or the performance by a Party of its obligations hereunder, if it is not also the result of willful or negligent action or a lack of reasonable diligence of the non-performing Party, provided that the contesting in good faith of any such failure to obtain, suspension, termination, interruption or failure of renewal shall not be construed as a willful or negligent action or a lack of reasonable diligence of such non-performing Party; and

(d) a Change in Law;

(e) the failure of any subcontractor or supplier (except a subcontractor or supplier which is an Affiliate of the Company or the managing partner thereof) selected with reasonable care and good faith to furnish labor, services, materials, or equipment in connection with the operation or maintenance of the Facility or the design, construction, equipping or testing of the Facility Improvements by the date agreed to, provided that the non-performing Party is not reasonably able timely to obtain substitute labor, services, materials or equipment; and

(f) the failure or inability of the City to accept for disposal residue or other materials deliverable pursuant to the Residue Disposal Contract; or the failure of the jurisdiction in which the Facility or any Residue Landfill is situated or the appropriate federal or state agencies or public utilities having operational jurisdiction in the area of location of the Facility or any Residue Landfill to provide and maintain and assure the maintenance of all utilities, services, sewerage, and water lines to the Facility or such Residue Landfill for operation of the Facility or such Residue Landfill, provided they are essential to the Facility.

"FF Baghouse" means a pulse jet baghouse (fabric filter) utilizing fabric filtration to remove particulate (fly ash, lime and carbon) from the flue gas by collecting particulate on fabric material.

"NO_X" means Nitrogen Oxides.

"NOx Emission Performance Guarantee" means an average 90 parts per million dry volume (PPMVD) corrected at 7% O_2 (calendar year flow rate weighted average basis) of NOX emissions for all three boiler unit trains combined on a calendar year flow rate weighted average basis.

"NOx Reduction Shortfall" has the meaning given to it in Section 4(a) of this Agreement.

"Phase 1 Facility Improvements" means the ASNCR and the first of three FF Baghouse systems.

"Phase 2 Facility Improvements" means the second and third FF Baghouse systems.

"Shutdown" shall mean any shutdown, reduction in capacity or any other inability of the Facility to accept and dispose of such tonnages of Acceptable Waste as the Company is required to accept from the Authority from time to time under Section 2.1(a) of the Waste Disposal Agreement, existing, for any reason, on or after the Original Effective Date.

"Subdivision User Contract" means the Amended and Restated Subdivision User Contract dated November 4, 2020 between the Authority and the City.

"TEQ" means $TEQ_{DF}WHO_{98}$, a unit of measurement for dioxins and furans, standardized to toxic equivalents, calculated in accordance with the World Health Organization's 1998 Method.

"Title V/Part 70 Permit" means the Part 70 permit issued to Wheelabrator with respect to the Facility pursuant to Code of Maryland Regulations Section 26.11.03.

"Waste Disposal Agreement" means the Amended and Restated Waste Disposal Agreement dated November 4, 2020 between the Company and the Authority.

2. <u>Facility Improvements.</u>

(a) No later than December 31, 2022, Wheelabrator shall, at its expense, complete the design, permitting, installation, construction, and commencement of operations at the Facility of the Phase 1 Facility Improvements in a good and workmanlike manner and shall furnish, directly through contractors or subcontractors selected by it all work, labor and materials required for the design, construction and equipping of the Phase 1 Facility Improvements. The City and the Authority shall have no responsibility therefor or liability with respect thereto except as expressly provided in this Agreement.

(b) No later than December 31, 2023, Wheelabrator shall, at its expense, complete the design, permitting, installation, construction, and commencement of operations at the Facility of the Phase 2 Facility Improvements in a good and workmanlike manner and shall furnish, directly through contractors or subcontractors selected by it all work, labor and materials required for the design, construction and equipping of the Phase 2 Facility Improvements. The City and Authority shall have no responsibility therefor or liability with respect thereto except as expressly provided in this Agreement.

(c) Wheelabrator shall commence permitting and engineering for the Facility Improvements within 30 days after the execution and delivery of this Agreement and shall carry out such work with reasonable diligence in order to complete the Facility Improvements by the Completion Date.

(d) Wheelabrator shall construct the Facility Improvements so that the Facility will comply with the Air Emissions Requirements and shall include the Air Emissions Requirements in any applicable permit or approval applications for the Facility Improvements. Wheelabrator at its expense shall obtain all permits, licenses and consents required by Applicable Law to construct, install and operate the Facility Improvements. The City shall cooperate in good faith and provide all reasonable assistance and support to the Company in order to assist Wheelabrator in obtaining all required permits and approvals. During the construction of the Facility Improvements Wheelabrator shall comply with the requirements of Article 5, Subtitle 28 of the Baltimore City Code, as applicable.

(e) From the date that Wheelabrator commences design and engineering work on the Facility Improvements until Completion Wheelabrator at its expense shall deliver to the City monthly reports describing the progress of the work on the Facility Improvements, such reports to be delivered no later than the tenth day of each month and describing such progress of the work occurring in the previous month.

(f) As among the City, the Authority, and Wheelabrator, Wheelabrator shall assume total responsibility for payment of all costs arising out of any accident or incident relating to the construction of the Facility Improvements and shall indemnify and hold harmless the City and the Authority and their employees, representatives and agents for all costs (including reasonable attorney's fees) resulting from such accident or incident except to the extent caused by the negligence or willful misconduct of the City or the Authority or their employees, agents or representatives. This paragraph survives expiration or termination of this Agreement.

3. Air Emissions Requirements.

(a) Wheelabrator shall cause the following air emissions limits to be incorporated into: (i) its permit to construct the Facility Improvements, and (ii) its Part V/Title 70 Permit upon the next renewal of such permit. On and after December 31, 2023, Wheelabrator shall cause the Facility to achieve the more stringent of: the air emissions limits set forth in its permit to construct the Facility Improvements; the air emissions limits set forth in its Title V/Part 70 Permit; or the air emissions limits set forth in this Agreement, as follows:

Pollutant	Emissions Limit
Nitrogen Oxides (NO_X)	105 parts per million dry volume (PPMVD) corrected at 7% O_2 (30-day rolling average)
Sulfur Dioxide (SO2)	18 parts per million dry volume (PPMVD) corrected at 7% O_2 (24 hour block geometric mean)
Dioxins/Furans (PCDD/F)	2 nanograms TEQ_{DF}-WHO_{98}* per dry standard cubic meter (ng/dscm), corrected at 7% O_2
Dioxins/Furans (PCDD/F)	15 nanograms per dry standard cubic meter (ng/dscm), corrected at 7% O_2
Mercury	15 micrograms per dry standard cubic meter (μg/dscm) corrected at 7% O_2
Cadmium	25 micrograms per dry standard cubic meter (μg/dscm) corrected at 7% O_2
Lead	250 micrograms per dry standard cubic meter (μg/dscm) corrected at 7% O_2

(b) Compliance with the Air Emissions Requirements shall be determined by the "Continuous Emissions Monitoring" or "CEM" referred to in Company's Title V/Part 70 Permit and the stack testing analytical results from the three time per year emissions monitoring conducted pursuant to the air emission monitoring and reporting provisions in Section 5(c).

4. NO_X Contractual Air Emissions Requirement.

(a) Beginning on the Completion Date and notwithstanding the Air Emissions Requirement for NOx, the Company shall use reasonable efforts to meet the NOx Emission Performance Guarantee. The determination of whether the Company has complied with the NOx Emission Performance Guarantee shall be made on a calendar year basis and be based upon continuous emission monitoring data and flow monitoring data. In the event the Company fails to meet the NOx Emission Performance Guarantee in any calendar year, the Company shall pay the City the difference between the actual tons of NO_X emissions (as calculated using the CEMS and flow monitoring) and the number of tons of NOx that would have been emitted had the Company met the NOx Emission Performance Guarantee at the same stack flow rates (the '"NOx Reduction Shortfall") expressed in $/ton of NOx Reduction Shortfall in the amount set forth below:

Tier 1	90 ppmdv <conc*<99 ppmdv	$2,000/ton of NOx Reduction Shortfall
Tier 2	conc* > 99 ppmdv	$3,000/ton of NOx Reduction Shortfall

*Annual Average NOx Stack Concentration

(b) Notwithstanding the foregoing in no event shall the amount payable by the Company for a NOx Reduction Shortfall in any calendar year exceed $50,000. Within thirty days after the end of each calendar year the Company shall provide the Authority its NOx emissions for the calendar year and together if applicable the calculation of any NOX Reduction Shortfall and any amounts payable by the Company as a result.

5. Air Emissions Monitoring and Reporting.

(a) Wheelabrator shall continue to operate at the Facility CEM equipment for measurement of NO_X and SO_2 as required by Wheelabrator's Title V/Part 70 Permit.

(b) Wheelabrator shall provide CEM results for NOx and SO_2 emissions to the City's Director of Public Works or designee, by email or such other method as is prescribed by such Director, no later than the fifth business day after the end of each week, commencing the first week after the Facility is required to meet the Air Emission Requirements as provided in Section 3.

(c) On and after December 31, 2023, in addition to all monitoring required by its Title V/Part 70 Permit, Wheelabrator shall perform emissions monitoring at the Facility three times each calendar year, by collecting samples of stack emissions and sending such samples to a qualified laboratory for analysis for Dioxins, Mercury, Cadmium, and Lead, using the sampling and analysis methods prescribed for annual monitoring in Wheelabrator's Title V/Part 70 Permit. Three emissions monitoring tests shall be performed in each calendar year with each monitoring test no less than three months nor more than five months apart.

(d) Wheelabrator shall provide stack testing analytical results for Dioxins, Mercury, Cadmium, and Lead to the City's Director of Public Works or designee, by email or such other method as is prescribed by the Director, no later than five business days after Wheelabrator receives the final results of such testing.

6. Default and Termination.

The following shall constitute an Event of Default on the part of the Company under this Agreement:

(a) The failure on the part of the Company to pay any undisputed amount required to be paid to the City under this Agreement when such amount becomes due and payable if the City has made written demand therefor accompanied by notice that unless such amount is paid within 90 days after such demand the default will constitute an Event of Default, and such amount is not so paid; and

(b) The failure or refusal by the Company to (x) install the Facility Improvements by the Completion Date, (y) meet the Air Emissions Requirements as provided in Section 3 of this Agreement, or (z) perform the air emissions monitoring and reporting obligations of the Company provided in Section 5 of this Agreement, unless in each case such failure or refusal shall be excused or justified by a Facility Improvements Uncontrollable Circumstance or a default by the City under the City Agreement or a default by the Authority under the Waste Disposal Agreement, provided, however, that no such failure or refusal shall constitute an Event of Default unless and until:

(i) the City or Authority shall have given prior written notice to the Company stating that in its opinion a particular default or defaults (to be described in reasonable detail in such notice) exist which will, unless corrected, constitute a material breach of this Agreement on the part of the Company and which will, in its opinion, give the Authority a right, or the City the right to direct the Authority, to terminate this Agreement for cause under this Section unless such default is corrected within a reasonable period of time, and

(ii) the Company shall have neither corrected such default nor initiated reasonable steps to correct the same within a reasonable period of time (which shall in any event be not less than thirty (30) days from the date of the notice given pursuant to clause (i) of this Section 6(b)), provided that if the Company shall have commenced to take appropriate steps to correct such default within such reasonable period of time, the same shall not constitute an Event of Default.

7. Continuing Operation of the Facility.

During the construction of the Facility Improvements, Wheelabrator shall continue to accept and dispose of all Acceptable Waste it is required to accept from the Authority under the Waste Disposal Agreement. Notwithstanding the foregoing, the City recognizes that during the construction of the Facility Improvements there may be periods of Shutdown. During any Shutdown, Wheelabrator and the Authority shall have the rights and obligations with respect to Shutdowns as set forth in Section 4.1 of the Waste Disposal Agreement. Wheelabrator shall use reasonable efforts to minimize the number of Shutdowns during the construction of the Facility Improvements.

8. Financing of the Facility Improvements.

Wheelabrator may finance the cost of the Facility Improvements through tax-exempt bonds or otherwise. The City shall reasonably cooperate with Wheelabrator in obtaining such financing including without limitation executing such documents as Wheelabrator may reasonably request in connection therewith, except that the City will not be an obligor, guarantor, or otherwise liable for payment of such bonds.

9. Additional Provisions.

(a) Drafting of the Agreement: The Parties acknowledge and agree that this Agreement represents the products of negotiations and shall not be deemed to have been drafted exclusively by any one party. In the event of a dispute regarding the meaning of any language contained in this Agreement, the Parties agree that the same shall be accorded a reasonable construction and shall not be construed more strongly against one party other than the other.

(b) Knowing and Voluntary Act: Each of the Parties represents that it has read this Agreement and acknowledges that it has been represented or had the opportunity to be represented by legal counsel of its own choice throughout all of the negotiations which preceded the execution of this Agreement and that each party has voluntarily executed this Agreement with the consent and/or on the advice of such legal counsel. Each of the Parties further acknowledges that each and such party's counsel have had adequate opportunity to make whatever investigation or inquiry they may deem necessary or desirable in connection with the subject matter of this Agreement prior to the execution hereof and the delivery and acceptance of the considerations specified herein.

(c) Notice: All notices, consents, invoices and other communications required, permitted or otherwise delivered under this Agreement shall be in writing and may be delivered by hand or mailed by first class registered or certified mail, return receipt requested, postage prepaid, and in any case shall be addressed as follows:

If to the Mayor and City Council of Baltimore:

Director of Public Works
600 Abel Wolman Municipal Building
200 N. Holliday Street
Baltimore, Maryland 21202

with copies to:

Director of Finance
Room 469, City Hall
100 N. Holliday Street
Baltimore, Maryland 21202

and

City Solicitor
Room 101
City Hall
Baltimore, Maryland 21202

If to Wheelabrator:

Wheelabrator Baltimore, L.P.
c/o Wheelabrator Technologies Inc.
100 Arboretum Drive, Suite 310
Portsmouth, New Hampshire 03801
Attention: General Counsel

and

Wheelabrator Baltimore, L.P.
1801 Annapolis Road
Baltimore, Maryland 21230
Attention: Plant Manager

If to the Authority:

Northeast Maryland Waste Disposal Authority
100 South Charles Street
Tower II, Suite 402
Baltimore, Maryland 21201
Attention: Executive Director

Changes in the respective addresses to which such notices, consents, invoices or other communications may be directed and may be made from time to time by either Party by notice to the other Party. Notices and consents given by mail in accordance with this Section 9(c) shall be deemed to have been given five Business Days after the date of dispatch; notices and consents given by any other means shall be deemed to have been given when received.

(d) Governing Law: This Agreement shall be governed by and construed and enforced in accordance with the laws of the State of Maryland, without giving effect to its conflicts of law provisions, and any disputes arising out of or under this Agreement shall be subject to the exclusive jurisdiction of the state or federal courts located in Baltimore City, Maryland.

(e) Counterparts: This Agreement may be executed in any number of counterparts, each of which shall be deemed an original, but all of which together shall be deemed to be one and the same instrument.

(f) Third-Party Beneficiaries: The Parties agree and acknowledge that it is the express intent of the Parties that the Authority is an intended third-party beneficiary of this Agreement and is entitled to the rights and benefits hereunder and may enforce the provisions against Wheelabrator as if the Authority were a party to this Agreement. The Parties confer standing on the Authority to enforce this Agreement and its terms as against Wheelabrator, and Wheelabrator hereby waives any argument or defense that the Authority lacks standing to bring an action against Wheelabrator for enforcement of this Agreement or any of its provisions, for damages caused by Wheelabrator's breach of any provision of this Agreement, or for any similar remedy. Nothing in this Agreement shall create or be deemed to create any rights in any person or entity other than the Parties and the Authority and their respective successors and permitted assigns.

(g) Audits: At any reasonable time during business hours, there shall be made available to the City, Authority, and their authorized representatives for examination Wheelabrator's records with respect to matters covered by this Agreement. Wheelabrator shall permit the City, Authority, and their representatives, at the cost and expense of the City and the Authority, to audit, examine and make excerpts or transcripts from such records relating to matters covered by this Agreement.

(h) Retention of Records: Wheelabrator shall retain and maintain all records and documents relating to this Agreement for a minimum of three (3) years from the date of its termination, except in cases where unresolved audit questions require retention for a longer period as determined by federal, state, or local authorities. Wheelabrator shall make such records and documents available for inspection and audit at any reasonable time during business hours to authorized representatives of the City or Authority, and if applicable to federal, state, or local government authorized representatives. If Wheelabrator should cease to exist, custody of all records related to this Agreement will be transferred to the City and the Authority.

(i) No Agency: This Agreement shall not be deemed to create any relationship of agency, partnership, or joint venture between the Parties, and a Party shall not make any contrary representation to any person.

(j) Severability: If any provision of this Agreement is determined to be invalid, illegal or unenforceable in any material respect, the Parties shall take such actions as are provided in Section 11.14 of the Waste Disposal Agreement, and the other provisions of this Agreement shall, as the same may be amended, modified or supplemented, or otherwise affected by any such action, remain in full force and effect.

(k) Effect of Agreement: The rights and obligations set forth in this Agreement are binding upon and shall inure to the benefit of the Parties and their respective successors, heirs, executors, administrators, and permitted assigns of the Parties.

(l) Assignment: Neither Party may assign any of its rights or obligations under this Agreement without the prior written consent of the other Party.

(m) Waiver: Either Party's waiver of, or failure to exercise, any right provided for in this Agreement shall not be deemed a waiver of any further or future right under this Agreement. No waiver of any right, obligation, restriction or breach under this Agreement will be effective or binding unless it is specifically set forth in a writing signed by the Party against whom enforcement of such waiver is sought.

(n) Headings: The headings of the various sections hereof are intended solely for the convenience of reference and are not intended for any purpose whatsoever to explain, modify or place any construction upon any of the provisions of this Agreement.

(o) Representation on Authority of Signatories: Each person signing this Agreement represents and warrants that he or she is duly authorized to execute and deliver this Agreement. Each Party represents and warrants to the other Party that the execution and delivery of the Agreement and the performance of such Party's obligations hereunder have been duly authorized, and that the Agreement is a valid and legal agreement.

(p) Recitals: The recitals are hereby incorporated as part of this Agreement.

(q) Facility Improvements Uncontrollable Circumstances: Neither Party will be liable for its non-performance or delayed performance if caused by a Facility Improvements Uncontrollable Circumstance, except that in no event shall any Facility Improvements Uncontrollable Circumstance excuse either Party from making any payment hereunder in accordance with the terms hereof. Each Party shall seek diligently and in good faith to overcome or remove such Facility Improvements Uncontrollable Circumstance (subject to the proviso set forth in Section 11.1 of the Waste Disposal Agreement). Each Party will notify the other if it becomes aware of any Facility Improvements Uncontrollable Circumstance that will significantly delay performance. The notifying Party will give such notice promptly (but in no event later than fifteen (15) calendar days) after it discovers the Facility Improvements Uncontrollable Circumstance. Without limiting the generality of the foregoing, the Completion Date, the date for completion of the Phase 1 Facility Improvements and the Phase 2 Facility Improvements in Section 2 and the date for achieving the air emissions limits in Section 3 may be extended for such reasonable period of time as is required as a result of the occurrence of a Facility Improvements Uncontrollable Circumstance.

(r) Complete Agreement/Amendment: This Agreement, with all exhibits hereto, together with the Subdivision User Contract, the Waste Disposal Agreement, the Residue Disposal Contract (as defined in the Waste Disposal Contract) and the assignment of the Residue Disposal Contract by the Authority to Wheelabrator, and the Guaranty (as defined in the Waste Disposal Agreement), with all exhibits to such agreements, represents the entire and integrated agreement between the Parties with respect to the subject matter hereof and supersedes all prior negotiations, representations, communications, understandings, or agreements, between the Parties, whether written or oral, concerning its subject matter. This Agreement shall not be amended except by a written instrument signed by all the Parties.

(s) Term: This Agreement shall be effective as of the date hereof, and, unless sooner terminated in accordance with the terms hereof or the Waste Disposal Agrement, shall continue in effect until December 31, 2031.

[The remainder of this page is intentionally left blank.]

IN WITNESS WHEREOF, the Parties have executed this Agreement by the duly authorized representatives as of the date first written above:

Wheelabrator Baltimore, L.P.
By: WESI Baltimore Inc.

Dennis Dalles

Attest

(SEAL)

By: Michael O'Friel
General Counsel and Senior Vice President

Mayor and City Council of Baltimore

Custodian of the City Seal

Bernard C. "Jack" Young
Mayor

Approved as to form and legal sufficiency:

Approved by the Board of Estimates:

Dana P. Moore
Acting City Solicitor

Clerk | Date

IN WITNESS WHEREOF, the Parties have executed this Agreement by the duly authorized representatives as of the date first written above:

Wheelabrator Baltimore, L.P.
By: WESI Baltimore Inc.

_____________________________ (SEAL)
By: Michael O'Friel
General Counsel and Senior Vice President

____
Attest

Mayor and City Council of Baltimore

____
Bernard C. "Jack" Young
Mayor

____
Custodian of the City Seal

Approved as to form and
legal sufficiency:

Dana P. Moore
Dana P. Moore
Acting City Solicitor

Approved by the Board of Estimates:

____
Clerk Date

Attachment 5

Babcock Power
ENVIRONMENTAL
a Babcock Power Inc. company

WASTE TO ENERGY NO_X FEASIBILITY STUDY

PREPARED FOR:

WHEELABRATOR TECHNOLOGIES
BALTIMORE WASTE TO ENERGY FACILITY
BALTIMORE, MARYLAND

BPE PROJECT NO. : 100825

BPE DOCUMENT NO.:
100825-0908400100
FINAL REVISION

FEBRUARY 20, 2020

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this study is to provide a feasibility analysis for additional control of NO_X emissions from the Wheelabrator Baltimore Waste-to-Energy (WTE) Facility. The three (3) Municipal Waste Combustors (MWCs) at Wheelabrator Baltimore converts a maximum of 2,250 tons per day (750 tpd per MWC) of post-recycled municipal solid waste from Baltimore area homes and businesses as a local, sustainable fuel to generate as much as 64.5 gross (52 net) MW of electricity for sale to the local utility in addition to supplying steam to downtown Baltimore city businesses.

In this study, Babcock Power Environmental (BPE) details existing facility operations and performance and provides an overview of currently available technologies to enhance current NO_X emission levels. Each technology is then analyzed for technical feasibility. Capital and operating costs, along with an estimated timeline for installation are also included for those technologies deemed technically feasible.

BPE is not a subject matter expert on Selective Non-Catalytic Reduction (SNCR) systems. BPE therefore contracted with Fuel Tech, Inc. as a part of this study to provide a more comprehensive analysis of SNCR and Advanced SNCR (ASNCR) system capabilities. Discussions in this study on SNCR and ASNCR technology and performance are the work of Fuel Tech, Inc.

This NO_X feasibility study addresses the NO_X control technology processes, predicted performance, and plant arrangement. Detailed engineering, design, and construction of essential project parameters such as electrical work, civil work (foundations, pilings, site preparation), and balance of plant for integrating the various NO_X control technologies into existing plant have not been technically evaluated as a part of this feasibility study. However, costs for these have been considered per industry standards in the estimation of capital costs [1].

2.0 EXISTING FACILITY OPERATIONS

2.1 Boiler Design

Wheelabrator Baltimore WTE Facility consists of three (3) MWCs with Sterling power boilers supplied by the Babcock & Wilcox Company. The facility has been operating since 1983. Each MWC boiler was designed to process 750 tons per Day (TPD) of municipal solid waste (MSW), having a high heating value of 5,200 Btu/lbm, and generates 193,600 lbm/hr of superheated steam at 850 psia and 830°F. An economizer heats the feedwater temperature from 290°F to 500°F. The stoker on this MWC is a Von Roll reciprocating design. The height, width, and depth of the boiler's furnace are 88 feet (measured in the middle of the furnace from top of stoker to the roof tubes), 26.5 feet, and 19 feet 11 inches respectively. The bullnose on the rear wall at the middle elevation of the furnace redirects flue gas upward toward the front of the furnace and through the waterwall platens. Each furnace is equipped with twelve (12) waterwall platens located across the width of the furnace front wall. The waterwall platens provide additional surface area for heat absorption to moderate gas temperature entering the superheater to minimize high temperature corrosion of the superheater tubes. The flue gas flows across the superheater tubes in the direction east to west. It then flows down across and over the vertical boiler bank tubes and then across and up through the economizer's vertical tubes.

The flue gas flow is pushed towards the rear wall, reducing residence time and limiting chemical coverage for SNCR urea injection.

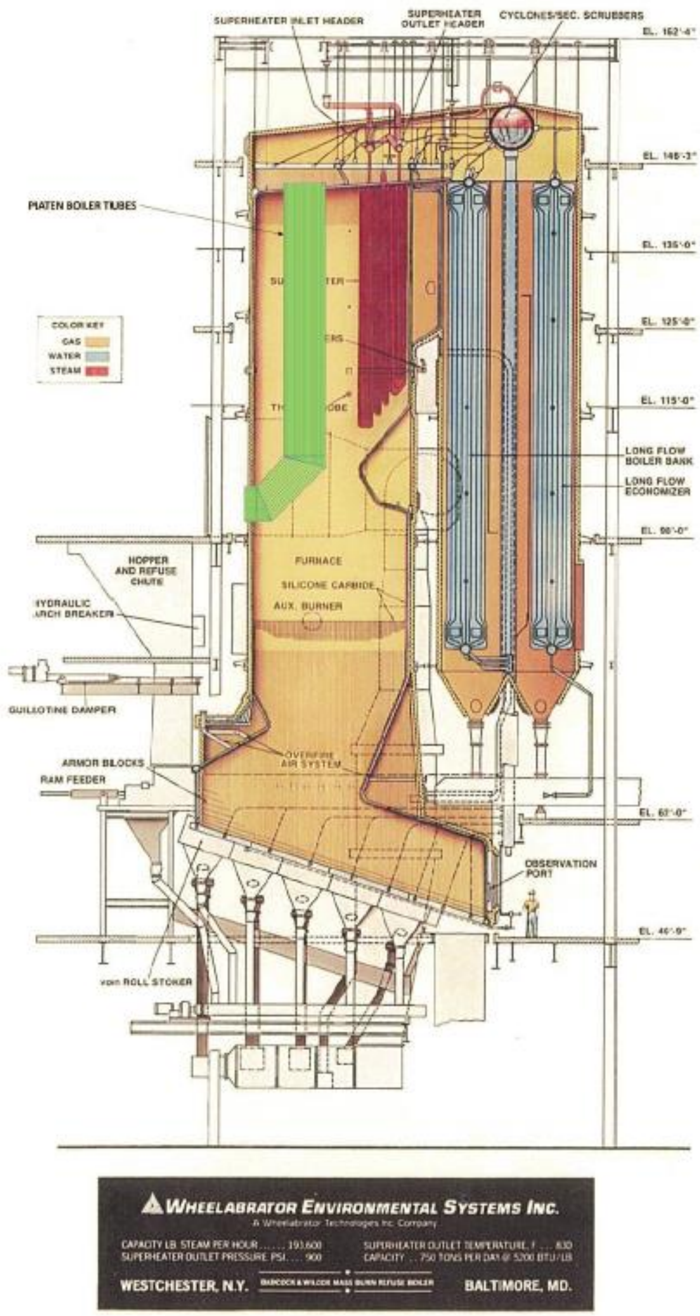

Figure 1: Wheelabrator Baltimore Municipal Waste Combustor

2.2 Existing NO_X Control Technologies & Emissions Performance

At the Baltimore facility, each of the three (3) MWCs is currently equipped with a Selective Non-Catalytic Reduction (SNCR) system supplied by Fuel Tech. Section 3.1 provides a high-level description of the SNCR process, along with some critical SNCR process parameters.

The existing SNCR systems have been optimized to meet the NO_X Reasonably Available Control Technology (RACT) limit of 150 ppmvd at 7% O_2 (average), which became effective on May 1, 2019. The existing systems will also be able to meet the 30-day rolling average limit of 145 ppmvd 7% O_2 that will become effective on May 1, 2020. The 150 ppmvd limit has been met to date without evidence of excess ammonia that could potentially cause a visible ammonium chloride plume.

The SNCR system has injectors located at Elevation 82'-3" with one (1) injector per corner, one (1) injector per side wall, and two (2) injectors on the rear wall for a total of eight (8) in each MWC furnace. The injectors are equipped with variable spray angle tips. Although the injectors are fixed, changing the point of chemical release by changing injector tip angle and adjusting atomizing air and/or dilution water flow provides additional flexibility to optimize system further. Specifically, if the temperature is higher than anticipated, larger droplets will delay the chemical evaporation and the reaction will take place at a lower temperature environment thus optimizing the performance of the SNCR system.

3.0 POTENTIAL NO_X CONTROL TECHNOLOGIES

BPE and Fuel Tech have identified several potential NO_X control technologies that were evaluated as part of this feasibility analysis. The following section outlines the identified technologies in general terms. The feasibility of those technologies as they relate to the Baltimore facility is detailed in Section 4.0.

3.1 Existing SNCR

As discussed in Section 2.2, each of the three (3) units is currently equipped with a Selective Non-Catalytic Reduction (SNCR) system. Urea (a nitrogen-based reducing agent, or reagent) is injected into the post-combustion flue gas. The SNCR process occurs within the furnace, which acts as the reaction chamber. The reagent is injected via nozzles mounted on the walls of the furnace. The heat of the boiler provides energy for the reaction, which reduces the NO_X molecules into molecular nitrogen (N_2) and water vapor (H_2O). Note that the NO_X is represented as NO since it is the predominant form of NO_X within the boiler. The temperature window for effective SNCR performance is a function of the baseline NO_X but typically ranges between 1600°F and 2000°F.

The successful implementation of the urea based SNCR technology is predicated on the ability to introduce urea as a liquid spray (a mixture of 50% urea solution and dilution water as carrier) into the boiler using specialized injectors. These spray droplets travel through the furnace until they evaporate with NO_x reduction reactions start only after the chemical has been released. The SNCR reactions are all gas phase and the term "reaction temperature" is used interchangeably with temperature at the point of chemical release. This reflects the location where the chemical starts to react. Residence time refers to the time available for reaction after chemical release while the reducing agent is still within the appropriate chemical and thermal environment.

Figure 2 below illustrates the mechanics of urea injection into a boiler.

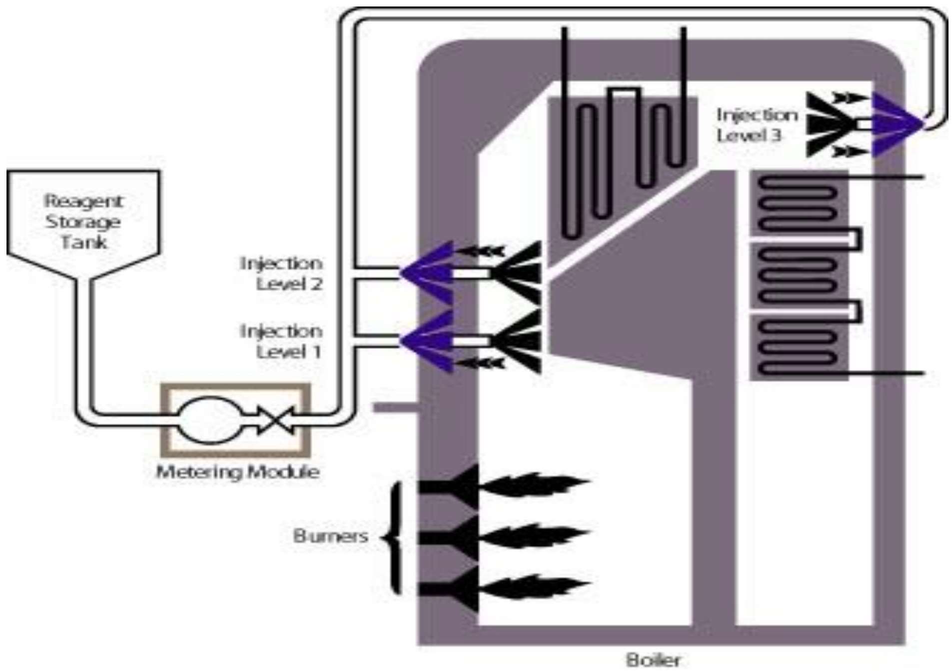

Figure 2: SNCR System with Multiple Levels of Injection

There are close to 100 chemical reactions involving more than 30 species in the SNCR mechanism that utilizes urea as a reducing agent. The overall reaction, however, can be expressed as follows:

$$CON_2H_4 + 2NO + \tfrac{1}{2}\,O_2 \rightarrow CO_2 + 2H_2O + 2N_2 \qquad (1)$$

Chain radical species such as O, H, and OH are required for the reactions to proceed. While NO_X reduction and formation reactions take place continuously, the temperature and the concentration of the OH radicals are the determining factors as to which reaction path will dominate. The activation, reduction and formation reactions are listed below:

3.1.1 Urea Breakdown and Activation Reactions

Urea in itself does not react with NO_X, but under high temperature conditions generates NH_2 and NCO. These are the species that react with NO_X.

$$CON_2H_4 \rightarrow NH_3 + HNCO \qquad (2)$$

$$NH_3 + OH \rightarrow NH_2 + H_2O \qquad (3)$$

$$HNCO + OH \rightarrow NCO + H_2O \qquad (4)$$

3.1.2 NO_X Reduction Reactions

NH_2 and NCO react with NO_x, stripping off an oxygen atom and reducing it to molecular nitrogen.

$$NH_2 + NO \rightarrow NNH + OH \rightarrow N_2 + H_2O \quad (5)$$

$$NCO + NO \rightarrow N_2O + CO \rightarrow N_2 + CO_2 \quad (6)$$

3.1.3 NO_X Formation Reactions

NH_2 and NCO react with hydroxyl radicals and generate NO_X.

$$NH_2 + 3OH \rightarrow NO + 2H_2O + H \quad (7)$$

$$NCO + OH \rightarrow NO + CO + H \quad (8)$$

Although application specific, typically at high temperatures above approximately 2050°F), the NO_x formation reactions dominate while at lower temperatures the NO_X reduction reactions become predominant. At temperatures below 1500°F, the chemical kinetics slow down considerably, and the activation reactions proceed at a very slow rate. Not only is NO_X not reduced, but the NH_3 is not converted to NH_2 quickly enough resulting in high ammonia slip as a byproduct of the injection. Figure 3 below shows a generic depiction of NO_X reduction and ammonia slip vs. temperature.

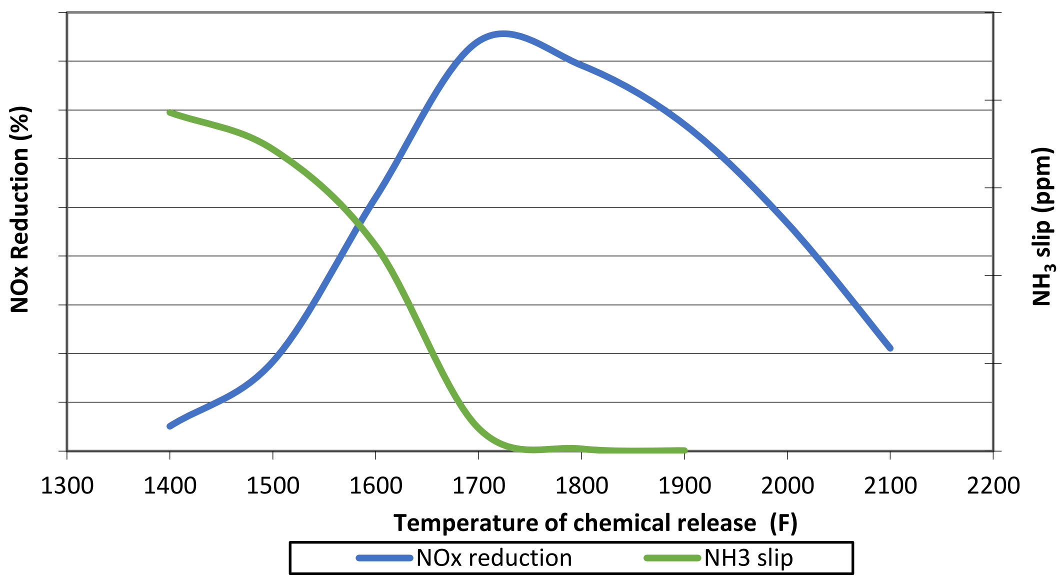

Figure 3: NO_X Reduction and Ammonia Slip vs. Temperature

3.2 Advanced SNCR (ASNCR)

An Advanced-SNCR (ASNCR) system utilizes acoustic or laser-based means of producing near real-time maps of furnace temperature conditions that are then used to control the location and manner of injection for NO_X control. In some cases, the temperature monitoring is the primary control signal used to control urea and/or dilution water flow. In other cases, the temperature monitoring is used to select injectors within an injection zone for special operations.

Typically, urea based SNCR systems have logic designed to control operations based on unit load, CEMS NO_X, upper furnace temperature, and ammonia slip data. The Advanced SNCR system provides additional flexibility, utilizing Computational Fluid Dynamics (CFD) modeling and Chemical Kinetic Modeling (CKM) technology in concert with near real-time furnace temperature maps to modify individual injection selection or urea flow rates.

SNCR “performance” can be measured in many ways, and all are important to varying degrees. The achievable NO_X reduction and ammonia slip are the foremost measures of performance. The chemical utilization is also critical to the operating cost of the system, as are the amount of dilution water and injection air used. Finally, the ability of the system to operate dynamically and effectively over a wide load range is also significant.

In simplified terms, the temperature profile can be mapped over an existing control scheme to activate only the injectors that are expected to provide the best performance. This can be managed in the short-term by responding to apparent conditions in the furnace. A schematic illustrating temperature-based injector selection is shown in Figure 4. It has also been possible to measure variations in the furnace and develop algorithms to predict expected conditions in the near future. These algorithms include predictions of furnace gas concentrations and temperature changes that can be anticipated to improve chemical use and minimize balance of plant impacts.

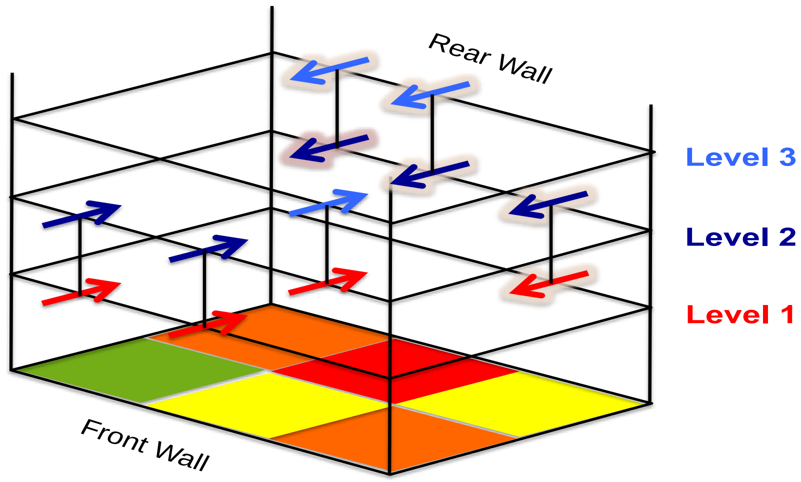

Figure 4: Schematic Illustrating Temperature-Based Injector Selection

The optimized injection strategy can be determined by CFD and CKM modeling and field evaluation.

3.3 FGR-SNCR

The FGR-SNCR option incorporates Flue Gas Recirculation (FGR) into the SNCR design.

In this option, a portion of the flue gas from combustion is recirculated from the ID fan inlet duct and is then re-injected back into the furnace through the over-fire air system. FGR is used to replace a portion of the secondary air flow, this reduces use of ambient air and O_2 concentration or stoichiometric excess ambient air while still maintaining the secondary air gas flow needed for mixing in the furnace.

The addition of FGR provides additional NO_X emission reduction in several ways:

- Lowers combustion temperatures in the furnace.
- Improves mixing in the furnace; and
- Reduces excess ambient air during the combustion process.

NO_X formation is the inevitable result of combustion. NO_X is formed by three potential mechanisms. The first mechanism entails the high-temperature oxidation of the nitrogen found in the combustion air, and NO_X formed in this manner is called thermal NO_X. The second mechanism refers to the oxidation of the nitrogen component in the fuel, and NO_X formed in this manner is called fuel NO_X. The final mechanism forms what is called prompt NO_X, and is based on reactions between hydrocarbon radicals and molecular nitrogen in the flame zone. Prompt NO_X is a minor contributor to the overall NO_X, while fuel NO_X on the other hand, contributes between 50 and 80% of the overall NO_X emissions. The formation of thermal NO_x is described by the Zeldovich Equation:

$$[\mathrm{NO}] = \mathrm{K}_1 e^{\left(-\mathrm{K}_2/\mathrm{T}\right)}[\mathrm{N}_2][\mathrm{O}_2]^{1/2}\mathrm{t} \tag{9}$$

where, T = temperature, t = time, and K_1 and K_2 are constants.

According to the above equation, NO_X can be reduced by lowering the average flame temperature as well as the average oxygen concentration. This can be accomplished by adding recirculated flue gas to the combustion air, thus lowering the flame temperature and diluting the local oxygen concentration.

3.4 FGR-ASNCR

It is also possible to combine the FGR technology described in Section 3.3 with the ASNCR technology described in Section 3.2. The implementation of ASNCR by adding additional independent zones of injection and an acoustic pyrometer can provide additional NO_X reduction while controlling the ammonia slip.

3.5 Hybrid SNCR-SCR

The Hybrid SNCR-SCR option utilizes two treatment stages: an SNCR treatment stage followed by an SCR treatment stage. There is a common misconception that, in a hybrid arrangement, the reagent is over-injected in the SNCR stage. In a stand-alone SNCR application, the reducing agent is released at higher temperatures to minimize ammonia slip formation. In hybrid applications, the ammonia slip becomes the reducing agent over the catalyst. As such, the SNCR process is no longer restricted by temperature, and injection at lower temperature is customary to the extent that unit geometry allows it and there is no risk of chemical impingement on the boiler surfaces.

Releasing the chemical at a cooler temperature accomplishes three (3) objectives: it allows the SNCR to achieve lower target NO_X limits, minimizes NO_X formation reactions, and improves chemical utilization. In addition, due to the lower temperature of chemical release, a controlled, but higher concentration of ammonia is available to feed the catalyst. The excess ammonia slip from the first stage then reacts in the presence of the downstream in-duct catalyst located downstream in the flue gas path. In some cases, a static mixer is installed at the economizer outlet to provide the additional mixing required to achieve good NH_3/NO_X distribution across the face of the catalyst.

The combination of these two technologies also allows for a higher NO_X reduction and improved chemical utilization versus a standalone SNCR system. For a standalone SNCR, higher SNCR NO_x reductions are theoretically possible, with the limiting factors being the ability to treat a large percentage of the total flue gas and being restricted by NH_3 slip limitations. Perhaps the most advantageous aspect of combining the two technologies is that by having the catalyst behave as an ammonia “mop,” one removes the second limitation and increases the potential NO_x reduction efficiency of the SNCR.

Installing an in-duct catalyst downstream of an SNCR has an enabling effect on SNCR performance. The SCR catalyst is typically installed in a high dust environment at the boiler economizer outlet. Urbas explains that “SNCR NOx reduction occurs in a defined temperature window, roughly bell-shaped, with maximum SNCR NO_X reduction occurring at the top, or plateau of the bell. In a commercial ‘stand-alone’ SNCR, the system is operated within the slope area on the right side of the temperature window curve. In this region, the hot side of the performance maximum, ammonia slip is very low or nonexistent. This is often an operating constraint imposed by the source owner. In contrast, the SNCR component of the hybrid system operates best at the plateau, which is in a lower temperature region. In this region, SNCR NO_X reductions are maximized and some ammonia slip is produced. The ammonia slip that is produced is available for additional NO_X reductions with a downstream catalyst system. When operated in this manner, SNCR NO_X reduction is maximized (compared to its stand-alone performance) and additional NO_X reductions are realized from the catalyst, which is fueled by the SNCR generated ammonia slip [2].” Although this temperature window is a function of the baseline NO_X, it typically ranges between 1600°F and 2000°F. The “hot side of the performance maximum,” as described above, typically equates to chemical release temperatures in the 2000°F range. The SNCR component of hybrid systems are capable of operating at nominal temperatures in the 1800°F range (and slightly lower). Refer to Figure 3 for an illustration of the bell-shaped temperature curve discussed above. The operating temperature range of the SCR catlayst is generally between 550°F and 750°F. The actual minimum and maximum temperatures depend on the flue gas consitutents, catalyst design requirements, and boiler operation.

A hybrid SNCR-SCR also has a lower capital cost than a full-scale SCR. Given typical conditions, the ductwork modifications needed for a hybrid SNCR-SCR and additional component weights can be accommodated by the existing structural steel without the need for new foundations while far less catalyst is used. In addition, the pressure drop of the system is typically considerably less than for a standalone SCR.

3.6 DeNO$_X$ Catalytic Filter Bags

In lieu of typical Pulse Jet Fabric Filter (PJFF) bags, DeNO$_X$ catalytic filter bags can be utilized with ammonia injection to reduce NO$_X$ in a similar fashion to traditional SCR catalyst. These combination bags remove both dust and gaseous compounds simultaneously. A typical DeNO$_X$ catalytic filter bag is comprised of one to three layers of fabric; one lined with a PTFE membrane and each including its own unique catalytic formula. DeNO$_X$ filter bags provide good resistance to catalyst poisoning, and service life, and pressure drop are both comparable to conventional fabric filters. Typical minimum operating temperatures for catalytic filter bags range from 356°F [3] to 430°F [4] depending on flue gas constituents and catalyst formulation. Note that this range of minimum operating temperatures is not specific to the WTE industry.

3.7 Tail-End SCR Systems

A Tail-End system positions the SCR downstream of all other air pollution control equipment installed on a unit. A major benefit of this installation location is that many of the flue gas constituents that would be damaging to the catalyst have been removed prior to the SCR reactor inlet. However, the installation location results in flue gas temperatures below the acceptable range for catalytic reduction, and the flue gas consequently must be reheated via natural gas or oil burners or steam coil heaters.

The Tail-end SCR process converts the NO$_x$ contained in the flue gas into nitrogen and water with the use of ammonia as the reduction agent. The basic reactions are the following:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \quad (10)$$

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O \quad (11)$$

The following side reactions may occur on a small scale:

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O \quad (12)$$

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \quad (13)$$

The flue gas entering the SCR System typically contains SO$_2$, a portion of which will be catalytically oxidized to SO$_3$, as shown below:

$$2SO_2 + O_2 \rightarrow 2SO_3 \tag{14}$$

The NO_x reduction process requires specifically formulated catalyst to achieve the necessary reaction rates at the available Tail-End SCR operating temperatures, i.e., greater than 450°F. The NO_x reduction efficiency of the catalyst increases with rising temperature. At very high gas temperatures, above ~800°F, the catalyst can be damaged due to sintering. Additional consideration must be taken in the catalyst design to prevent the formation of ammonium bisulfate (ABS) from SO_3 and ammonia, a sticky salt that reduces catalyst activity by fouling the catalyst surface. ABS formation only becomes problematic for operation at low temperatures (below the ABS dew point). ABS condensation in the catalyst is a reversible reaction. If the catalyst is heated regularly to typically 320-350°C (608-662°F), the ABS will evaporate, regaining catalyst activity [5].

3.7.1 Traditional Tail-End SCR

A Traditional Tail-End SCR operates in much the same way as a high-dust SCR. However, the flue gas temperature at tail-end locations is typically expected to be between 300°F and 330°F. In order to increase the temperature of the flue gas, the SCR is equipped with a gas-gas heat exchanger (GGH), followed by an in-duct burner or steam coil heater to provide the energy required to raise the flue gas temperature to levels required for effective catalyst performance (see Figure 5). This arrangement increases the flue gas temperature for optimal performance by the catalyst, and then the GGH recovers the energy by using the heated gas at the SCR outlet to help increase the temperature of the cooler incoming gas.

Typically, there is leakage across the GGH. Additionally, the heat recovery is approximately 60%.

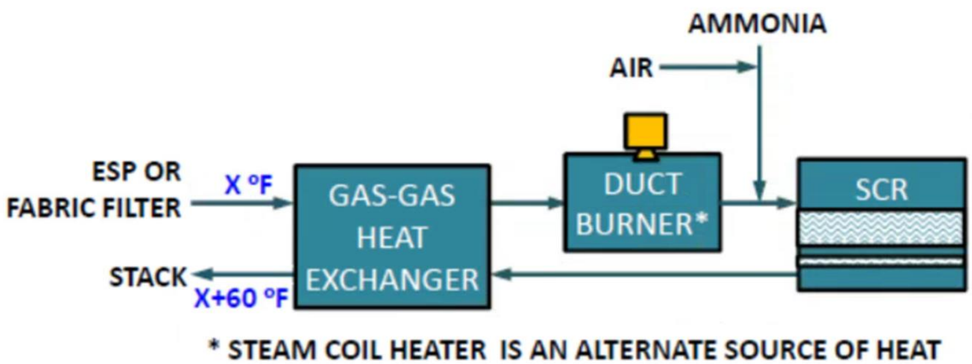

Figure 5: Traditional Tail-End SCR Arrangement

In a retrofit, most facilities are not able to overcome the additional pressure loss across the SCR and GGH with existing ID fans. In general, a new booster fan is provided for each reactor to bear the increased draft loss associated with this equipment. In lieu of a new booster fan, replacement or modification of the existing ID fans may also be considered.

3.7.2 Regenerative SCR (RSCR)

An RSCR system is designed to reduce NO_x, CO and VOCs as a tail-end unit. Similar to the traditional tail-end SCR discussed above, the flue gas temperature is too low to reduce NO_X and oxidize CO/VOC emissions. To increase the temperature of the flue gas, the RSCR system is equipped with either natural gas burners, oil burners, or steam coil heaters to increase the temperature to an acceptable range for the catalytic reduction. To recover the added heat, the RSCR utilizes a heat recovery bed comprised of >95% thermal efficient ceramic media and flue gas directional changes to transfer the heat between canisters.

The RSCR reactor is configured in a canister pair with a heat retention chamber connecting the two canisters, as shown in Figure 6 and Figure 7 below. Each canister has an inlet and outlet damper which directs the flow through the canister pair.

Once the RSCR system is at steady state, the incoming low temperature flue gas will absorb heat from the inlet heat recovery bed to achieve temperatures suitable for emission reduction prior to entering the catalyst. As the flue gas passes through one layer of catalyst, it continues to increase in temperature by passing through the burner flame/steam coil between canisters. As the flue gas exits the second layer of catalyst, it passes through the outlet heat recovery bed where the ceramic thermal media recovers the heat added to the inlet flue gas. The heat recovery beds have greater than 95% thermal efficiency which minimizes the amount of external energy required to offset the heat loss through the system.

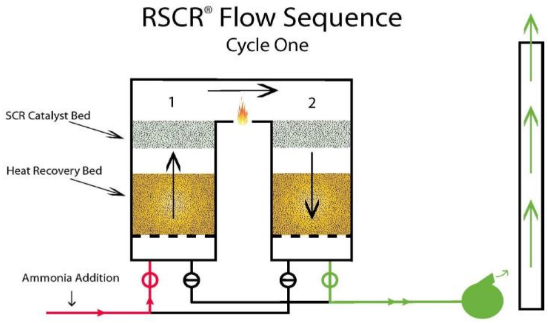

Figure 6: RSCR Flow Sequence Cycle One [15]

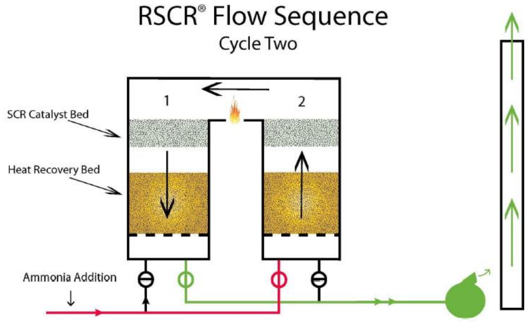

Figure 7: RSCR Flow Sequence Cycle Two [15]

As discussed in Section 3.7.1, most facilities cannot overcome the additional pressure loss across the RSCR with existing ID fans in a retrofit. In general, a new booster fan is provided for each reactor to bear the increased draft loss associated with this equipment. In lieu of a new booster fan, replacement or modification of the existing ID fans may also be considered.

4.0 TECHNICAL FEASIBILITY OF NO_X CONTROL TECHNOLOGIES

The technical feasibility of each of the technologies discussed in Section 3.0 above was evaluated based on the existing equipment arrangement, system performance, and site constraints of the Baltimore facility. For the purposes of the feasibility study, all values presented in this section were based on a single point steam flow of 191,840 lb/hr, not a range of values. For detailed design, a full fuel analysis, heat input, and fuel throughput range should be analyzed to confirm that the values presented herein are applicable for the entire boiler load range.

4.1 Existing SNCR

CFD models show a large recirculation zone that pushes the flue gas towards the rear wall. This recirculation zone is a result of the geometry of the lower furnace arches and the waterwall platens. The velocity contours suggest that the flue gas velocity is in the 10 to 14 m/s range, leading to reduced residence time and increasing the potential for ammonia slip formation.

The SNCR performance of the Baltimore MWCs is impacted by the presence of the waterwall platens and pendant superheater in the furnace. In order to minimize the risk of impingement on these surfaces and control the ammonia slip, the injectors are placed at a lower elevation thus releasing chemical at higher temperature somewhat limiting the achievable NO_x reduction.

The existing SNCR system can consistently control NO_X to levels below 150 ppmvd @ 7% O_2 on a 24-hour block average and 145 ppmvd @ 7% O_2 on a 30-day rolling average. The existing SNCR system may be capable of maintaining a controlled NO_X level of 135 ppmvd @ 7% O_2 on a 24-hour block average and 130 ppmvd at 7% O_2 on a 30-day rolling average while limiting the ammonia slip to approximately 5 ppmvd to avoid a visible ammonium chloride plume. However, the exact magnitude of these values must be confirmed via further tuning. As the City of Baltimore has a 0 visible plume limit, the amount of ammonia slip leaving the system is a critical process parameter. The capture rate of any ammonia slip in the particulate collection system is extremely limited with the existing ESP. This option is technically feasible with further field optimization and tuning.

Overall improvement of the remaining technologies is evaluated against a baseline of the further-optimized controlled NO_X level of 135 ppmvd @ 7% O_2 on a 24-hour block average and 130 ppmvd at 7% O_2 on a 30-day rolling average.

4.2 Advanced SNCR

Taking into account the presence of the recirculation zone and the need to avoid waterwall platen and superheater impingement from urea injection, injectors will need to be placed at multiple (at least two) elevations for the ASNCR concept to be viable. The average temperature at the 4th floor elevation is 2050°F, so placing injectors below the 4th floor will have the potential to increase NO_X or at least degrade the chemical utilization. The chemical coverage may be improved by adding more injectors on the rear wall at the 4th floor, and also by adding some injectors on the front wall at a slightly higher elevation. The front wall injectors may be releasing a small amount of chemical within the recirculation zone, but these droplets are expected to be fully evaporated by the time they reach the waterwall platens. To eliminate any risk of impingement, the injectors will be placed based on guidance from the CFD and chemical spray modeling that will be done during the design phase. These injectors will be releasing chemical at lower temperature allowing for lower target NO_X levels. The acoustic pyrometer will provide the temperature profile across the entire furnace cross section. It should be noted that when implementing the ASNCR process, the ability to release chemical at a lower temperature is not so much a result of placing injectors at much higher elevations, but rather taking advantage of local, low temperatures across the cross-sectional area and biasing chemical toward that section of the furnace. Similarly, certain injectors will be removed from service if they are spraying in an area where the temperature falls above a design value while other injectors will be operating at different chemical and dilution water flows.

The optimum injector locations cannot be specified at this time as Fuel Tech has not performed the CFD and chemical spray modeling on these units. Based on experience, however, a 5% improvement in chemical coverage is feasible, leading to a target NO_X of 110 ppmvd @ 7% O_2 on a 24-hour block average and 105 ppmvd at 7% O_2 on a 30-day rolling average while the ammonia slip is kept at the 5 ppm range. It should be noted that without the acoustic pyrometer, this lower level of controlled NO_X would not be feasible at low slip. The anticipated chemical consumption, allowing for baseline swings and higher temperatures, ranges between 35 and 40 gph. An Advanced SNCR (ASNCR) system may be capable of maintaining a controlled NO_X level of 110 ppmvd @ 7% O_2 on a 24-hour block average and 105 ppmvd at 7% O_2 on a 30-day rolling average while limiting the ammonia slip to 5 ppmvd by incorporating an acoustic pyrometer and by the automatic addition/redistribution of injectors at different elevations as guided by CFD modeling.

This option is technically feasible with future CFD and chemical spray modeling where particular attention will be paid to injector placement so that there is no risk of chemical impingement on the superheater and waterwall platens and other boiler surfaces. An improvement of 25 ppmvd at 7% O_2 on a 30-day rolling average can be realized over the optimized existing SNCR.

4.3 FGR-SNCR

The FGR-SNCR option was evaluated using a boiler heat transfer model. FGR rate was limited to 15% of the total flue gas from combustion because of superheat attemperator spray flow rates considerations. The boiler model showed higher FGR rates would increase superheater heat pick up. FGR rates were limited to not increase attemperator spray flow above the attemperator system capacity. FGR allowed stoichiometric excess ambient air to be reduced from 80 -100% down to 60%.

The flue gas for the FGR system will be extracted from the ID fan inlet duct through an FGR fan. The FGR fan will re-inject the flue gas into the over-fire air ports. Some modifications to the units will be needed to install the ductwork and FGR fan. See Appendix B for the Proposed Flue Gas Recirculation Addition modifications. Duct routing must be verified during a detailed analysis to confirm final arrangement feasibility. Additional local analysis of the steel supporting the new ductwork and fan would also be required to determine the extents of any required steel reinforcements. Reinforcements are assumed to be minimal and a nominal tonnage was included in the cost evaluation. It is anticipated that no changes would be required to main steel and existing columns.

The FGR-SNCR option is designed jointly by BPE and Fuel Tech. Fuel Tech has applied SNCR on municipal solid waste combustors equipped with FGR. SNCR systems have been installed on units equipped with FGR worldwide. These applications include multi-pass furnace units such as the Covanta design and single pass furnace units such as the Volund or CNIM designs. FGR tends to impact the thermal and chemical environment of the flue gas by lowering the temperature and baseline NO_X, and increasing the CO concentration. Multi-pass furnace units tend to provide longer residence time at temperatures conducive to SNCR than single pass furnace units such as Wheelabrator Baltimore. These parameters are all taken into consideration during the evaluation of the SNCR process and selection of injector locations.

BPI has provided Fuel Tech with an estimate of operating conditions if FGR were to be implemented. The baseline NO_X for the purpose of this study is assumed to be 190 ppmvd at 7% O_2, however the exact magnitude and/or range must be confirmed during detailed design. The temperature at the bullnose elevation is expected to be 25°F lower than the base case, while the operating O_2 is 1.4% lower on a dry basis than the base case. This lower oxygen may give rise to a slightly higher CO concentration at the point of chemical release, but overall the thermal and chemical environment is not expected to change significantly. Since the acoustic pyrometer will not be in use under this condition, injectors cannot be placed at higher elevations (lower temperature of chemical release) to ensure that the ammonia slip stays under control. Guided by the CFD, however, injectors can be repositioned at the 4th floor elevation thus improving the chemical coverage in excess of 60%.

Based on the performance attained by the existing SNCR system, an FGR-SNCR system should be capable of maintaining a controlled NO_X emissions level of 120 ppmvd @ 7% O_2 on 24- hour block average and 115 ppmvd at 7% O_2 on a 30-day rolling average while limiting the ammonia slip to 5 ppmvd after redistribution of injectors as guided by CFD modeling and starting from a lower baseline NO_X. Since the injectors will only be redistributed at the 4th floor elevation to optimize chemical coverage and will not be placed at a higher elevation due to ammonia slip concerns, the risk of chemical impingement on the superheater platens will be negligible as in the case with the existing SNCR system.

This option is technically feasible from both an arrangement and performance perspective with future CFD modeling. An improvement of 15 ppmvd at 7% O_2 on a 30-day rolling average can be realized over the optimized existing SNCR.

4.4 FGR-ASNCR

As mentioned in Section 4.3, the installation of FGR on the Baltimore combustors has the potential of reducing the baseline NO_X to 190 ppmvd at 7% O_2. The implementation of ASNCR by adding additional zones of injection and an acoustic pyrometer can provide significant reduction while controlling the ammonia slip. Assuming the same 5% improvement in chemical coverage used for the stand alone ASNCR, a target NO_X of 100 ppmdv at 7% O_2 while the ammonia slip is kept at the 5 ppm range is expected to be achievable. The anticipated chemical consumption, allowing for baseline swings and higher temperatures, ranges between 30 and 35 gph. An FGR/ASNCR system should be capable of maintaining a controlled NO_x level of 105 ppmvd @ 7% O_2 on a 24-hour block average and 100 ppmvd at 7% O_2 on a 30-day rolling average while limiting the ammonia slip to 5 ppmvd. This is accomplished by incorporating an acoustic pyrometer and by the addition/redistribution of injectors at different elevations as guided by CFD modeling while starting from a lower NO_x baseline.

This option is technically feasible from both an arrangement and performance perspective with future CFD modeling. An improvement of 30 ppmvd at 7% O_2 on a 30-day rolling average can be realized over the optimized existing SNCR.

4.5 Hybrid SNCR-SCR

As in the case of Advanced SNCR, injectors can be repositioned to achieve better chemical coverage and injectors can be added at slightly higher elevations to target those flue gas temperatures that provide higher utilization without creating concerns about ammonia slip. Based on the geometry of these units, and out of concern for impingement on the front waterwall platens, the SNCR NO_x reduction will be limited to an approximately 10 to 15% increase above the reduction achieved by the existing “as-is” SNCR system by not limiting the slip and without reducing the chemical utilization.

The design of the catalyst component must consider facility requirements for ammonia slip and allowable additional pressure loss. Multiple catalyst vendors were consulted regarding their previous experience with hybrid arrangements, potential issues, catalyst poisons, and typical catalyst life in a high-dust municipal solid waste (MSW) application. Some vendors had no direct experience at all with this arrangement and were unable to provide insight. Those with experience indicate that deactivation is very high in a high-dust environment, and therefore the vendor would be unable to provide any performance guarantees for this arrangement.

For waste to energy facilities firing municipal solid waste, lead and other trace metals are present in the flyash. Lead has been reported to “cause serious catalytic poisoning by either chemical reaction, or by the introduction of a barrier between the gas phase and the active sites [6].” Other publications also suggest that in waste combustion, catalyst must be placed downstream of particulate removal devices in order to prevent fouling [7].

A recent study analyzed SCR catalysts after placing them in a slipstream from an MSW combustion plant. In the most deactivated catalyst, there was a reduction in activity of 94% over a period of 1,951 hours [6].

BPE was unable to locate references of any full-scale Hybrid SNCR-SCR systems installed in the United States in the MSW combustion industry. Due to high deactivation rates of the catalyst and lack of reference installations, the Hybrid SNCR-SCR option is not considered technically feasible for the Baltimore facility.

4.6 DeNO$_X$ Catalytic Filter Bags

Several challenges exist with the DeNO$_X$ catalytic filter bag option. The addition of a PJFF will most certainly result in an increase in system pressure loss. ESP installations typically require a pressure drop of approximately 0.5 inches of water column [8] at minimum. PJFF installations typically require a pressure drop of around 4 to 10 inches of water column [9]. While the pressure drop across DeNO$_X$ catalytic filter bags is comparable to traditional PJFF bags, the resulting increase in pressure loss from the exchange of the existing ESPs for new PJFFs will require the upgrade or replacement of the existing ID fans; the currently installed fans are not capable of overcoming the additional loss.

Temperature presents another challenge for catalytic filter bags at the Wheelabrator Baltimore facility. In the current system arrangement, each of the ESPs is located downstream of a Spray Dryer Absorber (SDA). The USEPA states that "optimal temperatures for SO_2 removal for dry sorbent injection systems range from 150°C to 180°C (300°F to 350°F) [10]." Data from the facility indicates that from 2016 to 2018, ESP outlet temperatures ranged from 298°F to 313°F. Typical minimum operating temperatures for catalytic filter bags range from 356°F [3] to 430°F [4]. As these filter bags contain catalyst, similar concerns regarding ammonium bisulfate (ABS) exist when operating below the ABS dew point (see Section 3.7). Increase of the SDA operating temperature in order to satisfy the catalytic filter bag temperature requirement would sacrifice SO_2 removal and ability to meet the required SO_2 limit.

Additionally, the USEPA indicates that, as temperatures approach 350°F, the effectiveness of powdered activated carbon (PAC) reduces rapidly; an increase in ESP inlet temperature from 300°F to 350°F during one study reduced mercury removal from approximately 90% to 10 to 20% [11]. In fact, the ability of most PAC formulations to adsorb mercury begins to deteriorate at 333°F, with a more rapid deterioration beginning at 350°F [12].

Due to operating temperature requirements, the DeNO$_X$ Catalytic Filter Bag option is not considered technically feasible for the Baltimore facility.

4.7 Tail-End SCR Systems

<u>System Arrangement Considerations</u>

Potential locations for the tail-end SCR systems at grade are very limited. Sufficient space is not available between the outlet of the ESPs and the inlet of the ID fans at grade. The only available locations for the SCRs at grade are a significant distance from each respective flue gas path and would require a substantial amount of ductwork to and from each SCR. This carries with it not only a large material cost (in ductwork, steel, and foundations), but also an increase in additional pressure drop across the system. For these reasons, this layout is considered to be impractical.

Appendix B includes arrangement drawings detailing this option for the RSCRs (the larger of the tail-end options).

In order to overcome the lengthy ductwork runs of locating the SCRs at grade, placement above the existing ESPs or new PJFFs was considered. This location is more physically feasible. Appendix B includes arrangement drawings detailing this option for both Traditional Tail-End SCRs and RSCRs. Additional evaluations must be performed to determine final feasibility. These evaluations must look at the existing foundations and steel structures as well as ensuring there is adequate space for new foundations and steel required to support the new equipment while maintaining proper access to existing equipment for maintenance. BPE has located several traditional SCRs in a similar fashion (essentially framing them above existing equipment) and has found this to be a viable option when space is limited.

As discussed in Sections 3.7.1 and 3.7.2, installation of a traditional tail-end SCR or RSCR results in increased total system pressure loss. The existing ID fans do not have enough capacity to overcome this increase. The booster fan for each SCR should be located at grade, but this option requires a significant amount of ductwork between the SCRs and the booster fans. BPE believes that replacement of the existing ID fans with new fans capable of overcoming the additional pressure loss is a more practical option for both tail-end options due to the facility space constraints.

For the purposes of this study, both options are investigated in the interest of comprehensiveness.

All Tail-End systems have been evaluated at two (2) upstream conditions:

- Existing upstream ESP remains in service.
- Existing upstream ESP is removed from service and replaced with a PJFF.

BPE Regenerative SCR (RSCR) systems have been installed almost exclusively downstream of ESPs but have not been installed on a Municipal Waste Combustor.

The option of replacing the ESP with a PJFF is being considered with SCR feasibility analysis given that USEPA will be revising the MWC standards in future years that could require ESP replacement. In this case, it would be practical to install PJFF along with new SCR to avoid significant engineering construction difficulties and costs with replacing ESPs after SCR installation.

Installation of tail-end systems over the existing ESPs also presents several arrangement obstacles. The Baltimore facility requires full access to the ESP roof for maintenance activities, including replacement of collection plates, rigid frame discharge electrodes and transformer/rectifier (TR) sets. In order to access the aforementioned items, the ESP roof must be removed. Installing a tail-end system over the existing ESPs eliminates the ability for the plant to continue their current method of maintenance. Additional maintenance methods such as monorails can be difficult in nature due to side clearances and drop zones and material handling with multiple ESPs installed in parallel. For this study, BPE has assumed a TR set height of roughly 9.5 feet above the ESP roof based on scaling available drawings. BPE has allowed for 11.5 feet between the top of the TR set and the bottom of the outlet duct for the traditional tail-end SCR option and 18.5 feet between the top of the TR set and the bottom of the ductwork for the RSCR option. Note that for the traditional tail-end SCR option the main SCR support steel would be located an additional 11.5 feet higher than the bottom of the duct, which could then be hung from the same steel. If additional clearance was required, layouts with offset ductwork could be looked at such that the ducts were not directly over the TR sets. The above clearances also assumed the new equipment to be no higher than the top of the existing SDA inlet duct. BPE feels that with between 11.5 feet and 18.5 feet of clearance there is adequate room for support steel, monorails, and equipment removal. Final determination of equipment elevations, clearances, layouts, and maintenance requirements would need to be evaluated in more depth in the next phase to confirm.

System Inlet and Outlet NO_X

An SCR Inlet NO_X of 212 ppmvd @ 7% O_2 is assumed for the Tail-End systems. Outlet NO_X values are based on the Best Available Control Technology (BACT) Review [13] and Final Permit [14] for the Palm Beach Renewable Energy Facility No. 2 (PBREF-2) WTE plant located in West Palm Beach, Florida. The evaluation and permit establish the BACT for NO_X emissions from MWC each unit as 50 ppmvd @ 7% O_2 (24-hour block arithmetic mean) and 45 ppmvd @ 7% O_2 (12-month rolling average) with a Tail-End SCR installed. An ammonia slip value of 10 ppmvd @ 7% O_2 is also based on the PBREF-2 BACT Review [13] and Final permit [14].

4.7.1 Traditional Tail-End SCR

For both the upstream ESP and upstream PJFF conditions, each of the three (3) SCRs requires two (2) initial catalyst layers in a three (3) module wide by four (4) module deep arrangement. Space for one (1) future spare layer is also provided. Catalyst with a pitch of 4.9 mm is assumed under both conditions. The duct burner or steam coil heater must heat the flue gas to 500°F for optimal catalyst performance.

This option is technically feasible from both an arrangement and performance perspective with the caveats noted in Section 4.7 above.

Refer to Appendix B for arrangement drawings for the Traditional Tail-End SCR.

4.7.2 Regenerative SCR (RSCR)

For the upstream ESP condition, each of the three (3) RSCRs requires three (3) reactors (three (3) pairs of canisters) with a 5.9 mm pitch catalyst, with a total of 64 catalyst modules provided per unit.

For the upstream PJFF condition, each of the three (3) RSCRs requires two (2) reactors (two (2) pairs of canisters) with a 3.3 mm pitch catalyst, with a total of 48 catalyst modules provided per unit.

Note that the difference in catalyst pitch between the upstream ESP condition and the upstream PJFF condition is due to the higher dust capture efficiency of the PJFF. A grain loading of 0.03 – 0.04 gr/dSCF was assumed for the upstream ESP condition, while a grain loading of 0.006 gr/dSCF was assumed for the upstream PJFF condition.

The duct burner or steam coil heater must heat the flue gas to 465°F for optimal catalyst performance, however, for SO_3 approaching 0.3 ppmvd the temperature must be around 575°F in order to avoid ABS formation. The economics of operation may justify allowing the ABS to form and then be decomposed. It should be noted that separate catalyst suppliers were consulted for the Traditional Tail-End and RSCR options. This resulted in different operating temperatures for each technology. The ideal operating temperature for a chosen technology would be evaluated and determined during the detailed design phase of a project.

This option may be considered technically feasible from both an arrangement and performance perspective subject to additional analysis to determine final feasibility with respect to adequacy of the existing foundations and steel structures. Further analysis must also ensure that adequate space for new foundations and steel required to support the new equipment is available, while maintaining proper access to existing equipment for maintenance (see Section 4.7 above). BPE has worked on multiple projects where foundation mini piles, foundation bridges, etc., have been used reinforce existing foundations and bridge over obstructions in order to support new steel in tight locations. Based on past experience, it is believed that this is a workable solution to the additional load and steel structure required to support the new tail end equipment.

Refer to Appendix B for arrangement drawings for all RSCR options.

5.0 Estimated Capital and Operating Costs

Although many of the technologies discussed in this study are technically feasible, the cost of each technology must be weighed against the relative improvement of NO_X reduction to determine financial feasibility. As mentioned previously, detailed engineering, design, and construction of essential project parameters such as electrical work, civil work (foundations, pilings, site preparation), and balance of plant for integrating the various NO_X control technologies into existing plant have not been technically evaluated as a part of this feasibility study. However, costs for these have been considered per industry standards in the estimation of capital costs. Estimated Budget pricing for each technically feasible option is presented in Sections 5.1 through 5.5. Expected annual operating costs for reagent, steam, and significant power consumptions are also presented in Section 5.6.

5.1 Existing SNCR

Estimated Budget Price for Startup, Optimization, and Training [e]

$85,200.

Eighty-Five Thousand Two Hundred Dollars

5.2 Advanced SNCR

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Startup, Optimization, and Training [f]

Baseline Testing and CKM/CFD Modeling [e]

Replace and Upgrade SNCR Metering Modules [e]

Six (6) NOxOUT Injectors for 2nd Injection Level [e]

Acoustic Monitoring System [e]

Six (6) Boiler Tube Panels for New Injectors [f]

Boiler Tube Panels for Acoustic Monitoring System [f]

Piping Valves and Specialties [f]

Instrumentation [f]

$8,665,162.

Eight Million Six Hundred Sixty-Five Thousand One Hundred and Sixty-Two Dollars

5.3 FGR-SNCR

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Startup, Optimization, and Training [f]

Baseline Testing and CKM/CFD Modeling [e]

Ductwork [f]

Structural Steel [f]

FGR Fans [e]

Expansion Joints and Dampers [f]

Piping Valves and Specialties [f]

Instrumentation [f]

$5,829,591.

Five Million Eight Hundred Twenty- Nine Thousand Five Hundred and Ninety-One Dollars

5.4 FGR-ASNCR

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Startup, Optimization, and Training [f]

Baseline Testing and CKM/CFD Modeling [e]

Replace and Upgrade SNCR Metering Module [e]

Six (6) NOxOUT Injectors for 2nd Injection Level [e]

Acoustic Monitoring System [e]

Six (6) Boiler Tube Panels for New Injectors [f]

Boiler Tube Panels for Acoustic Monitoring System [f]

Ductwork [f]

Structural Steel [f]

FGR Fans [e]

Expansion Joints and Dampers [f]

Piping Valves and Specialties [f]

Instrumentation [e]

$12,993,524.

Twelve Million Nine Hundred Ninety -Three Thousand Five Hundred and Twenty-Four Dollars

5.5 Tail-End SCR Systems

For the traditional tail-end SCR and the regenerative SCR (RSCR), feasibility was investigated for both preserving the existing ESPs as well as r replacing the existing ESPs with a PJFFs. As noted in Section 4.7, additional evaluations must be performed to determine final feasibility. This includes evaluation of existing foundations and steel structures and to ensure adequate space for new foundations and steel required to support the new equipment while maintaining proper access to existing equipment for maintenance. BPE has worked on multiple projects were foundation mini piles, foundation bridges, etc., have been used reinforce existing foundations and bridge over obstructions in order to support new steel in tight locations. Based on past experience, it is believed that this is a workable solution to the additional load and steel structure required to support the new tail end equipment.

Pricing for all tail-end SCR systems (both traditional and RSCR) assumes 19% aqueous ammonia as reagent based on BPE's historical installations.

5.5.1 Traditional Tail-End SCR with Existing ESP [k]

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Physical Flow Model [f]

Startup, Optimization, and Training [f]

Traditional Tail-End SCR [f]

Catalyst [e]

Steam Coil Heaters [f,j]

Ductwork [f]

Structural Steel [f]

Gas to Gas Heat Exchanger [f]

Aqueous Ammonia System [f]

ID Fans [f]

Expansion Joints and Dampers [f]

Piping Valves and Specialties [f]

Instrumentation [f]

$60,574,340.

Sixty Million Five Hundred Seventy-Four Thousand Three Hundred and Forty Dollars

5.5.2 Traditional Tail-End SCR with New PJFF

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Physical Flow Model [f]

Startup, Optimization, and Training [f]

Traditional Tail-End SCR [f]

Catalyst [e]

Steam Coil Heaters [f,j]

Ductwork [f]

Structural Steel [f]

Gas to Gas Heat Exchanger [f]

Aqueous Ammonia System [f]

ID Fans [f]

PJFF [f]

Expansion Joints and Dampers [f]

Piping Valves and Specialties [f]

Instrumentation [f]

$92,929,377.

Ninety-Two Million Nine Hundred Twenty-Nine Thousand Three Hundred and Seventy-Seven Dollars

5.5.3 Regenerative SCR (RSCR) with Existing ESP [k]

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Startup, Optimization, and Training [f]

Regenerative SCR - 6 Canister [f]

Catalyst [e]

Ductwork [f]

Structural Steel [f]

Aqueous Ammonia System [f]

ID Fans [f]

Expansion Joints and Dampers [f]

Piping Valves and Specialties [f]

Instrumentation [f]

$76,278,652.

Seventy-Six Million Two Hundred Seventy-Eight Thousand Six Hundred and Fifty-Two Dollars

5.5.4 Regenerative SCR (RSCR) with New PJFF

Estimated Budget Price for Materials, Equipment, and Installation Including:

Equipment Design and Project Team Labor [f]

Startup, Optimization, and Training [f]

Regenerative SCR - 4 Canister [f]

Catalyst [e]

Ductwork [f]

Structural Steel [f]

Aqueous Ammonia System [f]

ID Fans [f]

PJFF [f]

Expansion Joints and Dampers [f]

Piping Valves and Specialties [f]

Instrumentation [f]

$92,161,155.

Ninety-Two Million One Hundred Sixty-One Thousand One Hundred and Fifty-Five Dollars

Notes on Budget Pricing

a. Pricing is Indicative Budget Pricing +/- 20%
b. Budget pricing shown is for three units
c. Pricing does not have a validity date due to budget pricing
d. Freight to Wheelabrator Baltimore Facility Site is included
e. Supplier solicited budget pricing
f. Recent, scaled, or allowance pricing
g. Installation estimates are based on 1.00 to 1.25 times material pricing, 4% to 5% total project cost for civil and site activities, and 4% to 5% total project costs for demolition (BPE, [1], Wheelabrator).
h. Pricing does not include Taxes
i. Pricing does not include permitting costs
j. BPE has traditionally supplied natural gas or oil-fired burners. However, BPE is capable of designing this system with steam coil heaters.
k. Pricing does not include additional costs associated with maintenance modifications required for ESP access.
l. Pricing does not include Wheelabrator internal project costs.

Material

The prices established herein are subject to adjustment in favor of seller to the extent of increases in applicable taxes, duties, tariffs, and/or similar charges that apply to seller or are otherwise to be borne by seller and become applicable after the date of this order but prior to delivery of all goods and/or services to the purchaser. Recent steel and aluminum tariffs imposed by the United States may impact seller's cost and/or schedule of procurement underlying this proposal/agreement. Seller shall promptly notify purchaser of any change to its price and/or schedule as a result of these changes outside its control and purchaser shall be responsible for the impact of such changes.

5.6 *Estimated Annual Operating Costs*

The expected annual operating costs for reagent, steam, and significant power consumptions for those technologies deemed technically feasible are outlined in Table 1 below.

Table 1: Expected Annual Operating Costs for NO_X Control Technologies[1]

Technology	Urea (50 wt%)[2,3]	Aqueous Ammonia (19 wt%)[4]	Steam[2,3]	Lost Electrical Revenue[2,3,5]	
Existing SNCR[6]	$695,000				
Advanced SNCR	$995,000				
FGR-SNCR	$735,000			0.3 MW	$80,000
FGR-ASNCR	$955,000			0.3 MW	$80,000
RSCR over Existing ESP		$500,000[7]	$320,000	1.3 MW	$355,000
RSCR over New PJFF		$500,000[7]	$285,000	1.3 MW	$355,000
Traditional Tail-End SCR[8]		$500,000[7]	$1,280,000	1.3 MW	$355,000

Table 2: Wheelabrator Costs[3]

Urea[9]	$1.19	per gallon
Aqueous Ammonia (19 wt%)[4]	$0.78	per gallon
Power[10]	$33.15	per MW
Turbine/Generator Conversion Rate[11]	9.06 klbs	per MW

1 All annual operating costs assume availability of the Baltimore Facility of 92%.
2 Expected annual operating costs and expected lost electrical revenue presented as total cost for all three (3) MWC units.
3 Power pricing for lost electrical revenue, urea price per gallon, and cost of diverting steam provided by Wheelabrator. See Table 2 for data.
4 Aqueous ammonia price per gallon based on October 2019 correspondence with Airgas Specialty Products [19].
5 Lost electrical revenue due to fan auxiliary power increase with new technology installation.
6 With further optimization and tuning.
7 Assuming existing SNCR is taken out of service.
8 Traditional Tail-End SCR operating costs are comparable for installation over both existing ESP and new PJFF.
9 Cost in 2020.
10 Average rate budgeted for 2020. To determine lost electrical revenue with installation of SCR.
11 For estimating lost electrical generation for diverting steam for SCR reheat.

Table 3: Expected Urea & Aqueous Ammonia Usage

Technology	Urea (50 wt%)[12,13]	Aqueous Ammonia (19 wt%)
Existing SNCR[14]	72 gal/hr	
Advanced SNCR	105 gal/hr	
FGR-SNCR	77 gal/hr	
FGR-ASNCR	100 gal/hr	
RSCR over Existing ESP		80 gal/hr[15]
RSCR over New PJFF		80 gal/hr[15]
Traditional Tail-End SCR[16]		80 gal/hr[15]

5.7 Catalyst Replacement Cost

For tail-end systems, catalyst must be replaced at the end of its life. Estimated replacement costs for tail-end systems are:

Table 4: Catalyst Replacement Cost for Tail-End SCR Systems

Technology	Replacement Cost[17]	Frequency[18]
RSCR over Existing ESP	$3,000,000	16,000 hours
RSCR over New PJFF	$1,600,000	16,000 hours
Traditional Tail-End SCR[16]	$700,000	24,000 hours

[12] Expected annual operating costs and expected lost electrical revenue presented as total cost for all three (3) MWC units.
[13] Power pricing for lost electrical revenue, urea price per gallon, and cost of diverting steam provided by Wheelabrator. See Table 2 for data.
[14] With further optimization and tuning.
[15] Assuming existing SNCR is taken out of service.
[16] Traditional Tail-End SCR operating costs are comparable for installation over both existing ESP and new PJFF.
[17] Catalyst replacement costs shown are material costs only. Installation, labor, and catalyst disposal or regeneration cost are not included.
[18] Replacement necessary at end of catalyst life, indicated in "Frequency" column.

6.0 ESTIMATED PROJECT SCHEDULE

High-level estimated project schedules were developed for all options deemed feasible in this study. The schedules do not include time for obtaining state and local permits and approvals. Permitting may add 6-12+ months to the schedule for tail-end SCR systems given the extensive nature of these types of retrofits. Preliminary schedules are presented in Appendix A for the following options:

- Existing SNCR
- Advanced SNCR (ASNCR)
- FGR-SNCR
- FGR-ASNCR
- Tail-End SCR Systems
    - Traditional Tail-End SCR with Existing ESP
    - Traditional Tail-End SCR with New PJFF
    - Regenerative SCR (RSCR) with Existing ESP
    - Regenerative SCR (RSCR) with New PJFF

6.1 Construction Approach for New PJFF Options

The preliminary schedules in Appendix A take the construction of new PJFFs into consideration.

For all Tail-End SCR systems (both traditional and RSCR) with new PJFFs, the suggested approach is to build the new PJFF and tail-end equipment and support structure for Unit 3 first, locating it to the north of the existing Unit 3 ESP. Once major construction is complete, a tie in outage will be used to tie the Unit 3 boiler to the new PJFF and tail-end SCR equipment. The Unit 3 ESP can then be demolished and construction of the new Unit 2 PJFF and tail-end equipment can be installed in its place. This methodology would continue towards the south until all existing units are tied into their new PJFF and tail-end SCR components. This essentially shifts all particulate control equipment north by one unit.

7.0 References

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[7] National Research Council, Waste Incineration and Public Health, Washington, DC: The National Academies Press, 2000.

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permit2k.dep.state.fl.us/adh/prod/pdf_permit_zip_files/0990234.032.AC.F_pdf.zip. [Accessed 01 October 2019].

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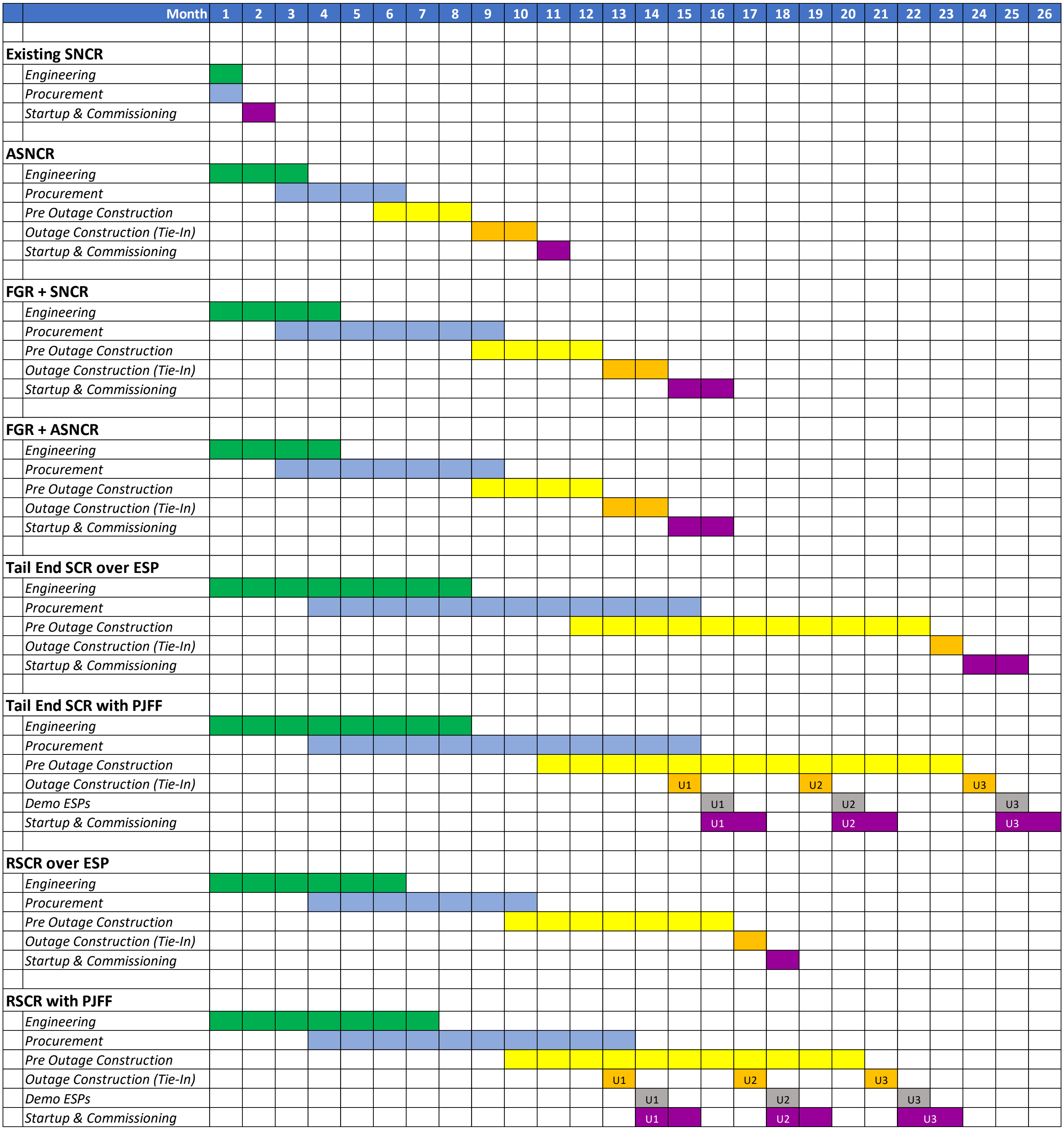
[18] International Solid Waste Association (ISWA), "Waste to Energy State of the Art Report, 6th Edition," 2012.

[19] R. Johnston, Airgas Specialty Products, *Re: New Entry: Request a Quote*, Personal Email, 2019.

APPENDIX A PRELIMINARY SCHEDULE



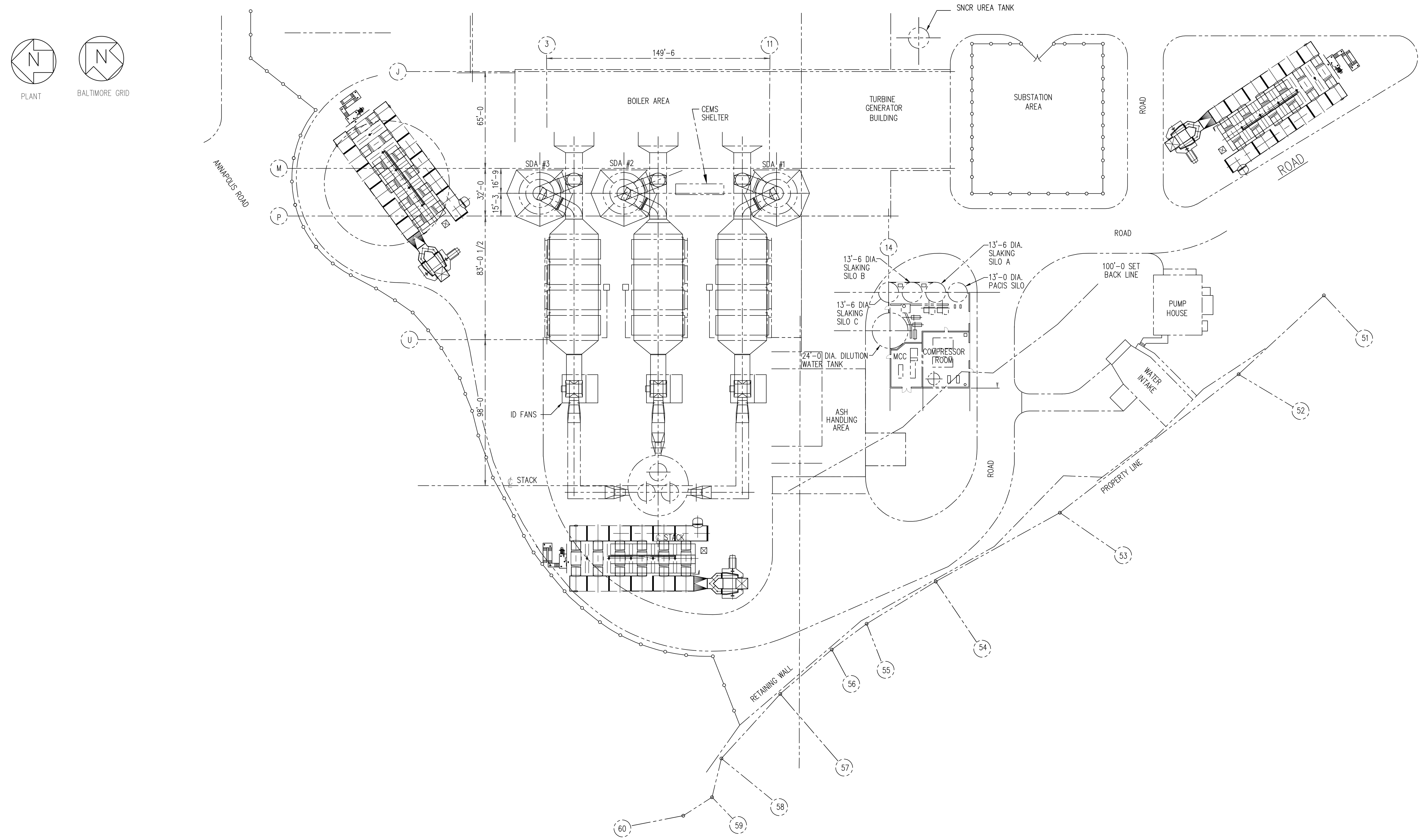
APPENDIX B ARRANGEMENT DRAWINGS

The table below summarizes the arrangement drawings provided in this Appendix for a number of the options presented in this study.

Table 5: Arrangement Drawings

Document Number	Description
100825-0926750100	Proposed RSCR Addition – RSCR at Grade
100825-0926750110	Proposed RSCR Addition – RSCR above Precipitators
100825-0926750111	Proposed RSCR Addition – RSCR above Precipitators – Elevation View Looking North
100825-0926750120	Proposed RSCR – Fabric Filter Addition – Elevation View Looking North
100825-0926750121	Proposed RSCR – Fabric Filter Addition – Plan View A-A
100825-0926750122	Proposed RSCR – Fabric Filter Addition – Plan Section B-B
100825-0926750123	Proposed RSCR – Fabric Filter Addition – Elevation View C-C
100825-0926750130	Proposed Flue Gas Recirculation Addition
100825-0926750140	SCR, Airheater & Fabric Filter Addition – Elevation View Looking North
100825-0926750141	SCR, Airheater & Fabric Filter Addition – Plan View A-A
100825-0926750142	SCR, Airheater & Fabric Filter Addition – Plan Section B-B
100825-0926750143	SCR, Airheater & Fabric Filter Addition – Elevation View C-C
100825-0926750150	SCR & Airheater Addition – Above Existing Precipitator – Elevation View Looking North

DWG. NO. 100825–0926750100



PRELIMINARY
7/9/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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RELEASED & APPROVED ______ DATE ______

THIRD ANGLE PROJECTION

DO NOT SCALE
USE DIMENSIONS ONLY

IFI

DRAWN A. Crowley
DATE 06/20/2019
CHECKED
DATE
APP'D
DATE
SCALE 1/32 IN. = 1 FT.

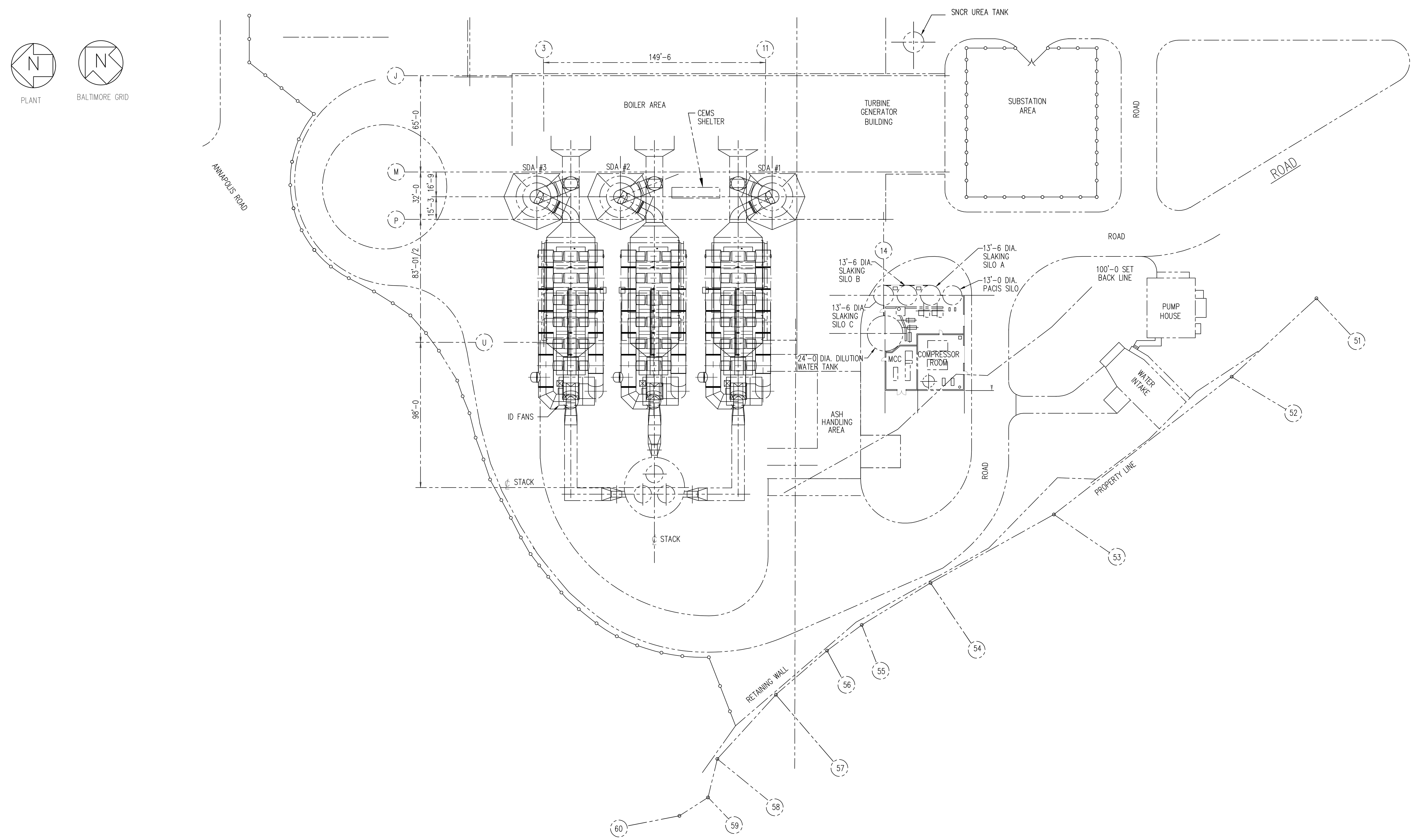
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED RSCR ADDITION
RSCR AT GRADE

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750100
REV. NO. P0

DWG. NO. 100825–0926750110



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7/9/19

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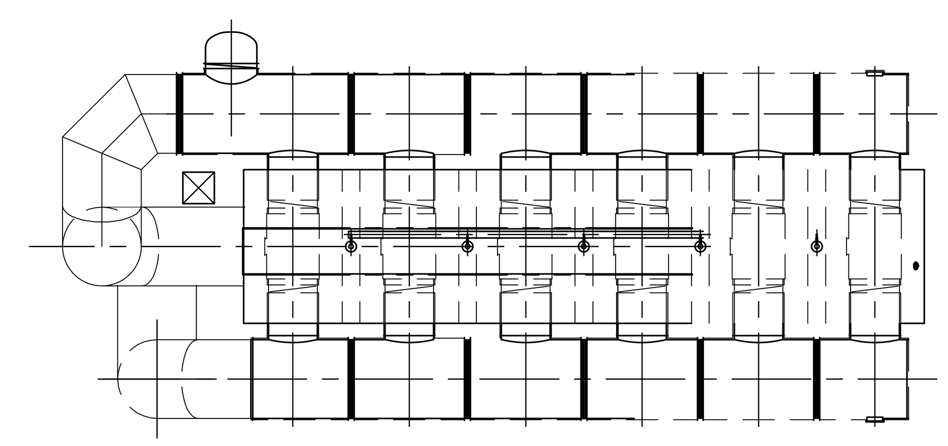
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED RSCR ADDITION
RSCR ABOVE PRECIPITATORS

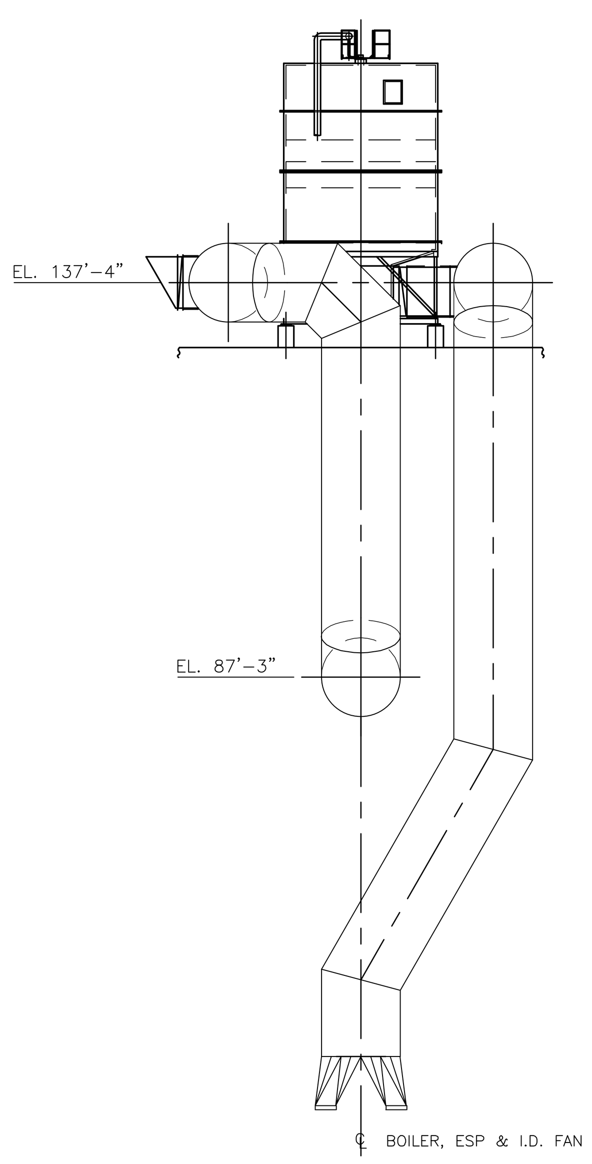
WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750110
REV. NO. P0

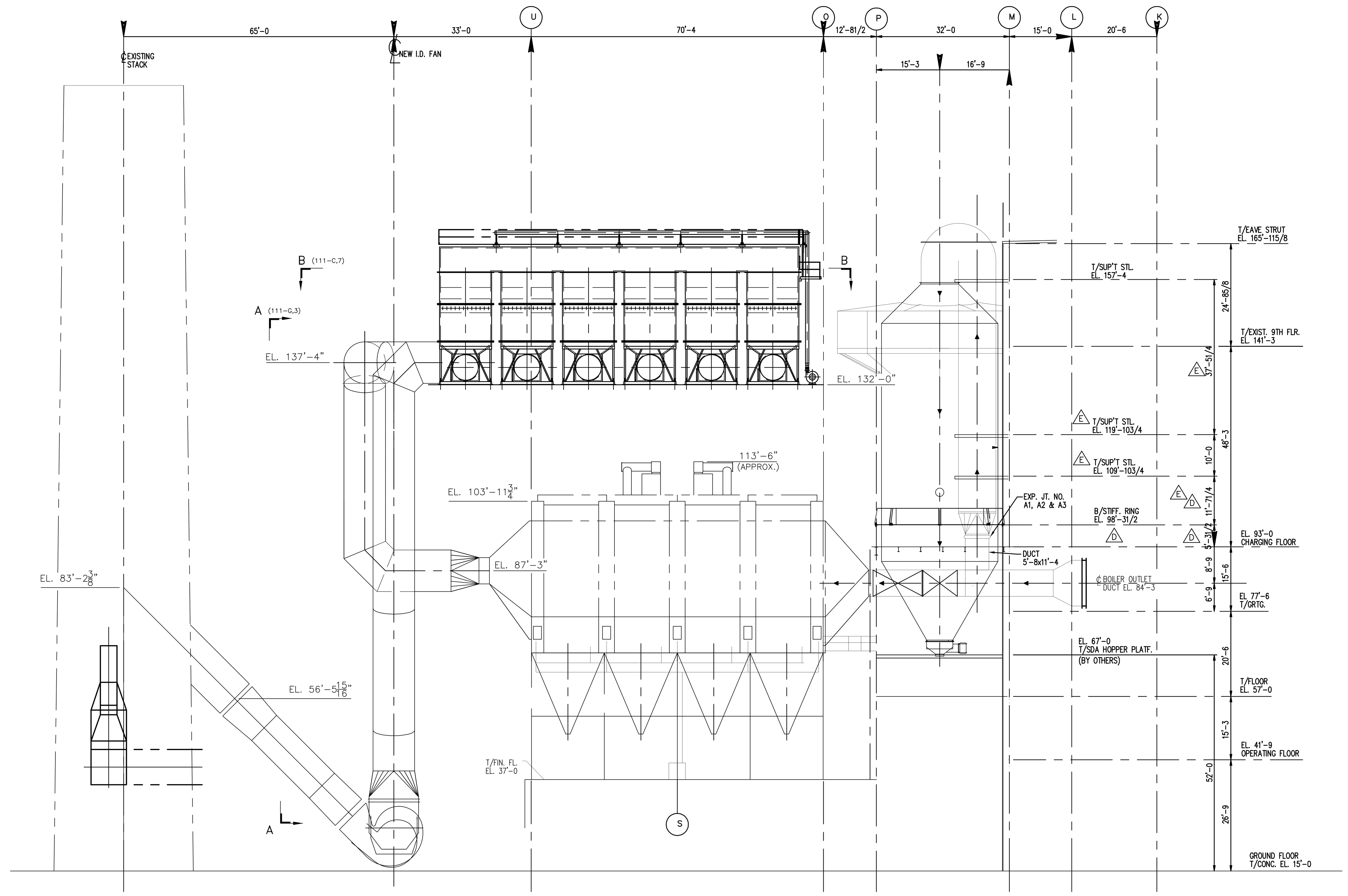
DWG. NO. 100825–0926750111



VIEW B–B
(111–C,6)



VIEW A–A
(111–C,6)



SIDE ELEVATION
LOOKING PLANT NORTH

PRELIMINARY
11/5/19

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ADDED TR SETS. RAISED RSCR.	P1	AC	–	–	–	–

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THIRD ANGLE PROJECTION

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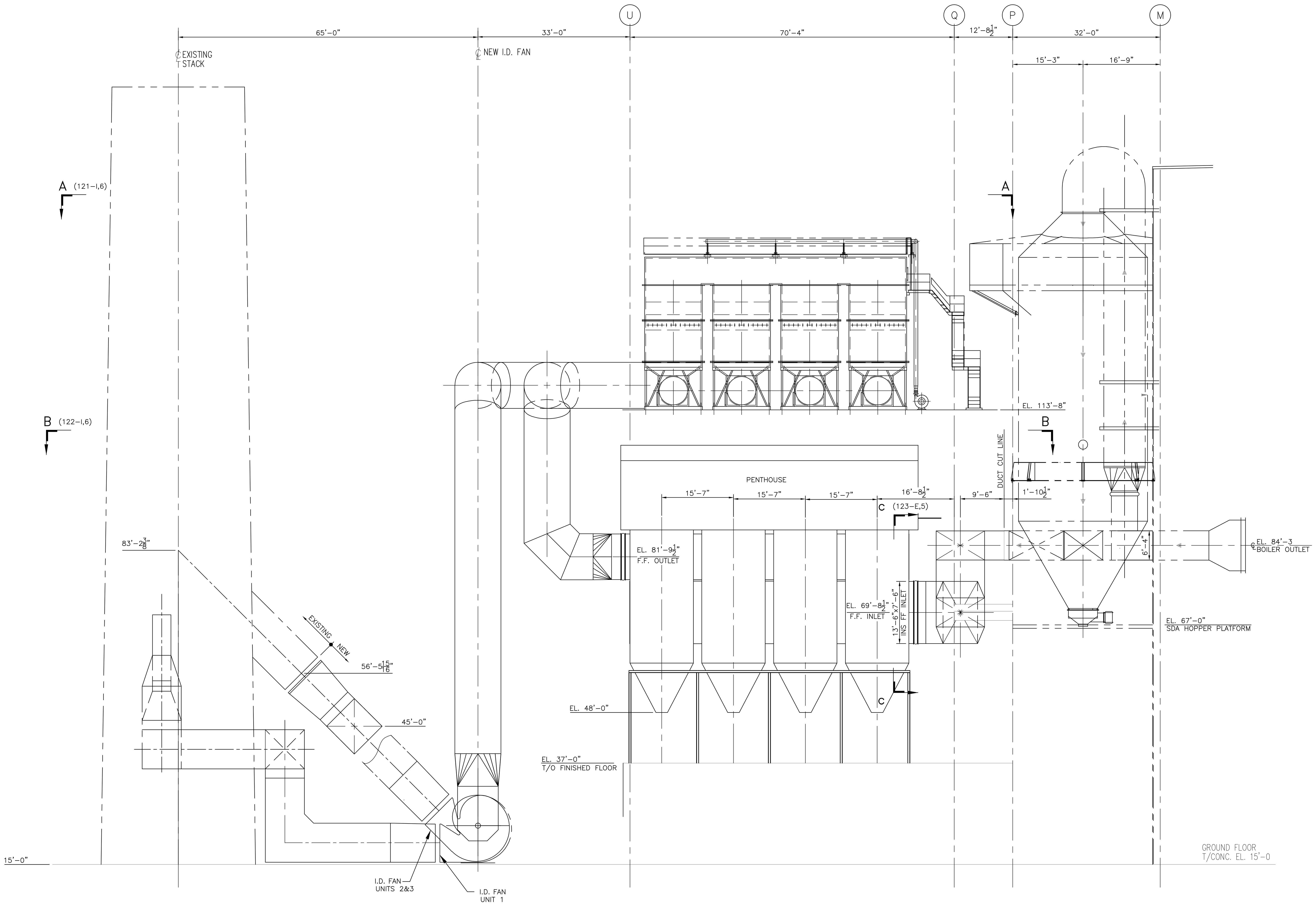
DATE
APP'D
DATE
SCALE 1/16 IN. = 1 FT.

BABCOCK POWER ENVIRONMENTAL INC.
PROPOSED RSCR ADDITION
RSCR ABOVE PRECIPITATOR
ELEVATION VIEW LOOKING NORTH
WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750111
REV. NO. P1

DWG. NO. 100825-0926750120



ELEVATION VIEW
PLANT VIEW NORTH

PRELIMINARY
6/26/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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RELEASED & APPROVED   DATE

THIRD ANGLE PROJECTION

DO NOT SCALE
USE DIMENSIONS ONLY

IFI

DRAWN A. Crowley
DATE 06/24/19
CHECKED
DATE
APP'D
DATE
SCALE ____ IN. = 1 FT.

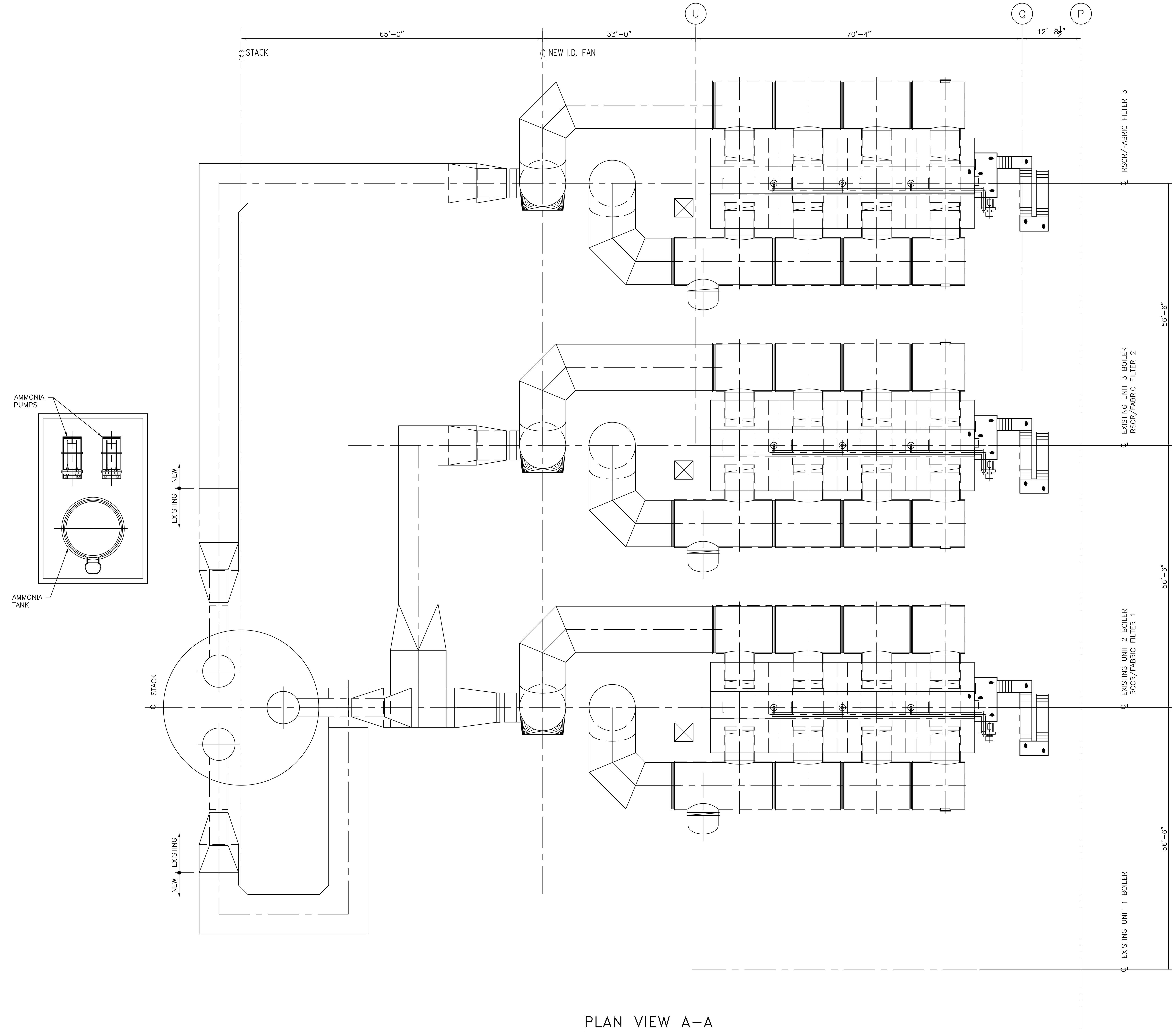
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED RSCR – FABRIC FILTER ADDITION
ELEVATION VIEW LOOKING NORTH

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825-0926750120
REV. NO. P0

DWG. NO. 100825-0926750121



PLAN VIEW A-A
(120-C,2)

PRELIMINARY
6/26/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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RELEASED & APPROVED ____ DATE ____

THIRD ANGLE PROJECTION

DO NOT SCALE
USE DIMENSIONS ONLY

IFI

DRAWN A. Crowley
DATE 06/24/19
CHECKED
DATE
APP'D
DATE
SCALE ____ IN. = 1 FT.

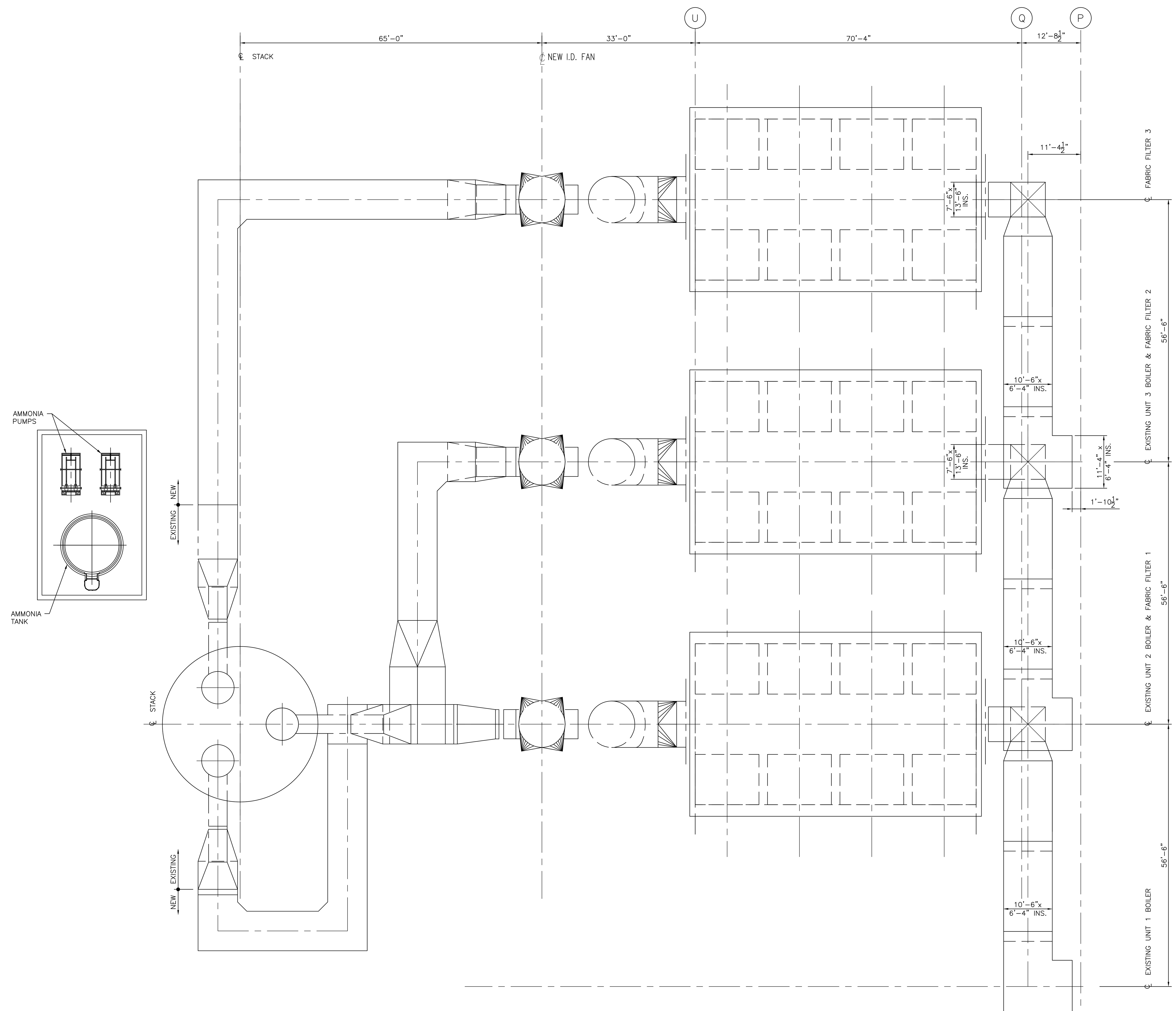
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED RSCR – FABRIC FILTER ADDITION
PLAN VIEW A-A

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825-0926750121
REV. NO. P0

DWG. NO. 100825–0926750122



PLAN SECTION B–B

(120–E,2)

PRELIMINARY
6/26/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

RELEASED & APPROVED DATE

THIRD ANGLE PROJECTION

DO NOT SCALE USE DIMENSIONS ONLY

IFI

DRAWN A. Crowley
DATE 06/24/19
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SCALE IN. = 1 FT.

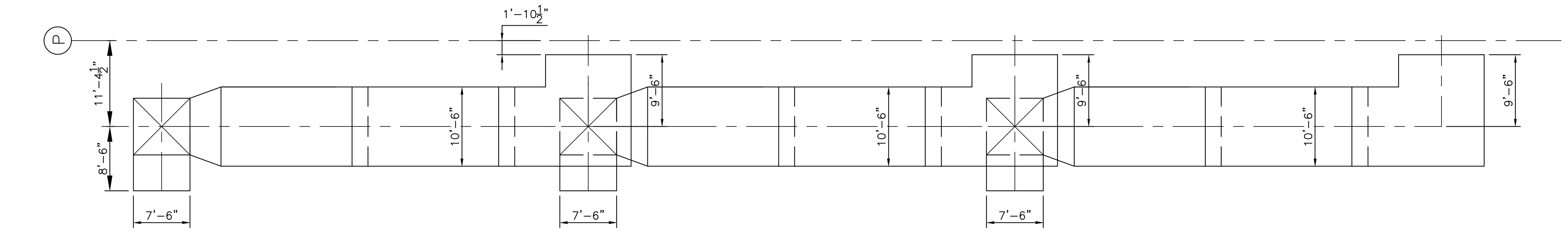
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED RSCR – FABRIC FILTER ADDITION
PLAN SECTION B–B

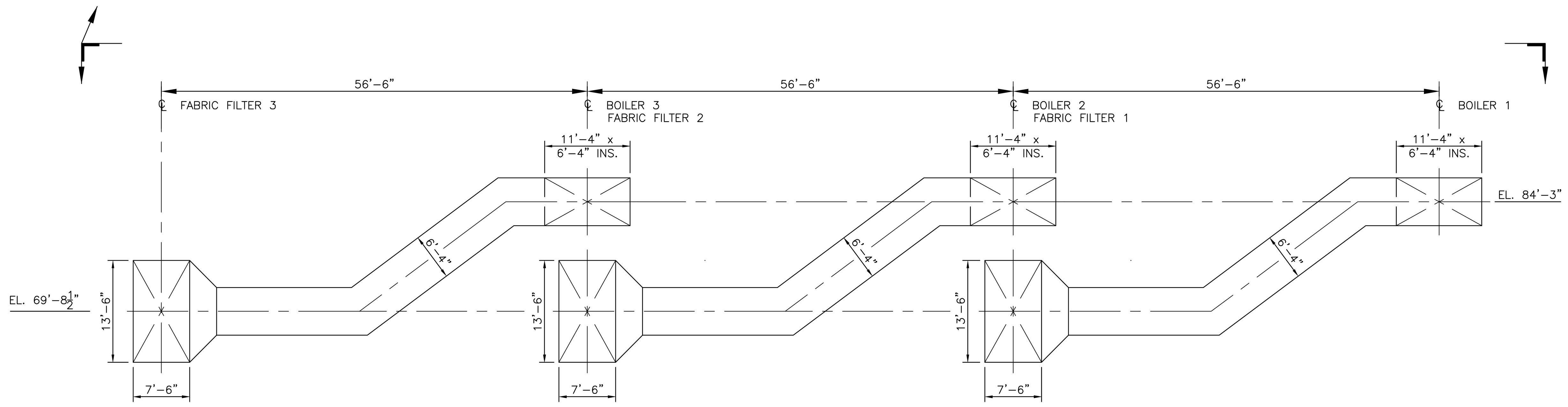
WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750122 REV. NO. P0

DWG. NO. 100825–0926750123



PLAN VIEW



VIEW C–C
(120–E,8)

PRELIMINARY
6/26/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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RELEASED & APPROVED DATE

THIRD ANGLE PROJECTION

DO NOT SCALE
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IFI

DRAWN A. Crowley
DATE 06/24/19
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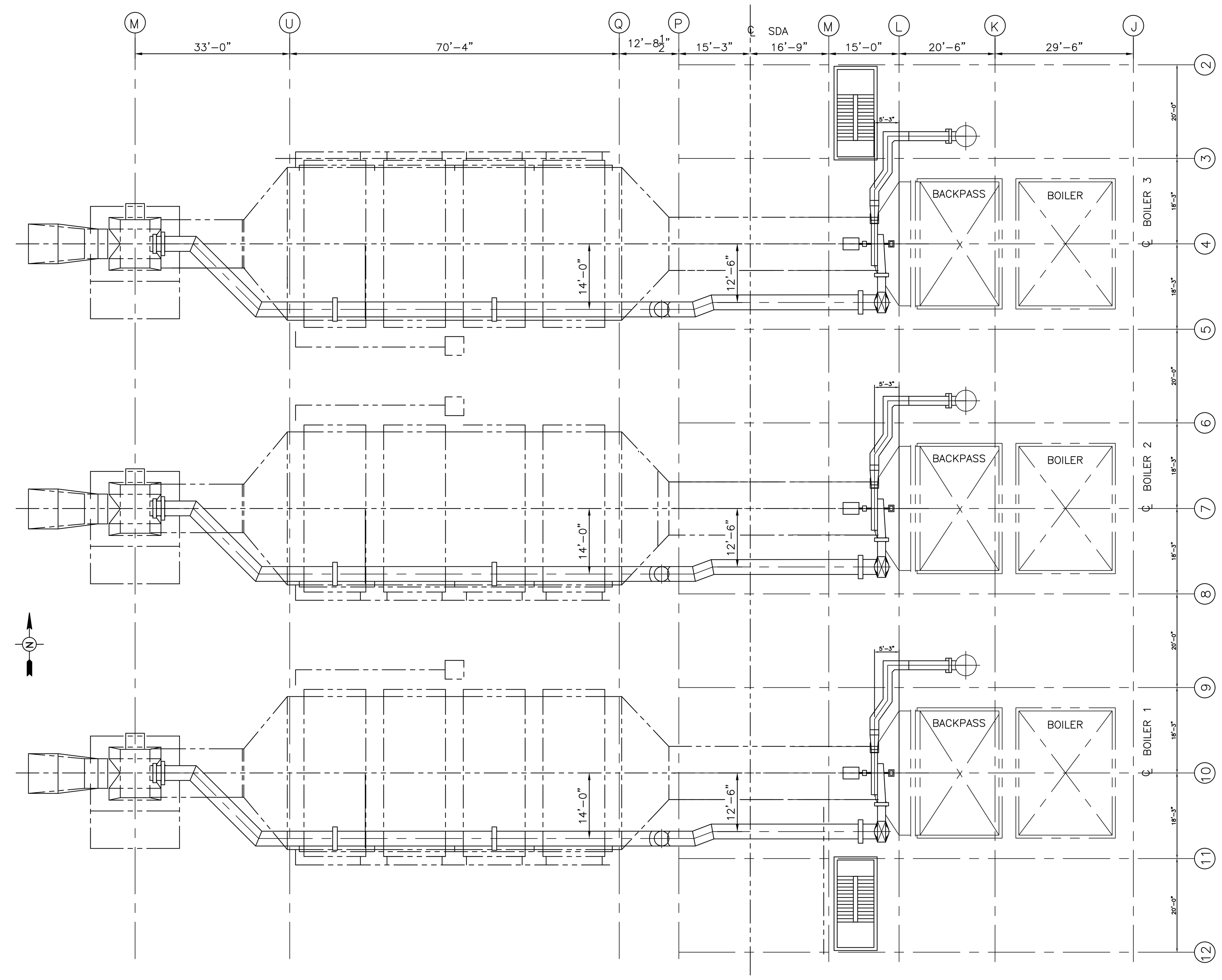
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED RSCR – FABRIC FILTER ADDITION
ELEVATION VIEW C–C

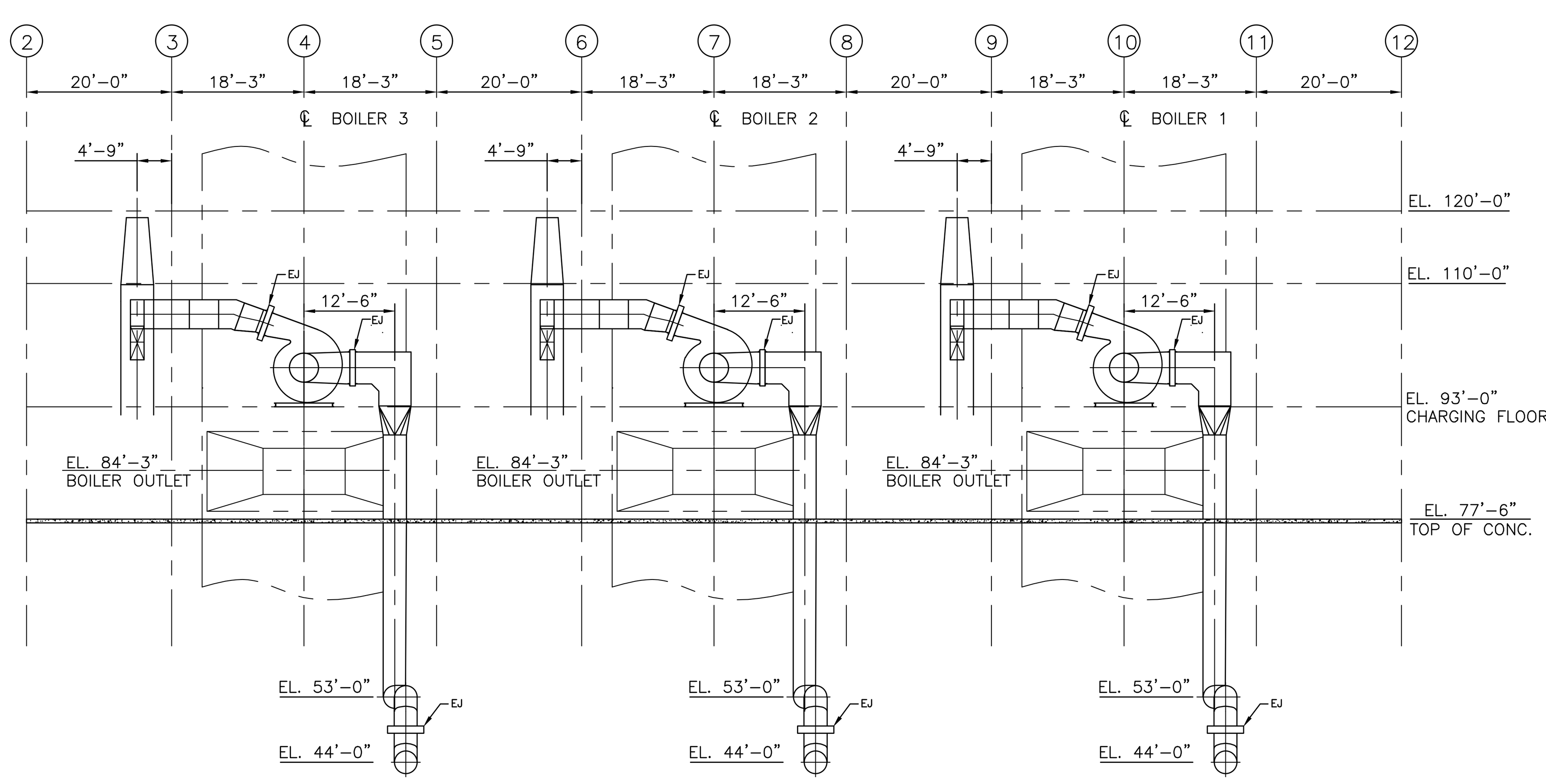
WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750123 REV. NO. P0

DWG. NO. 100825-0926750130

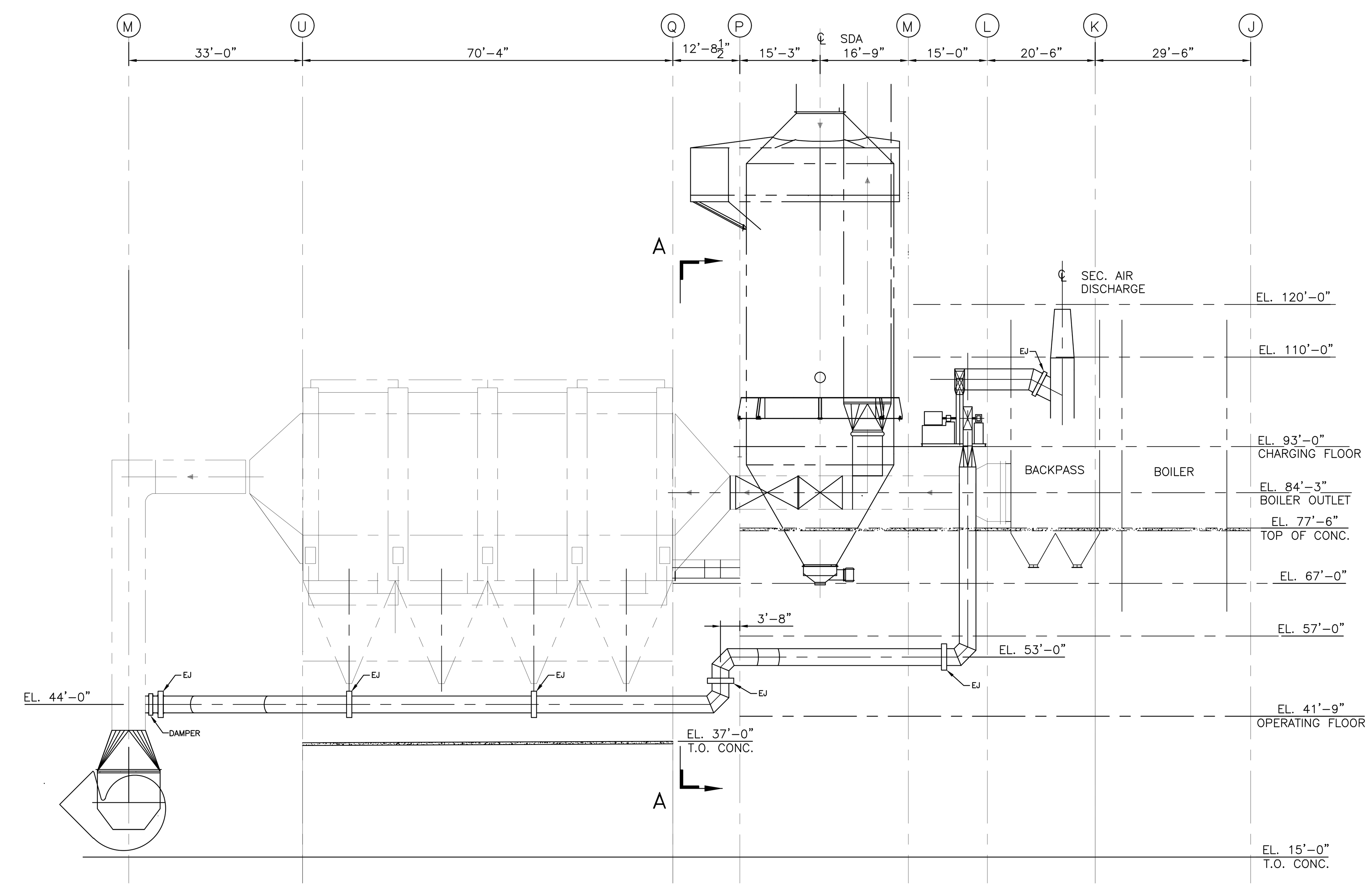


PLAN VIEW



SECTION A–A

ELEVATION VIEW
LOOKING EAST



ELEVATION LOOKING NORTH

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RELEASED & APPROVED DATE

THIRD ANGLE PROJECTION

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DRAWN A. Crowley
DATE 07/03/2019
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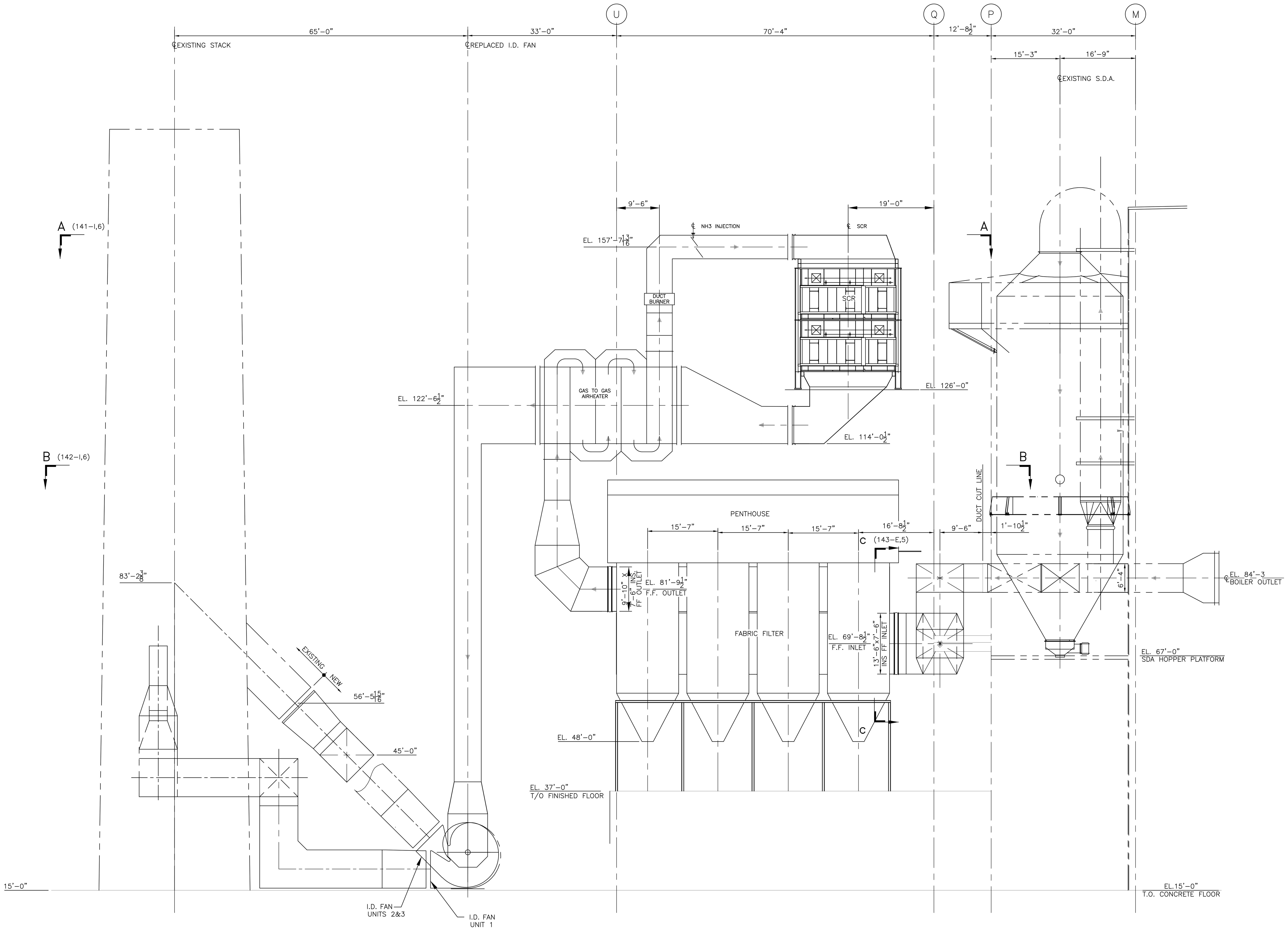
BABCOCK POWER ENVIRONMENTAL INC.

PROPOSED FLUE GAS RECIRCULATION ADDITION

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750130
REV. NO. P1

DWG. NO. 100825–0926750140



ELEVATION VIEW
PLANT VIEW NORTH

PRELIMINARY
7/15/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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THIRD ANGLE PROJECTION

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BABCOCK POWER ENVIRONMENTAL INC.

SCR, AIRHEATER AND FABRIC FILTER ADDITION
ELEVATION VIEW LOOKING NORTH

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750140 REV. NO. P0

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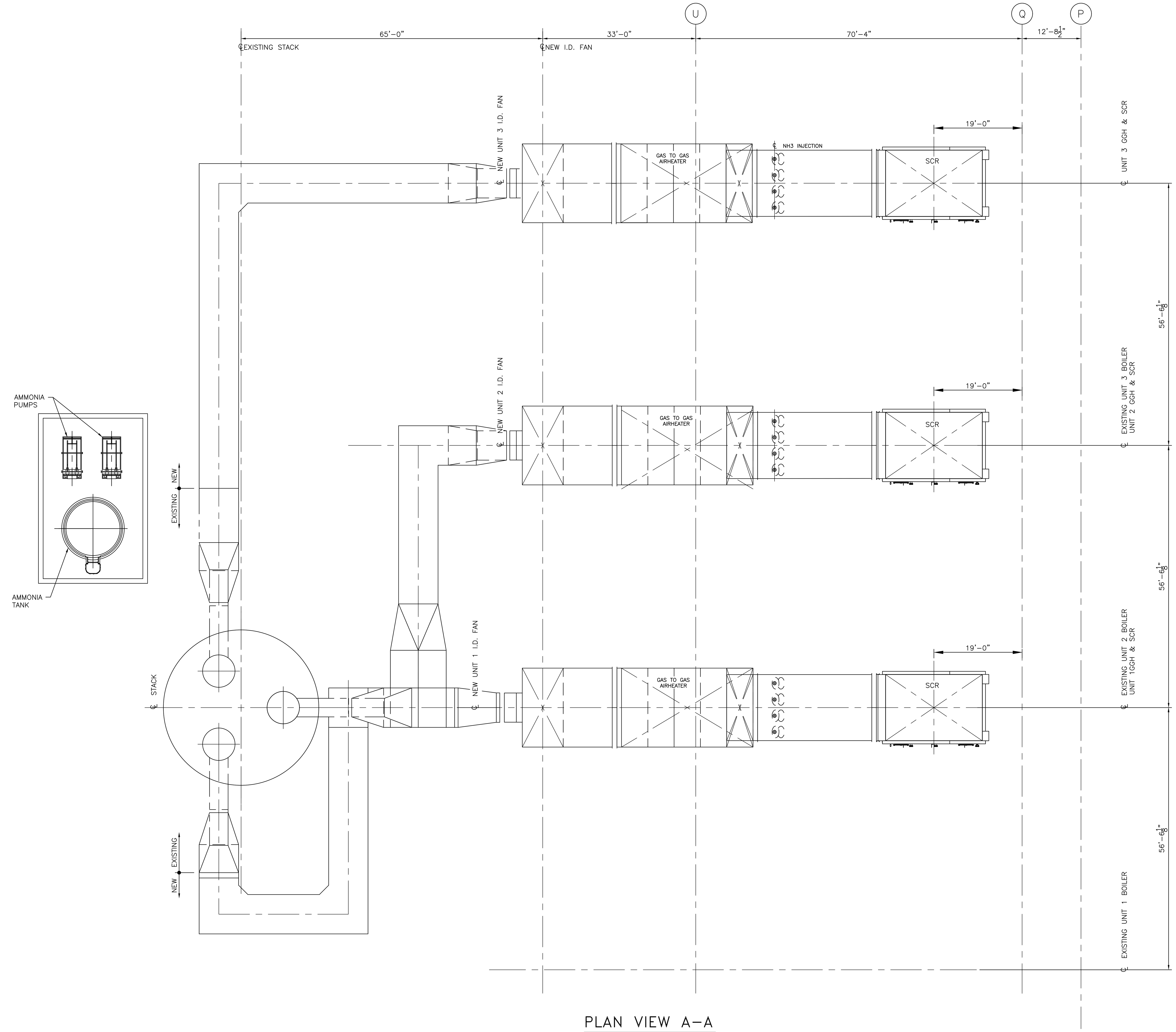

PLAN VIEW A-A
(140-C,2)

PRELIMINARY
7/15/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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THIRD ANGLE PROJECTION

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DRAWN A. Crowley
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SCALE 3/32 IN. = 1 FT.

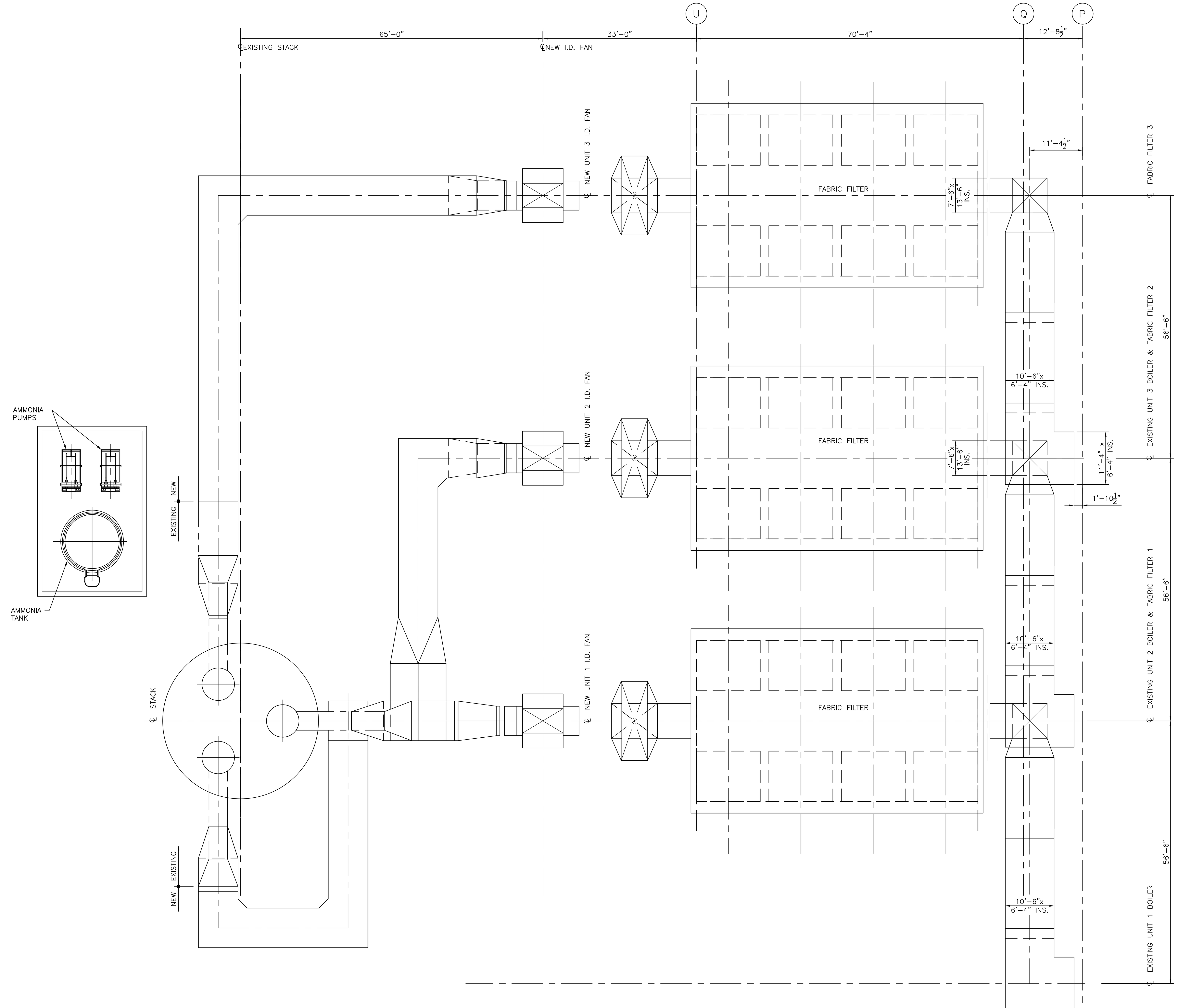
BABCOCK POWER ENVIRONMENTAL INC.

SCR, AIRHEATER AND FABRIC FILTER ADDITION
PLAN VIEW A-A

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825-0926750141 REV. NO. P0

DWG. NO. 100825–0926750142



PLAN SECTION B–B

(140–E,2)

PRELIMINARY
7/15/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

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THIRD ANGLE PROJECTION

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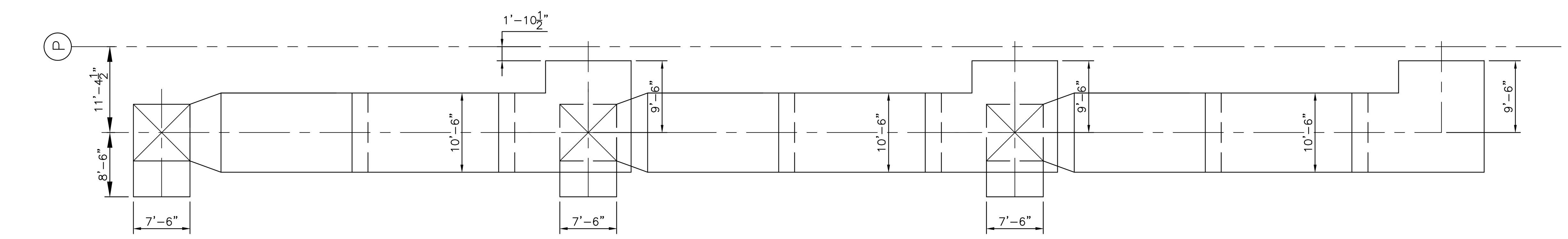
BABCOCK POWER ENVIRONMENTAL INC.

SCR, AIRHEATER AND FABRIC FILTER ADDITION
PLAN SECTION B–B

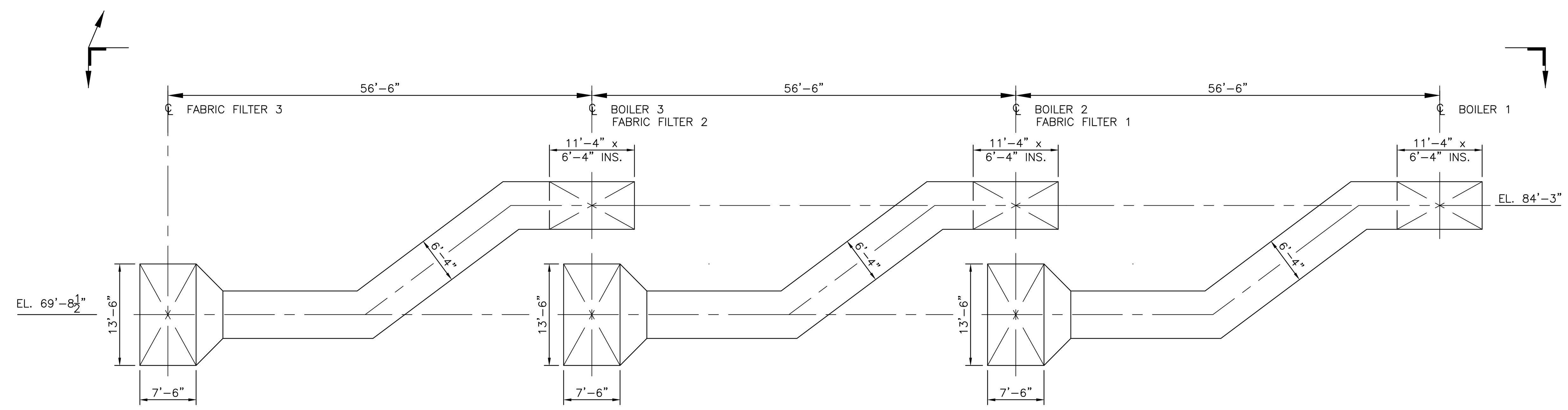
WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750142 REV. NO. P0

DWG. NO. 100825–0926750143



PLAN VIEW



VIEW C–C
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7/15/19

REVISION	NO.	BY	CHK	DATE	APP'D	DATE

THIS DRAWING IS NOT APPROVED FOR CONSTRUCTION UNLESS IT CONTAINS DATE AND SIGNATURE OF APPROVAL AND THE COMPANY RESERVES THE RIGHT TO CORRECT ANY ERRORS OR OMISSIONS PRIOR TO ACTUAL START OF WORK.

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THIRD ANGLE PROJECTION

DO NOT SCALE
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BABCOCK POWER ENVIRONMENTAL INC.

SCR, AIRHEATER AND FABRIC FILTER ADDITION
ELEVATION VIEW C–C

WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750143
REV. NO. P0

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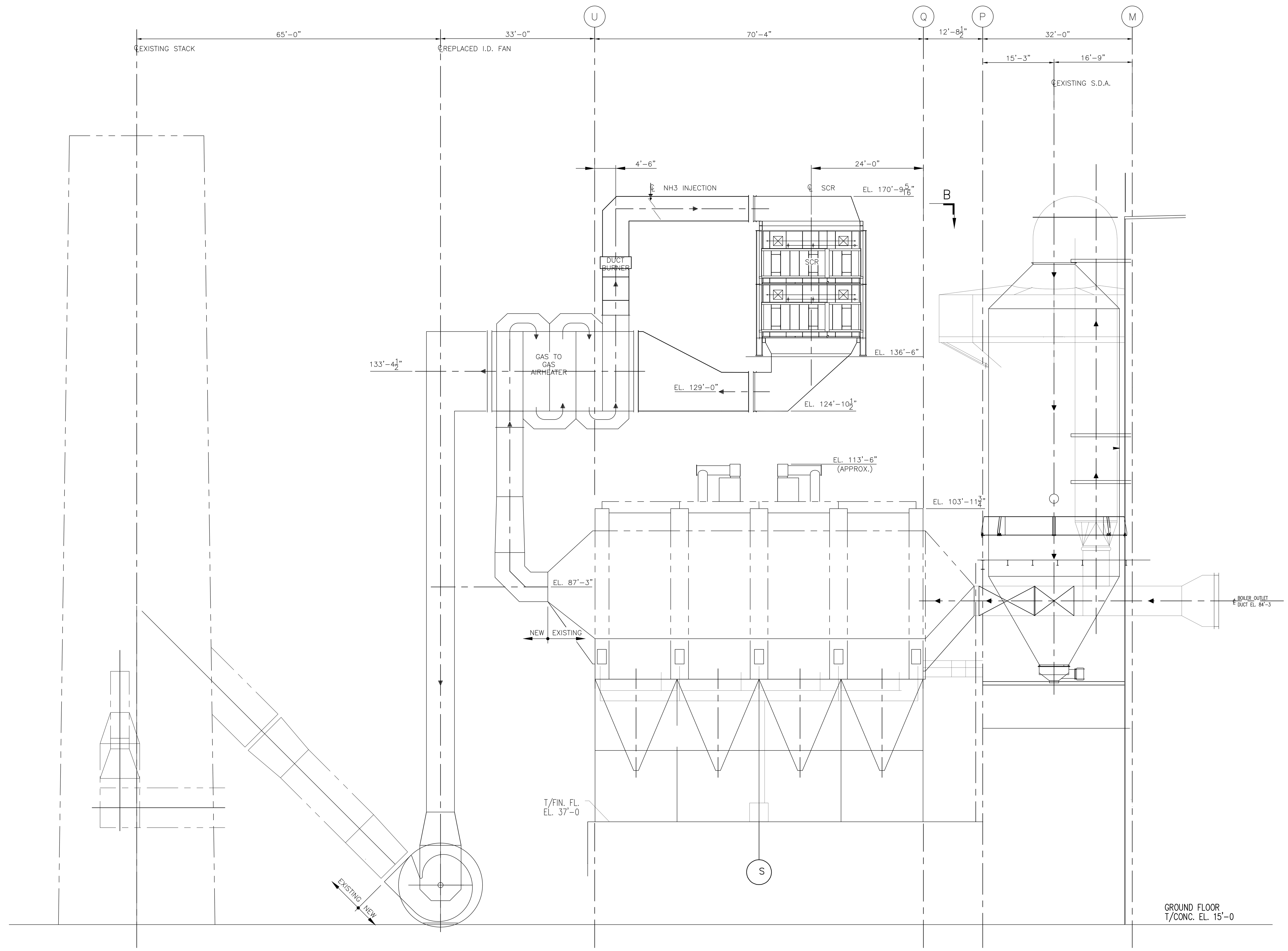

SIDE ELEVATION

LOOKING PLANT NORTH

PRELIMINARY
11/5/19

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THIRD ANGLE PROJECTION

DO NOT SCALE
USE DIMENSIONS ONLY

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DRAWN A. CROWLEY
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BABCOCK POWER ENVIRONMENTAL INC.
SCR & AIRHEATER ADDITION
ABOVE EXISTING PRECIPITATOR
ELEVATION VIEW LOOKING NORTH
WHEELABRATOR TECHNOLOGIES BALTIMORE
NOx FEASIBILITY STUDY
BALTIMORE, MARYLAND

DWG. NO. 100825–0926750150
REV. NO. P1

APPENDIX C REFERENCE LISTS

Reference lists for catalyst vendors who have tail-end experience with MWCs are presented on the following pages.

Waste Incineration

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Country	End User	Plant	Size	DeNOx	Catalyst	Start-Up Year
Belgium	Bruxelles Energie	Municipal Waste Plant - 3 lines	200,000 Nm^3/hr	83%	DNX-930	2005
China	Dow Corning	Chemical Waste Incinerator	286,000 Nm^3/hr	93%	DNX-949	2013
China	Qingdao Haiwan Chemical Co., Ldt.	Chemical Waste Incinerator	37,400 Nm^3/hr	88%	DNX-939	2019
China	Shandong New Synthesis Amino Acid	Waste Incineration	13,400 Nm^3/hr	96%	DNX-LD3	2015
China	Shandong Qingyuan	Waste Incineration	22,500 Nm^3/hr	90%	DNX-LD4	2016
China	Toure Shanghai	Hazardous Waste Incineration	60,000 Nm^3/hr	90%	DNX-LD3	2017
China	Urban Management Committee of Yiw	Waste Incineration Plant	175,000 Nm^3/hr	67%	DNX LD-939	2018
China	Wanhua Chemical Group Co., Ldt	Wanhua Yantai IPN Incinerator	39,800 Nm^3/hr	99%	DNX LD-949	2019
China	Zhejiang Feida Sci. and Tech. Co. Ldt.	Feixi Waste Incineration Units	---	50%	DNX LD-939	2020
China	Xian Tao Waste Incineration	Units 1-2	152,000 Nm^3/hr	60%	LD-939	2018
Czech Republic	Palivony Kombinat	Off-gas Incinerator (SNOX)	54,000 Nm^3/hr	95%	DNX-932	1993
Denmark	Amager Resourcecenter	Municipal Waste Plant - 2 lines	267,000 Nm^3/hr	95%	DNX-LD5	2016
Finland	Lahti Energia OY	Kymijarvi Unit 2	221,000 Nm^3/hr	90%	DNX-939	2011
France	Idex Fassa Envinronment	Dinan Units 1-2	46,100 Nm^3/hr	77%	DNX-939	2012
France	Siom de la Valee Chevreuse	Incineration Plant Line 1	90,000 Nm^3/hr	70%	DNX-939	2008
France	Siom de la Valee Chevreuse	Incineration Plant Line 2	54,000 Nm^3/hr	77%	DNX-930	2007
France	Sitom 19	Brive Incineration Plant	51,000 Nm^3/hr	47%	DNX-LD4	2014
France	SVDU	Usine d'Incineration, Cve de S	31,000 Nm^3/hr	60%	DNX-959	2017
France	Syvedac, Sirac	Incineration Plant - 2 Lines	60,700 Nm^3/hr	50%	DNX-940	2005
Ireland	Eli Lilly	Incinerator	10,000 Nm^3/hr	78%	DNX-930	2006
Italy	Accam SpA	Incineration Plant	67,000 Nm^3/hr	67%	DNX LD-939	2018
Italy	AEM Gestioni	Incineration Plant	42,000 Nm^3/hr	79%	DNX-LD3	2015
Italy	Alto Vincente Ambiente	Incineration Plant - Line 2	34,000 Nm^3/hr	86%	DNX-939	2011
Italy	Alto Vincente Ambiente	Incineration Plant - Line 3	49,300 Nm^3/hr	86%	DNX-939	2011
Italy	Alto Vincente Ambiente	Incineration Plant	32,000 Nm^3/hr	93%	DNX-LD3	2015
Italy	Brianza Energia Ambiente	Incineration Plant - 2 Lines	49,000 Nm^3/hr	70%	DNX-LD3	2016
Italy	Core	Incineration Plant - Units A-C	25,000 Nm^3/hr	59%	DNX-959	2010
Italy	Provincia Autonoma di Bolzano	Incineration Plant	117,000 Nm^3/hr	85%	DNX-930	1996
Italy	REA Rifuti Energia Embiente	Incineration Plant - Line A+B	68,000 Nm^3/hr	94%	DNX-930	2007
Italy	Undisclosed, (Area Impianti)	Waste Incineration, 2 Lines	84,300 Nm^3/hr		DNX-939	2012
Libya	SIPSA Engineering	Chem. Weapon Destruction	5,400 Nm^3/hr	50%	DNX-949	2011
Middle East	Undisclosed client	One Unit	34,700 Nm^3/hr	80%	DNX-920	2005
Romania	SNP Petrochem S.A. Arpechim	Gas Incineration	140,000 Nm^3/hr	99%	DNX-940	2004
Saudi Arabia	Sadara Chemical Company	Waste Gas Incineration, Units	147,000 Nm^3/hr	43%	DNX-949	2015
Spain	Union Wuimico Farmaceutica, A.A., Uq	Pharmaceutical Plant	9,000 Nm^3/hr	90%	DNX-950	1998
Thailand	Asahi Kasei	Industrial Waste Incineration	591,000 Nm^3/hr	98%	DNX-949	2011
Thailand	Ministry of Industrial Works	Waste Incinerator	45 tons/day	90%	DNX-930	2004
The Netherlands	AVR Afvalverwerking	Incineration Plant	70,000 Nm^3/hr	92%	DNX-929	2009
The Netherlands	BMC, Moerdijk	Chicken Manure Incineration	240,000 Nm^3/hr	71%	DNX-939	2012
The Netherlands	ESKA Graphic Board B.V.	Hoogezand Paper Mill	21,700 Nm^3/hr	86%	DNX-LD3	2016
The Netherlands	Lyondell Basell	Waste Incinerator	156,000 Nm^3/hr	88%	DNX LD-939	2019
The Netherlands	SITA ReEnergy	Incineration Plant	67,000 Nm^3/hr	80%	DNX-949	2007
UK	Suez	Suez Eco Park Surrey	40,800 Nm^3/hr	48%	DNX HD-864	2019
USA	Clean Harbors	Eldorao, Arkansas Facility	103,000 Nm^3/hr	95%	DNX LD-939	2018
USA	Clean Harbors	Incinerator Haz. Waste	103,000 Nm^3/hr	95%	DNX LD-939	2015
USA	OxyVinyls	Incinerator - 2 Units	36,000 Nm^3/hr		DNX-930	2002
USA	OxyMar	Incinerator - 2 Units	36,000 Nm^3/hr		DNX-930	2002
USA	White Mountain Energy	SOG Incinerator	87,000 Nm^3/hr	86%	DNX-958	2004

Reference List
for Honeycomb Catalyst
as of August 2018

Curr.No.	Project	Client	End user / Engineering company	Plant location	Application	Shipped quantity	Delivery date
1.	**MVA Spittelau**	SGP	Heizbetriebe Wien	AUT	Municipal Waste, Tail End	39 m³	1989
2.	**Ceilcote**	SGP	MGC Plasma AG	CHE	Hazardous Waste	2 m³	1990
3.	**MVA Heidelberg**	SGP	UNI-Bauamt Heidelberg	DEU	Hospital Waste, Low Temp.	3 m³	1990
4.	**MVA Spittelau Dioxin**	SGP	Heizbetriebe Wien	AUT	Municipal Waste, Tail End	22 m³	1991
5.	**Knoll**	SGP		CHE	Waste, High Dust	2 m³	1992
6.	**MVA Flötzersteig**	AEE	Heizbetriebe Wien	AUT	Municipal Waste, Tail End	52 m³	1992
7.	**MVA Burgkirchen**	SHL	ZAS	DEU	Waste, Tail End	24 m³	1993
8.	**München Nord**	BASF	Stadtwerke München	DEU	Waste, Tail End	49 m³	1993
9.	**MVA Rotterdam**	SGP	AVR	NLD	Municipal Waste, Low Temp.	321 m³	1993 / 95
10.	**Bayer Dormagen**	BASF	Lentjes	DEU	Hazardous Waste, Tail End	32 m³	1994
11.	**MVA Schwandorf**	BASF	Lentjes	DEU	Municipal Waste	130 m³	1994
12.	**Nijmegen**	BASF	KRC	NLD	Municipal Waste, Tail End	35 m³	1994
13.	**MVA Mannheim K1-3**	BASF	EVT	DEU	Municipal Waste, Tail End	86 m³	1994
14.	**MVA Essen Karnap**	BASF	EVT	DEU	Municipal Waste, Tail End	140 m³	1994
15.	**ZVSMM Schwabach**	BASF	Lurgi	DEU	Chemical Waste	9 m³	1994
16.	**RSMV Ciba Geigy**	BASF	Ciba Geigy	CHE	Hazardous Waste	12 m³	1995
17.	**BASF Residue Incin. N800**	BASF	BASF	DEU	Hazardous Waste, Low Dust	233 m³	1995
18.	**MVA Wels**	AEE	WAV	AUT	Municipal Waste, Tail End	20 m³	1995
19.	**MVA Leudelingen**	BASF		LUX	Municipal Waste, Tail End	16 m³	1995
20.	**MHKW Darmstadt**	BASF		DEU	Municipal Waste	100 m³	1995
21.	**Wuppertal**	BASF		DEU	Municipal Waste, Low Temp.	154 m³	1995
22.	**Bayer Bürrig**	BASF	Bayer AG	DEU	Chemical Waste	43 m³	1995
23.	**Bayer Uerdingen**	BASF	Bayer AG	DEU	Chemical Waste	12 m³	1995
24.	**SYSAV**	BASF	Sysav	SWE	Municipal Waste	11 m³	1995
25.	**ROW Wesseling**	BASF	ROW	DEU	Waste	24 m³	1995
26.	**Schwarzheide**	BASF	Integral	DEU	Hazardous Waste, Tail End	29 m³	1995
27.	**MVA Iserlohn**	BASF		DEU	Municipal Waste	87 m³	1995

Curr.No.	Project	Client	End user / Engineering company	Plant location	Application	Shipped quantity	Delivery date
28.	**SMVA Lonza**	AEE	Lonza AG	CHE	Residue, Tail End	25 m³	1995
29.	**KVA Thurgau**	AEE	Verband KVA Thurgau	CHE	Municipal and Industrial Waste, Tail End	33 m³	1996
30.	**MVA Bielefeld**	BASF		DEU	Municipal Waste	204 m³	1996
31.	**CZ Süd**	BASF	BASF	DEU	Residue, Tail End	3 m³	1996
32.	**Höchst**	BASF	Hoechst AG	DEU	Hazardous Waste	21 m³	1996
33.	**KVA St. Gallen**	BASF	AEE	CHE	Municipal Waste, Tail End	11 m³	1996
34.	**MHKW Ludwigshafen**	BASF		DEU	Municipal Waste	78 m³	1996
35.	**MVA Flingern**	BASF		DEU	Municipal Waste, Tail End	106 m³	1996
36.	**MHKW Bamberg**	BASF		DEU	Municipal Waste	21 m³	1996
37.	**HKW München Nord**	BASF		DEU	Municipal Waste	63 m³	1996
38.	**MKW Weissenhorn**	BASF		DEU	Municipal Waste	41 m³	1996
39.	**MVA Zavin**	AEE		NLD	Hospital Waste, Low Temp.	7 m³	1996
40.	**Colombes**	Integral		FRA	Waste, Tail End	20 m³	1996
41.	**CIBA Geigy**	Smogless		ITA	Waste	6 m³	1997
42.	**MVA Mannheim IV**	BASF		DEU	Municipal Waste, Tail End	46 m³	1997
43.	**MVA Zagreb**	Hafner		HRV	Waste	4 m³	1997
44.	**GMVA Niederrhein**	BASF		DEU	Municipal Waste	58 m³	1997
45.	**RMVA Köln**	BASF		DEU	Municipal Waste	115 m³	1997
46.	**MVA Lenzing**	Integral		AUT	Waste, Tail End	29 m³	1997
47.	**BASF N806**	BASF	BASF	DEU	Hazardous Waste, Low Dust	24 m³	1997
48.	**MVA Constanti**	BASF	AE-Energietechnik	ESP	Hazardous Waste, Low Dust	29 m³	1998
49.	**MVA Wuppertal**	Integral		DEU	Municipal Waste, Low Temp., Additional Delivery	51 m³	1998
50.	**KVA Basel**	BASF		CHE	Municipal Waste, Low Dust	58 m³	1998
51.	**MVA Würzburg**	BASF		DEU	Municipal Waste, High Dust	16 m³	1998
52.	**MVA Buchs**	BASF	AE	CHE	Municipal Waste, Tail End	54 m³	1998
53.	**SMVA Ostrava**	AE-Energietechnik		CZE	Hazardous Waste, Tail End	9 m³	1999
54.	**BASF N806**	BASF	BASF	DEU	Hazardous Waste, Low Dust	8 m³	1999

Curr.No.	Project	Client	End user / Engineering company	Plant location	Application	Shipped quantity	Delivery date
55.	**MVA Niederurnen**	BASF		CHE	Municipal Waste	57 m³	1999
56.	**Thermoselect Karlsruhe**	BASF	Steuler	DEU	Waste	9 m³	1999
57.	**TRV-Wesseling**	BASF		DEU	Industrial- and Hazardous Waste	13 m³	1999
58.	**Genf Linie 5, 6, 3**	BASF	SIG / AE-Energietechnik	CHE	Municipal Waste, Low Dust	139 m³	2000/01
59.	**Dalmine**	Integral		ITA	Waste, Tail End	13 m³	2000
60.	**Rhodia**	BASF	Rhodia	DEU	Hazardous/Liquide Waste	14 m³	2000
61.	**BASF N810**	BASF	BASF	DEU	Hazardous Waste, Low Dust, Additional Delivery	29 m³	2001
62.	**ROW-Wesseling TRV**	BASF	ROW	DEU	Industrial- and Hazardous Waste, Additional Delivery	13 m³	2001
63.	**MVA Fribourg**	BASF		CHE	Waste, Tail End	33 m³	2001
64.	**Creteil**	BASF	ELEX	FRA	Municipal Waste, Tail End	48 m³	2001
65.	**HIMTEC**	BASF		ITA	Industrial Waste, Tail End	5 m³	2001
66.	**CO-Catalyst Rotterdam**	AE-Energietechnik	AVR	NLD	Municipal Waste, Tail End, CO Oxidation	6 m³	2001
67.	**MVA Bamberg**	BASF		DEU	Municipal Waste, Tail End	7 m³	2001
68.	**MVA Zavin**	BASF	Steuler	NLD	Hospital Waste, Low Temperature, Additional Delivery	3 m³	2001
69.	**Thermoselect Karlsruhe**	BASF	EnBW	DEU	Waste	7 m³	2001
70.	**MVA Würzburg**	BASF	BBP Environment	DEU	Municipal Waste, High Dust	34 m³	2002
71.	**TRV Wesseling**	BASF		DEU	Industrial- and Hazardous Waste, Additional Delivery	13 m³	2002
72.	**Halmstads Renhallnings AB**	BASF	BBP Environment	SWE	Municipal Waste, Tail End	19 m³	2002
73.	**Bayer Antwerpen**	BASF	Bayer AG	BEL	Industrial Waste, Tail End	13 m³	2002
74.	**KVA Turgi**	BASF	GV Region Baden-Brugg	CHE	Municipal Waste, Tail End	11 m³	2002
75.	**GMVA Oberhausen**	BASF		DEU	Municipal Waste, Tail End	19 m³	2002
76.	**MVA Malmö**	BASF	LAB	SWE	Municipal Waste, Tail End	30 m³	2002
77.	**KVA Thurgau**	BASF	CTU	CHE	Municipal Waste, Tail End, Additional Delivery	8 m³	2002
78.	**Nijmegen**	BASF		NLD	Municipal Waste, Tail End, Additional Delivery	6 m³	2002
79.	**Genf Linie 5**	BASF	CTU	CHE	Municipal Waste, Low Dust, Additional Delivery	55 m³	2002
80.	**T.A. Lauta**	AE	STEAG	DEU	Municipal Waste, Tail End, Low Temp.	47 m³	2003
81.	**RSMVA Basel**	BASF	Valorec Services AG	CHE	Residue, Additional Delivery	12 m³	2003

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82.	**EBS WSO 4**	Integral	Fernwärme Wien	AUT	Sludge, Municipal Waste	22 m³	2003
83.	**Nimes**	Integral		FRA	Waste, Tail End	9 m³	2003
84.	**Le Havre**	Integral		FRA	Waste, Tail End	13 m³	2003
85.	**TRV Niklasdorf**	AEE		AUT	Waste, Tail End	12 m³	2003
86.	**Nijmegen Line 2**	BASF		NLD	Municipal Waste, Tail End, Additional Delivery	11 m³	2003
87.	**MVA Constanti**	BASF		ESP	Hazardous Waste, Low Dust, Additional Delivery	10 m³	2003
88.	**KVA St. Gallen**	BASF		CHE	Municipal Waste, Tail End, Additional Delivery	9 m³	2003
89.	**TBA Arnoldstein**	AEE	KRV	AUT	Municipal Waste, Tail End, Low Temp.	14 m³	2003
90.	**DOMO Caproleuna**	BASF		DEU	Residue, Tail End	3 m³	2003
91.	**Höchst**	BASF	Höchst	DEU	Hazardous Waste, Additional Delivery	11 m³	2003
92.	**TRV Wesseling**	BASF		DEU	Industrial- and Hazardous Waste, Additional Delivery	13 m³	2004
93.	**Colleferro Unit 1 & 2**		Termokimik	ITA	Municipal Waste, Tail End	36 m³	2004
94.	**Genf Linie 6**	BASF	SIG / CTU	CHE	Municipal Waste, Low Dust, Additional Delivery	72 m³	2004
95.	**ICDI Charleroi**	HRC		BEL	Municipal Waste, Low Dust	7 m³	2004
96.	**KVA Basel**	BASF		CHE	Municipal Waste, Low Dust	29 m³	2004
97.	**WAV II Wels**	LAB GmbH	Energie AG Oberösterreich	AUT	Municipal Waste, Tail End	41 m³	2005
98.	**Sammel SCR Simmering**	Envirgy	Fernwärme Wien	AUT	Sludge, Hazardous Waste, Tail End, Low Temp.	125 m³	2005
99.	**Ostrava**	SPOVO	SPOVO	CZE	Hazardous Waste, Tail End, Low Temp. Additional Delivery	3 m³	2005
100.	**Saint Ouen Unit 1-3**	BASF	LAB / SYCTOM	FRA	Municipal Waste, Tail End	219 m³	2005
101.	**Brest**		Termokimik	FRA	Municipal Waste, Tail End	14 m³	2005
102.	**MSWI Bordeaux**	BASF	ASTRIA / HRC	FRA	Municipal Waste, Tail End	85 m³	2005
103.	**CVDU Nice**	BASF	LAB	FRA	Municipal Waste, Tail End, Dioxin	157 m³	2005
104.	**MVA Malmö**	BASF	LAB	SWE	Municipal Waste, Tail End, Additional Delivery	22 m³	2005
105.	**Tirmadrid**	Integral		ESP	Municipal Waste, Tail End, Low Temp.	133 m³	2005
106.	**Rennes**	BASF	Von Roll	FRA	Municipal Waste, Tail End	23 m³	2005
107.	**Nantes**	BASF	Von Roll	FRA	Municipal Waste, Tail End	34 m³	2005
108.	**Coueron / Nantes**	BASF	LAB	FRA	Municipal Waste, Tail End	12 m³	2005

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109.	**Recycling Komb. Rotterdam**	BASF	Steuler	NLD	Residue, Tail End	13 m³	2005
110.	**BASF Incineration plant**	BASF	BASF	DEU	Residue, Raw gas, NOx- + CO-removal	5 m³	2005
111.	**Chaumont**	HRC	SHMVD Chaumont	FRA	Municipal Waste, Tail End	13 m³	2005
112.	**Constanti**	BASF		ESP	Residue, Low Dust, Additional Delivery	20 m³	2005
113.	**Kimhae**	BASF	SPECO	KOR	Municipal Waste, Tail End, Additional Delivery	5 m³	2005
114.	**BASF CZ Süd**	BASF	BASF	DEU	Residue, Tail End, Additional Delivery	3 m³	2005
115.	**Steuler**	BASF	Steuler	DEU	Waste, Tail End	6 m³	2005
116.	**Sangju**	BASF	David Chemical	KOR	Waste, Tail End, Additional Delivery	3 m³	2005
117.	**Genf Linie 5**	BASF	SIG	CHE	Municipal Waste, Low Dust, Additional Delivery	72 m³	2006
118.	**MSW Ludres**	Hamon	Nancy Energie	FRA	Waste, Tail End, Low Temperature	40 m³	2006
119.	**CENON**	Hamon	UIOM de Cenon	FRA	Municipal Waste, Tail End	20 m³	2006
120.	**Rhodia**	BASF	Rhodia	DEU	Hazardous/Liquide Waste, Additional Delivery	14 m³	2006
121.	**Kimhae**	BASF	SPECO	KOR	Municipal Waste, Tail End, Additional Delivery	5 m³	2006
122.	**NANYA**	BASF	Lucky Lotus Corp.	TWN	Industrial Waste Additional Delivery	2 m³	2006
123.	**Ferrara**	Alstom	Hera	ITA	Municipal Waste, Tail End, Low Temp.	54 m³	2006
124.	**MVA Flötzersteig**	Integral	Fernwärme Wien	AUT	Municipal Waste, Tail End, Low Temp.	71 m³	2006
125.	**MVA Pfaffenau**	Integral	WKU / Envirgy	AUT	Municipal Waste, Tail End, Low Temp.	68 m³	2007
126.	**Dunkerque**	BASF	Dunkerque Grand Littoral / Von Roll	FRA	Municipal Waste, Tail End	9 m³	2007
127.	**Issy-les-Moulineaux**	BASF	SYCTOM / Von Roll	FRA	Municipal Waste, Tail End, Low Temp.	163 m³	2007
128.	**Forli**	Alstom	Hera	ITA	Municipal Waste, Tail End, Low Temp.	44 m³	2007
129.	**BMC Moerdijk**	AEE	BMC Moerdijk BV	NLD	Chicken litter, Tail End	20 m³	2007
130.	**AMSA Silla 2**	Termokimik	AMSA	ITA	Municipal Waste, Tail End, Low Temperature	171 m³	2007
131.	**BASF CZ Süd II**	BASF	BASF	DEU	Residue Incineration	4 m³	2007
132.	**MVA AVS 4825**	BASF		DEU	Residue Incineration	9 m³	2007
133.	**VA-Schottland**	BASF	LTB	DEU	Residue Incineration	3 m³	2007
134.	**MVA Prag Linie 1-4 Prague-Malešice**	BASF	Pražske služby	CZE	Municipal Waste, Low Dust	236 m³	2007
135.	**Constanti**	BASF		ESP	Residue, Low Dust, Additional Delivery	10 m³	2007

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136.	**Dadae MSWI**	SPECO		KOR	Municipal Waste, Additional Delivery	8 m³	2007
137.	**Myungji MSWi**	SPECO		KOR	Municipal Waste, Additional Delivery	25 m³	2007
138.	**Constanti**	BASF	Gestio De Residus Especials De Catalunya, S.A.	ESP	Residue, Low Dust, Additional Delivery	10 m³	2007
139.	**MSW Antibes**	Hamon	Veolia	FRA	Municipal Waste, Tail End	37 m³	2007
140.	**MVA Malmö**	BASF	LAB	SWE	Municipal Waste, Additional Delivery	63 m³	2007
141.	**MVA Twence**	BASF	LAB	NLD	Municipal Waste, Tail End	50 m³	2007
142.	**MVA Marseille**	BASF	LAB	FRA	Municipal Waste, Tail End	29 m³	2007
143.	**Lamballe**	BASF	Marguin	FRA	Municipal Waste	8 m³	2007
144.	**Icheon MSWI**	Dongbu	Dongbu	KOR	Municipal Waste	16 m³	2007
145.	**Padova Line 2+3**	Termokimik		ITA	Municipal Waste Low Temperature	55 m³	2008/2009
146.	**Borsodchem NYRT**	BASF	Borsodchem ZRT	HUN	Municipal Waste, Tail End	15 m³	2008
147.	**Rohdia Residue Boiler 5**	BASF	Rhodia	FRA	Residue Incineration	96 m³	2008
148.	**Jeonggwan MSWI**	SPECO	SPECO	KOR	Municipal Waste	6 m³	2008
149.	**Bazenheid**	ELEX	Bazenheid	CHE	Municipal Waste, Tail End	51 m³	2008
150.	**Eunpyung MSWI**	Eco En Top		KOR	Municipal Waste	5 m³	2008
151.	**Myungji MSWI**	SPECO	SPECO	KOR	Municipal Waste Additional Delivery	25 m³	2008
152.	**Haewundae MSWI**	Busan Environmental Corp	Busan Environmental Corp	KOR	Municipal Waste, Additional Delivery	17 m³	2008
153.	**MVA Zistersdorf**	BASF	Von Roll	AUT	Municipal Waste Tail End	41 m³	2008
154.	**Mida Crotone**	Hafner	Mida S.r.l.	ITA	Municipal Waste, Tail End	7 m³	2008
155.	**TBA Arnoldstein**	KRV	KRV	AUT	Municipal Waste Low Temperature, Additional Delivery	6 m³	2008
156.	**Yangju MSWI Plant**	SPECO	SPECO	KOR	Municipal Waste	13 m³	2008
157.	**Pangyo MSWI Plant**	SPECO	SPECO	KOR	Municipal Waste	7 m³	2008
158.	**Masan MSWI Plant**	SPECO	SPECO	KOR	Municipal Waste	5 m³	2008
159.	**Ferrara**	Alstom	HERA	ITA	Municipal Waste, Tail End, Low Temp. Additional Delivery	44 m³	2008
160.	**Rimini**	Alstom	HERA	ITA	Municipal Waste, Tail End, Low Temperature	44 m³	2008
161.	**Genf**	BASF	Usine de Cheneviers	CHE	Municipal Waste, Low Dust, Additional Delivery	72 m³	2008
162.	**MVA Dürnrohr Linie 3**	Envirgy	AVN	AUT	Municipal Waste, Tail End	35 m³	2009

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163.	**Mallorca P 3095**	BASF	TIRME SA	ESP	Municipal Waste, Tail End	45 m³	2009
164.	**Gwangmyeong**	Blue Bird	Blue Bird	KOR	Waste Heat Boiler	9 m³	2009
165.	**MSW Giubiasco**	BASF	Von Roll	DEU	Municipal Waste, Tail End	30 m³	2009
166.	**Kuri MSWI**	SPECO	SPECO	KOR	Municipal Waste, Low Dust	18 m³	2009
167.	**Daejeon MSWI**	SPECO	SPECO	KOR	Municipal Waste	6 m³	2009
168.	**Dadae MSWI**	MSWI Dadae	MSWI Dadae	KOR	Municipal Waste, Additional Delivery	9 m³	2009
169.	**TBA Arnoldstein**	KRV	KRV	AUT	Municipal Waste Low Temperature, Additional Delivery	8 m³	2009
170.	**NANYA**	BASF	Lucky Lotus Corp.	TWN	Industrial Waste Additional Delivery	3 m³	2009
171.	**MVA Dordrecht**	BASF	LAB	NLD	Municipal Waste	65 m³	2009
172.	**MVA Göteborg**	BASF	LAB	SWE	Municipal Waste	39 m³	2009
173.	**Constanti**	BASF		ESP	Residue, Low Dust, Additional Delivery	3 m³	2009
174.	**MSW Reims**	Hamon	Hamon	FRA	Municipal Waste, Tail End Low Temperature	31 m³	2009
175.	**Ulsan MSWI**	Halla Energy & Environment		KOR	Municipal Waste, Additional Delivery	10 m³	2009
176.	**Mapo MSWI**	Kolon		KOR	Municipal Waste, Additional Delivery	27 m³	2009
177.	**Chaumont**	HRC	SHMVD Chaumont	FRA	Municipal Waste, Tail End, Additional Delivery	13 m³	2009
178.	**TABA Leudelange**	BASF	Von Roll / Sidor	LUX	Municipal Waste, Tail End Low Temperature	47 m³	2010
179.	**Sivom Mulhouse**	Hamon	Sivom	FRA	Municipal Waste, Tail End	61 m³	2010
180.	**MSW Sangju**	BASF	David Chemical	KOR	Municipal Waste	3 m³	2010
181.	**MSWI Kimhae**	SPECO		KOR	Municipal Waste, Additional Delivery	10 m³	2010
182.	**MSWI Chungju**	SPECO		KOR	Municipal Waste, Additional Delivery	7 m³	2010
183.	**MSWI Yongin**	Kolon E&C	Yongin City	KOR	Municipal Waste, Additional Delivery	7 m³	2010
184.	**MSWI Rennes**	BASF	Veolia	FRA	Municipal Waste, Tail End, Additional Delivery	10 m³	2010
185.	**RHKW Linz**	Integral	Linz AG	AUT	Municipal Waste, Tail End	40 m³	2010
186.	**Rhodia**	BASF	Rhodia	FRA	Residue Waste, Additional Delivery	26 m³	2010
187.	**Sungseo MSWI # 3**	Sungseo		KOR	Municipal Waste	21 m³	2010
188.	**MSW Le Mans**	BASF	Veolia	FRA	Municipal Waste	26 m³	2010
189.	**Mistral Spilimbergo**	Hafner	Hafner/Mistral Spilimbergo	ITA	Hospital Waste	7 m³	2010

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190.	**T.A. Lauta**	BASF	T.A.Lauta GmbH	DEU	Municipal Waste, Tail End, Low Temp., Additional Delivery	16 m³	2010
191.	**MSW Harlingen**	BASF		DEU	Municipal Waste, Tail End	37 m³	2010
192.	**Mataro Line 1+2**	Fuel Tech	TEM UTE Constructora	ITA	Municipal Waste	23 m³	2010
193.	**Rhodia**	BASF	Rhodia	FRA	Residue Incineration, Additional Delivery	26 m³	2010
194.	**Cenon**	BASF	Veolia	FRA	Municipal Waste, Tail End, Additional Delivery	20 m³	2010
195.	**San Vittore Linie 2+3**	ATS Air Treatment System	MSWI San Vittore	ITA	Municipal Waste, Tail End	65 m³	2010/2011
196.	**Forli**	Hera	Hera	ITA	Municipal Waste, Tail End, Additional Delivery	21 m³	2011
197.	**HDO Incineration Freeport**	BASF	BASF	USA	Residue, Additional Delivery	36 m³	2011
198.	**San Vittore Linie 1**	ATS Air Treatment System	MSWI San Vittore	ITA	Municipal Waste, Tail End	23 m³	2011
199.	**MVA Moskau MSZ3**	Condor	EVN	RUS	Municipal Waste, Tail End	30 m³	2011
200.	**Iksan DHP**	Samyoung Plant Co., Ltd.	Samyoung Plant Co., Ltd.	KOR	Waste Incineration (RDF&Coal)	15 m³	2011
201.	**Namyangju MSWI**	Ilshin Environmental Co.	Ilshin Environmental Co.	KOR	Waste Incineration	7 m³	2011
202.	**LWI BASF YPC Nanjing**	BASF	BASF YPC	CHN	Residue Incineration	13 m³	2011
203.	**Dunkerque - Spare Layer 2011**	BASF	Von Roll	FRA	Waste Incineration, Additional Delivery	4 m³	2011
204.	**MSWI Ulsan (New Line)**	Tong Yang Magic Co., Ltd.	Tong Yang Magic Co., Ltd.	KOR	Waste Incineration	10 m³	2011
205.	**MSW Flamoval**	BASF	LAB	NLD	Municipal Waste, Tail End	20 m³	2011
206.	**MSWI Kimpo**	Donglim Eng. Co.	Donglim Eng. Co.	KOR	Municipal Waste	8 m³	2011
207.	**MSWI Dadae**	Kolon	Kolon	KOR	Municipal Waste, Additional Delivery	8 m³	2011
208.	**MSWI Myungji**	Kolon	Kolon	KOR	Municipal Waste, Additional Delivery	25 m³	2011
209.	**MSWI Haewundae**	Kolon	Kolon	KOR	Municipal Waste, Additional Delivery	17 m³	2011
210.	**Colombes Ligne 2 & Ligne 3**	INTEGRAL	SIAAP	FRA	Sewage Sludge Incineration	10 m³	2011
211.	**MSWI Kyungju**	Tong Yang Magic Co., Ltd.	Tong Yang Magic Co., Ltd.	KOR	Municipal Waste	9 m³	2011
212.	**MSWI Torino**	BASF	LAB	ITA	Waste Incineration, Tail End, Low Temp.	181 m³	2011
213.	**RDF MSWI Busan**	KIC	KIC	KOR	Municipal Waste	29 m³	2011
214.	**MSWI Icheon**	Dongbu	Dongbu	KOR	Municipal Waste, Additional Delivery	16 m³	2012
215.	**RVA Castrop Rauxel**	BASF	Thermtec	DEU	Residue Incineration	3 m³	2012
216.	**KVA Zürich Hinwil**	BASF	Hitachi Zosen Inova	CHE	Municipal Waste, Low Temp.	111 m³	2012

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217.	**T.A. Lauta**	BASF	T.A.Lauta GmbH	DEU	Municipal Waste, Tail End, Low Temp.	15 m³	2012
218.	**JGC C&C China project**	JGC C&C	Tongfang	CHN	Municipal Waste	105 m³	2012
219.	**RSMVA Basel**	BASF	RSMVA Basel	CHE	Residue, Additional Delivery	12 m³	2012
220.	**BASF Bologna**	BASF	BASF	ITA	Residue Incineration	5 m³	2012
221.	**CVE d'Halluin Unit 1-3**	BASF	Elex	FRA	Municipal Waste, Tail End	26 m³	2012
222.	**Acerra**	A2A		ITA	Municipal Waste	26 m³	2012
223.	**Ivry Unit 1+2**	BASF	Novergie	FRA	Municipal Waste, Low Dust, Dioxin/Furan, Additional Delivery	156 m³	2012
224.	**MSWI Dadae**	Kolon	Busan City	KOR	Municipal Waste, Additional Delivery	8 m³	2012
225.	**MSWI Myungji**	Kolon	Busan City	KOR	Municipal Waste, Additional Delivery	25 m³	2012
226.	**H&H Bozen**	BASF	H&H Umwelttechnik GmbH	ITA	Municipal Waste	31 m³	2012
227.	**MVA Prag**	Zauner	Pražske služby	CZE	Municipal Waste, Low Dust, Additional Delivery	7 m³	2012
228.	**Rhodia**	BASF	Rhodia	DEU	Residue Waste, Additional Delivery	17 m³	2012
229.	**EEW Delfzijl**	E.ON Delfzijl NL	E.ON Delfzijl NL	NLD	Municipal Wast	20 m³	2012
230.	**Verbrennung DE #1**	CTP	Tridelta Thermprozess	DEU	Hazardous Waste	4 m³	2012
231.	**Giubiasco**	BASF	Hitachi Zosen Inova	ITA	Municipal Waste, Tail End, Additional Delivery	15 m³	2012/2013
232.	**AMSA**	A2A	AMSA	ITA	Waste Incineration, Low Temp., Additional Delivery	87 m³	2012/2013
233.	**Ivry Unit 3+4**	BASF	Novergie	FRA	Municipal Waste, Low Dust, Dioxin/Furan, Additional Delivery	156 m³	2013
234.	**MSW Lyon Nord**	BASF	Sita	FRA	Municipal Waste, Tail End	51 m³	2013
235.	**MVA Prag**	Zauner	Pražske služby	CZE	Municipal Waste, Low Dust, Additional Delivery	15 m³	2013
236.	**Anyang MSWI**	Coreco Co.	Anyang MSWI	KOR	Municipal Waste	10 m³	2013
237.	**MSW Ludres**	Hamon Environmental s.a.r.l.	Nancy Energie	FRA	Municipal Waste, Tail End, Low Temperature with Regeneration	20 m³	2013
238.	**Acerra 2013**	A2A	A2A	ITA	Municipal Waste Incineration with Dioxin	26 m³	2013
239.	**Lasse**	BASF	Veolia	FRA	Municipal Waste, Tail End	10 m³	2013
240.	**MVA Spittelau**	STRABAG AG	Wien Energie	AUT	Municipal Waste, Tail End, Low Temperature	81 m³	2013
241.	**Pluzunet**	BASF	CNIM/LAB	FRA	Municipal Waste Incineration, Additional Delivery	7 m³	2013
242.	**Sangju MSWI**	Sangju	Sangju	KOR	Waste Incineration, Additional Delivery	3 m³	2013
243.	**Orlen Unit K6**	Babcock Noell	PKN	POL	Residue Oil Boiler	61 m³	2013

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244.	**MSWI Colleferro**	Thermokimik		ITA	Municipal Waste Incineration	29 m³	2013
245.	**ACN Plant**	BASF		CHN	Residue Incineration	15 m³	2013
246.	**MSWI Bordeaux Spare Layer 2013**	BASF		FRA	Waste Incineration, dioxine, Tail End	14 m³	2013
247.	**MSWI Bordeaux Spare Layer 2014**	BASF		FRA	Waste Incineration, dioxine, Tail End	29 m³	2013
248.	**MSWI Yongin #2 + #3 Repl.**	Kolon Env.Co./Yongin City	Kolon Env.Co./Yongin City	KOR	Waste Incineration	13 m³	2013
249.	**Dioxin Kat Israel**	BASF		DEU	Residue Incineration plant	3 m³	2013
250.	**Acerra part 2 - 2013**	A2A	A2A	ITA	Municipal Waste Incineration with Dioxin	26 m³	2014
251.	**MVA Prag Spare Layer**	Zauner		CZE	Municipal Waste Incinerator, Low Dust	30 m³	2014
252.	**MSWI Mapo**	Kolon	MSWI Kolon	KOR	Municipal Waste Incinerator, Additional Delivery	27 m³	2014
253.	**Rhodia**	BASF	Rhodia	FRA	Residue Incinerator, Additional Delivery	17 m³	2014
254.	**HDO Incineration Freeport**	BASF	BASF	USA	Residue Incineration	36 m³	2014
255.	**West Palm Beach Unit 1, 2, 3**	Babcock & Wilcox	Solid Waste Authority of Palm Beach	USA	Municipal Waste, Tail End	95 m³	2014
256.	**Creteil**	BASF	CIE	FRA	Municipal Waste, Tail End, Additional Delivery	24 m³	2014
257.	**MSW Haidian**	BASF		CHN	Municipal Waste, Tail End	47 m³	2014
258.	**Schwarzheide**	BASF	BASF	DEU	Residue Incinerator, Additional Delivery	10 m³	2014
259.	**CVDU Nice**	BASF	LAB	FRA	Municipal Waste, Tail End, Dioxin Additional Delivery	24 m³	2014
260.	**Borsodchem**	BASF	Borsodchem ZRT	HUN	Municipal Waste, Tail End Additional Delivery	8 m³	2014
261.	**MSW Chotikov**	Zauner Anlagenbau GmbH	Skládka Chotíkov	CZE	Municipal Waste, Tail End, Dioxin	29 m³	2014
262.	**Mistral Spilimbergo**	Mistral FVG S.R.L.	Mistral FVG S.R.L.	ITA	Hospital Waste, Additional Delivery	3 m³	2014
263.	**MSWI Gyeongsan**	EG Corp.		KOR	Municipal Waste Incinerator	5 m³	2014
264.	**MSWI New Cheongju**	EG Corp.		KOR	Municipal Waste Incinerator	4 m³	2014
265.	**Saint Ouen**	BASF		FRA	Waste Incineratior, Tail End	25 m³	2014
266.	**KVA Hagenholz**	BASF	KVA Hagenholz	CH	Municipal waste incineration, Low Dust	50 m³	2014
267.	**Saint Ouen**	BASF		FRA	Waste Incineratior, Tail End	24 m³	2014
268.	**MSWI Modena**	ATS	MSWI Modena	ITA	Waste Incineration Tail End	17 m³	2014
269.	**BASF N800**	BASF	BASF	DEU	Residue Waste Incineration Low Dust; Additional Delivery	117 m³	2014
270.	**MSWI Eunpyung**	UET Engineering Co.	Eunpyung MSWI	KOR	Waste Incineration; Additional Delivery	5 m³	2014

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271.	**Sarpi Dorog**	BASF		HUN	Residue Incinerator	8 m³	2014
272.	**BASF C 19.8700**	BASF	BASF	CHN	Residue Waste Incineration	4 m³	2015
273.	**BASF C 19.8730**	BASF	BASF	CHN	Residue Waste Incineration	5 m³	2015
274.	**MSWI Icheon**	Dongbu Construction	Icheon City	KOR	Municipal Waste; Additional Delivery	16 m³	2015
275.	**JGC China / BN Project**	JGC Catalysts & Chemicals Ltd.	Tongfang	CHN	Waste Incineration Tail End	59 m³	2015
276.	**Orlen K4**	Babcock Noell GmbH	PKN	PL	Residue Oil Boiler	61 m³	2015
277.	**KVA Hagenholz Linie 2**	BASF	KVA Hagenholz	CH	Waste Incineration, Low Dust	51 m³	2015
278.	**Dijon**	BASF		FRA	Waste Incinerator; Tail End	26 m³	2015
279.	**Saint Ouen**	BASF		FRA	Waste Incineration Tail End; Additional Delivery	24 m³	2015
280.	**Colleferro**	Termokimik Corp.	C.T.E. Colleferro	ITA	Municipal Waste Incinerator; Additional Delivery	10 m³	2015
281.	**Schwarzheide**	BASF	BASF	DEU	Residue Incineration, Additional Delivery	10 m³	2015
282.	**Creteil**	BASF	CIE	FRA	Municipal Waste, Tail End, Additional Delivery	24 m³	2015
283.	**Nice Ligne 3-4**	BASF	LAB	FRA	Municipal waste incineration, Tail End	30 m³	2015
284.	**Sukmoon DHP**	KOLON Env. Service Co.		KOR	Waste Wood & RDF	21 m³	2015
285.	**Amsa 3rd Layer**	A2A	A2A	IT	Municipal waste incineration, low temp.	28 m³	2015
286.	**Beijing Chaoyang MSWI**	Beijing Golden State		CHN	Municipal waste incineration	66 m³	2015
287.	**MSWI Myungji**	Busan City		CHN	Municipal waste incineration, Additional Delivery	26 m³	2015
288.	**Filago**	Ecolombardia 4 / Boldrocchi Ecologia		IT	Municipal waste incinerator, low temperature	74 m³	2015
289.	**Daegu RDF**	Donglim Engineering		KOR	Waste incineration	17 m³	2015
290.	**Ulsan SRF**	Donglim Engineering		KOR	Waste Incineration	13 m³	2015
291.	**Mulhouse**	BASF		FRA	Waste Incineration Tail End; Additional Delivery	61 m³	2015
292.	**Rhodia Spare Layer**	BASF	Rhodia	FRA	Residue incineration; Additional Delivery	32 m³	2015
293.	**Taizhou Delixi Waste Incinerator**	Changzhou Elex Environmental		CHN	Hazardous Waste Incineration	11 m³	2015
294.	**Saint Ouen Repl.**	BASF		FRA	Waste Incineration Tail End; Additional Delivery	97 m³	2016
295.	**Benesse Maremne**	BASF		FRA	Municipal waste incineration	12 m³	2016
296.	**Chengdu Wanxing MSWI**	Shanghai ZOSUM Engineering Co., Ltd.		CHN	Municipal waste incineration	86 m³	2016
297.	**BASF Pasadena**	BASF		USA	Residue incineration plant	9 m³	2016

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298.	**Orlen K2**	Babcock Noell	PKN	PL	Residue Oil Boiler	49 m³	2016
299.	**BASF Pasadena 2nd + 3rd Layer**	BASF	BASF	USA	Residue incineration plant, Additional Delivery	18 m³	2016
300.	**Rhodia Spare Layer**	BASF		FRA	Residue incineration, Spare layer	21 m³	2016
301.	**Mucha RIP**	Yara Taiwan		TWN	Waste Incineration, Dioxin removal	29 m³	2016
302.	**MSWI Rouen Unit 1-3**	BASF		FRA	Waste incineration Tail end	38 m³	2016
303.	**San Vittore L1 Additional Layer**		Termomeccanica Ecologia	ITA	Waste Incineration Tail End; Additional D	4.86	2016
304.	**Jeonju Power SRF**	EG Corp.	Samchullyes Co.	KOR	Municipal waste incineration	26 m³	2016
305.	**MSWI Bordeaux**	BASF	Astria	FRA	Waste Incineration, Dioxine, Tail End, low temp.; Additional Delivery	43 m³	2016
306.	**MSWI Tornino Spare Layer**		IREN Energia	IT	Waste Incineration; Additional Delivery	89 m³	2016
307.	**Aplex Cremator**	Aplex Cremator	Aplex	KOR	Cremator	5 m³	2016
308.	**Nox Vent Treatment DOW**	DOW Olefinverbund GmbH	DOW Olefinverbund GmbH		Residue incineration plant; Additional Delivery	4 m³	2016
309.	**HDO Incineration Freeport**	BASF	BASF	USA	Residue incineration; Additional Delivery	36 m³	2016
310.	**Constanti**	Envirotherm GmbH	SARPI	DEU	Residue incineration; Additional Delivery	3 m³	2016
311.	**Colombes Ligne 2**	Le Gaz Integral	Le SIAAP	FRA	Waste Incineration; Additional Delivery	5 m³	2016
312.	**CTO Project**	Tialoc (Shanghai) Environmental, Ltd	-	CHN	Waste gas furnance	8 m³	2016
313.	**KVA Thurgau**	BASF	Elex	CH	Waste Incineration Tail End	42 m³	2016
314.	**Asuwei MSWI**	Shanghai Dingtu Env.		CHN	Waste Incineration	119 m³	2016
315.	**Wenzhou Yongqiang MSWI**	Shanghai Dingtu Env.	Weiming	CHN	Waste Incineration	74 m³	2016
316.	**Dabrowa Gornicza**	Envirotherm	SARPI	PL	Waste tail end	8 m³	2016
317.	**Lyon Süd**	BASF		FRA	Waste Incineration, Tail End, Low Temp.	10 m³	2016
318.	**MSW Le Mans**	BASF	Veolia	FRA	Waste incineration tail end low temp.; Additional Delivery	5 m³	2016
319.	**Saint Ouen Repl.**	BASF		FRA	Waste Incineration Tail End; Additional Delivery	49 m³	2017
320.	**Aplex Cremator (low dust)**	Aplex Cremator	Aplex	KOR	Crematory	5 m³	2017
321.	**BASF C520**	BASF		DEU	Residue waste incineration	3 m³	2017
322.	**Pohang RDF**	Aerix Co.	Pohang City	KOR	Municipal Solid Waste Incinerator	11 m³	2017
323.	**Soprano Ron**	Hamon Environmental s.a.r.l.	Sita Rekem	FRA	Municipal Waste; Additional Delivery	15 m³	2017
324.	**Kwangju SRF**	KC Cottrell	Korea District Heating Coorp.	KOR	Municipal Solid Waste Iincinerator, Additional Delivery	25 m³	2017

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325.	**MSWI Saint Thibault des Vignes Ligne 1+2**		Suez Environment	IT	Waste incineration	77 m³	2017
326.	**MSWI Shunyi**	Changzhou Elex Env.	Changzhou Elex Env.	CHN	Waste Incineration	25 m³	2017
327.	**AMSA 3rd Layer part 2&3**		A2A S.p.A.	IT	Muncipal waste incineration	56 m³	2017
328.	**Issy-les-Monlineaux**	BASF		FRA	Waste Incineration Tail End; Additional Delivery	20 m³	2017
329.	**MSWI Torino Spare Layer**		IREN S.p.A.	IT	Waste incineration	29 m³	2017
330.	**MSWI Prague**	Zauner	Prazske Sluzby	CZE	Waste incineration low dust; Additional Delivery	237 m³	2017
331.	**Constanti**	Envirotherm	SARPI	DEU	Residue Incineration; Additional Delivery	19 m³	2017
332.	**Beijing Huairou MSWI**	Shanghai ZOSUM Engineering Co., Ltd.	Shanghai ZOSUM Engineering Co.Ltd.	CHN	Waste Incineration	15 m³	2017
333.	**Dabrowa Gornicza**	Envirotherm		PL	Waste Incineration Tail End; Additional Delivery	8 m³	2017
334.	**Colombes Ligne**	Le Gaz Integral	SIAPP	FRA	Waste Incineration Tail End; Additional Delivery	5 m³	2017
335.	**Yantai Wanhua TDI Incinerator**	Shanghai Dingtu		CHN	Liquid hazardous waste incineration	27 m³	2017
336.	**Cixi Zhongmao MSWI**	Shanghai Dingtu		CHN	Municipal Solid Waste Incinerator	55 m³	2017
337.	**Aplex Cremator High Dust**	Aplex Cremator	Aplex	KOR	Crematory	10 m³	2017
338.	**Baoan 1st + 2nd Phase MSWI**	Shanghai Dingtu		CHN	Municipal Solid Waste Incinerator	130 m³	2017
339.	**Nanshan 1st Phase MSWI/**	Shanghai Dingtu		CHN	Municipal Solid Waste Incinerator	21 m³	2017
340.	**Aplex Cremator (Low dust)**	Aplex Cremator	Aplex	KOR	Crematory; Additional Delivery	10 m³	2017
341.	**Bordeaux**	BASF	Astria	FRA	Waste Incineration, Tail End, Additional Delivery	43 m³	2017
342.	**Oschatz Thermal Oxidizer**	Yara Environmental Protection (Qingdao) Co. Ltd	Oschatz	CHN	Waste liquids, Tail End	10 m³	2017
343.	**Currenta SCR-1**	Envirotherm	Currenta	DEU	Residue Waste Incineration, Tail End	22 m³	2017
344.	**KVA Zürich Hinwil**	BASF	KEZO Zweckverband Kehrichtverwertung Zürcher Oberland	CH	Waste, low temp. Additional Delivery	28 m³	2017
345.	**Haeraeus Bitterfeld**	BASF	Steuler	DEU	Silicone-Oil incineration	6 m³	2018
346.	**Cangnan MSWI**	Shanghai Dingtu Environmental		CHN	Municipal Solid Waste Incinerator	52 m³	2018
347.	**Qingzhou MSWI**	Shanghai Dingtu Environmental		CHN	Municipal Solid Waste Incinerator	36 m³	2018
348.	**Linyi MSWI**	Shanghai Dingtu Environmental		CHN	Municipal Solid Waste Incinerator	44 m³	2018
349.	**Taian MSWI**	Shanghai Dingtu Environmental		CHN	Municipal Solid Waste Incinerator	45 m³	2018
350.	**Rhodia**	BASF	Rhodia	FRA	Hazardous/Liquide Waste	13 m³	2018
351.	**Currenta SCR II Leverkusen**	Andritz	Currenta	DEU	Residue Waste Incineration, Tail End	39 m³	2018

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352.	**MSWI Lujiashan Repl.**	Shanghai Dingtu Environmental Engineering		CHN	Municipal Waste Incinerator	26 m³	2018
353.	**Orlen K4/K5/K6/K7**	PKN Orlen	PKN Orlen	POL	Residue Oil Boiler	61 m³	2018
354.	**NOx Vent Treatment DOW**	DOW Olefinverbund GmbH	DOW Olefinverbund GmbH	DEU	Residue incineration plant, Additional Delivery	4 m³	2018
355.	**Jiangbei MSWI**	Shanghai Dingtu		CHN	Waste Incineration Tail End, Additional Delivery	44 m³	2018
356.	**RuiAn MSWI**	Shanghai Dingtu	Weiming	CHN	Waste Incineration Tail End	57 m³	2018
357.	**Coueron-Nantes**	BASF	Veolia	FRA	Waste Incineration Tail End, Additional Delivery	6 m³	2018
358.	**Shougang Lujiashan MSWI (3 Lines)**	Shanghai Dingtu	Beijing Shougang	CHN	Waste Incineration Tail End	79 m³	2018
359.	**Rhodia - Spare Layer 2+3/2018**	BASF	Rhodia	FRA	Liquide Waste Incineration	34 m³	2018
360.	**Aplex Cremator (high dust)**	Aplex Cremator	Aplex	KOR	Crematory, Additional Delivery	10 m³	2018
361.	**Aplex Cremator (low dust)**	Aplex Cremator	Aplex	KOR	Crematory, Additional Delivery	10 m³	2018
362.	**Currenta SCR**	Currenta		DEU	Toxic Waste, Low Dust	22 m³	2018
363.	**MSWI Jeju**	S Tech Korea		KOR	Waste Incineration, Tail End	20 m³	2018
364.	**Qingdao MSWI**	Shanghai Dingtu Environmental	Kangheng	CHN	Municipal Solid Waste Incinerator	71 m³	2018
365.	**Cixi Zhongmao MSWI 2nd phase**	Shanghai Dingtu Environmental	Huaxing East	CHN	Municipal Solid Waste Incinerator	27 m³	2018
366.	**Colombes Ligne 2**	Le Gaz Integral		FRA	Waste Incineration Tail End; Additional Delivery	5 m³	2018
367.	**Wenling MSWI**	Shanghai Dingtu Environmental	Shanghai Zosum	CHN	Municipal Solid Waste Incinerator	56 m³	2018
368.	**Hongbaoli**	Shanghai Dingtu Environmental	Shanghai Hoto	CHN	Municipal Solid Waste Incinerator	8 m³	2019
369.	**Soprano PCX**	Hamon	Suez Environment	FRA	Chemical Waste Incinerator	23 m³	2019
370.	**MSWI San Sebastian Unit 1+2**			ESP	Waste Incineration Tail End	38 m³	2019
371.	**Puyang MSWI**	Shanghai Dingtu	Huaxing East	CHN	Waste Incineration, Tail End	32 m³	2019
372.	**Gaoantun Medical Waste**	Shanghai Dingtu	Huaxing East	CHN	Medical Waste Incineration	13 m³	2019
373.	**Zhuji Bafang MSWI**	Shanghai Dingtu Environmental	Zhejiang	CHN	Municipal Solid Waste Incinerator	16 m³	2019