# Municipal Waste Combustor Workgroup Report

Prepared by the Ozone Transport Commission Stationary and Area Sources Committee

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# Contents

## Acronyms

| | |
|---|---|
| ASNCR | Advanced selective non-catalytic reduction |
| BACT | Best available control technology |
| CEM | Continuous emission monitor |
| CFD | Computational fluid dynamics |
| CFR | Code of federal regulations |
| EGU | Electric generating units |
| EIA | Energy Information Administration |
| EPA | U.S. Environmental Protection Agency |
| FGR | Flue gas recirculation |
| LN$^{TM}$ | 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 |
| PTE | Potential to emit |
| 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$^{TM}$ | 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.

Waste incinerators are a common means of handling municipal trash and they provide a valuable solid waste disposal service to the communities they serve. However, their operation produces a variety of harmful pollutants, such as particles, nitrogen oxides, dioxin, lead, mercury, and greenhouse gases. The emissions released by the burning of trash contribute to ozone and adverse health impacts, especially for nearby communities that are often overburdened with environmental justice issues. Emissions from MWCs also affect the environment in areas downwind from the facilities. Many of these facilities operate with technology that is 30 to 40 years old. Urban areas are working to transition towards cleaner alternatives of waste management, such as anaerobic digestion or composting and recycling. In the interim, additional air pollution control technologies are available to bridge the gap and lessen the public health impacts from MWCs. Ensuring the use of modern pollution controls on MWCs will improve public health and assist states in achieving clean air goals.

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.

NOx reduction technologies applicable to MWCs have evolved over time, providing a greater selection of NOx reduction controls and strategies to cost effectively reduce NOx emission rates in retrofit situations. This SAS MWC workgroup effort included the evaluation of available information to help identify technically feasible and cost effective NOx controls for MWCs. This RACT type evaluation of available NOx controls is intended to identify numerical presumptive NOx RACT emission rate limits that could be widely met across the various sizes and configurations of the MWC category.

While it is believed that the proposed presumptive NOx RACT rate limits are generally attainable for many or most existing MWCs, it is understood that the proposed presumptive NOx RACT rate limits may not be attainable at every subject MWC. It is anticipated that the proposed presumptive NOx RACT rate limits will assist states in their conduct of case-by-case RACT determinations, considering the technological and economic circumstance for individual MWCs in their respective states.

Further, information developed in this work effort is intended to provide input to the OTC Modeling Committee. It is anticipated that the information will be used to help estimate the air quality impact of the existing OTR MWCs and any potential air quality benefit of adopting the presumptive NOx RACT 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 250 tons or less 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 also identified non-OTR MWC electric generating units (EGUs) in the 48 contiguous states. The Results section provides an overview of findings, and Appendix D lists the MWCs outside of the OTR.

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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.

## 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 an estimate of the potential tons of NOx that could be reduced with the application of additional emissions controls.

## Conducting a Literature Review to Identify Additional NOx Control Technologies

The MWC workgroup identified and reviewed a number of guidance documents and engineering analyses that evaluated the technical potential to reduce NOx emission from MWCs. Of particular interest to the workgroup were 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

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[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.

[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.

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, which 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™) developed by Covanta for certain MWC configurations owned by Covanta; 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]; and
- 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 regarding the retrofit of NOx controls to 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.

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[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] HDR, "Montgomery County Resource Recovery Facility NOx Optimization," May 18, 2016.

[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.

## 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 existing 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 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. Note that a 110 ppmvd @ 7% $O_2$, 24-hr standard, if achieved by subject large OTR MWCs, would result in NOx reductions during ozone season days that may have a positive impact on air quality during ozone events. It is estimated that, relative to existing permit limits, compliance with a 110 ppmvd @ 7% $O_2$ 24-hr standard, and assuming a daily 90% capacity factor, at subject large OTR MWCs could result in an approximate 19 ton/day reduction in NOx emissions.

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 existing large MWCs in the region that were also equipped with SNCR but were excluded from the estimation of further NOx reductions. The excluded units 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. The installation of DeNOx filter bags may be a technically feasible NOx reduction strategy for retrofit of small MWCs. But because the available information appears to indicate the use of the DeNOx filter bags may not be cost effective for larger installations, it was assumed that the economics would be no better for small capacity installations. 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. However, the workgroup recommends that this category of sources not be forgotten as it is possible that additional reductions from this category may be found to be technically and economically feasible in the future as control options are introduced and improved.

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.

## 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 certain MWC configurations utilized in 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, associated costs and emissions reduction capability 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 | 2,169 | 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** | **21,221** | **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. The Covanta LN™ is not applicable to all MWC configurations, including some that are owned or operated by Covanta, and its overall NOx reduction effectiveness may vary from unit to unit depending upon individual MWC characteristics.

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. (Note also that while the Covanta LN™ technology is highly effective on some MWC configurations, including the facility discussed in the Trinity report, it is not applicable to all MWC configurations operated by Covanta.)

### *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, including the reduction in magnitude of NOx spikes associated with the combustion of a heterogeneous fuel. 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$^{TM}$ 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$^{TM}$ 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.

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

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[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.

[15] See footnotes 16 and 17 for sources.

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-hour

*** 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 significant NOx reductions. However, the workgroup understands that the Covanta LN™ technology is not applicable to all MWC configurations operated by Covanta and that not all of the MWCs converted to the Covanta LN™ technology may be able to achieve NOx reduction results similar to the table values. That a number of these units have been retrofitted with the LN™ technology and have been permitted

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[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.

at 110 ppmvd @7% $O_2$ 24-hr average supports a proposed 110 ppmvd 24-hr average presumptive 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$^{TM}$ 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$^{TM}$ 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 6,700 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 3,300 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 | 6,742 | 29% |
| Small MWC | 1,006 | Not estimated | Not estimated |
| Total | 23,998 | 6,742 | 28% |

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[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. Note that the cost estimate values included in the report, and copied below in Table 4, were based on year 2017 dollars. 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)”

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

shows NOx emissions before and after installation of Covanta's Low NOx technology. The NOx emission 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. Note that the cost estimate values included in the report, and copied below in Table 5, were based on year 2017 dollars. 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 and annual operating costs shown in Table 8 were taken from the Babcock study for the Wheelabrator Baltimore facility. Note that the cost estimate values included in the report, and copied below in Table 8, were based on year 2019 dollars. "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

Costs 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. To date, the workgroup has not quantified the emission reduction potential associated with the non-OTR MWCs, but may do so in the future as time and resources allow, as indicated in the section on Additional Research. However, 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. OTC estimates the 2018 potential to emit from non-OTR MWCs was 20,506 tons of NOx per year, indicating that non-OTR MWC and OTR MWC NOx emissions each comprise approximately half of total U.S. MWC NOx emissions. See Appendix D for additional detail.

## 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. The estimated range of cost-effective NOx controls associated with these presumptive limits are in line with a range of values some states have already considered RACT. 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.
- Research the potential for additional NOx reductions 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, or combinations of technologies, as described in this report. The MWC workgroup concludes that a NOx 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 and could be viewed as presumptive NOx RACT limits to assist states in the conduct of case-by-case RACT evaluations. This conclusion is based on a review of publicly available information and 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 6,700 tons annually with additional controls achieving a 105 ppmvd level on a 30-day average. Approximately 3,000 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 approximately $2,900 per ton reduced to approximately $6,200 per ton of NOx reduced. (Note that this range of values is roughly equivalent to a range of $3,350 per ton of NOx reduced to $6,870 per ton of NOx reduced, in 2022 dollars.)

## 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% | -11 | -25% | -37 | 137 | 110 |
| Montgomery County Resource Recovery | MD | 147 | 140 | -7% | -11 | -25% | -37 | 137 | 110 |
| Montgomery County Resource Recovery | MD | 147 | 140 | -7% | -11 | -25% | -37 | 137 | 110 |
| Wheelabrator Baltimore Refuse | MD | 367 | 150 | -13% | -49 | -30% | -110 | 318 | 257 |
| Wheelabrator Baltimore Refuse | MD | 367 | 150 | -13% | -49 | -30% | -110 | 318 | 257 |
| Wheelabrator Baltimore Refuse | MD | 367 | 150 | -13% | -49 | -30% | -110 | 318 | 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 | 150 | -13.3% | -48 | 30% | -107 | 310 | 250 |
| Covanta Hempstead | NY | 380.28 | 150 | 13.3% | -51 | 30% | -114 | 330 | 266 |
| Covanta Hempstead | NY | 465.8 | 150 | 13.3% | -62 | 30% | -140 | 404 | 326 |
| Covanta Niagara I, LLC | NY | 341.73 | 150 | -13% | -46 | -30% | -103 | 296 | 239 |
| Covanta Niagara I, LLC | NY | 378.41 | 150 | -13% | -50 | -30% | -114 | 328 | 265 |
| Huntington Resource Recovery | NY | 443 for all 3 units | 150 | -13% | -16 | -30% | -35 | 101 | 82 |
| Huntington Resource Recovery | NY | 443 for all 3 units | 150 | -13% | -15 | -30% | -35 | 101 | 81 |
| Huntington Resource Recovery | NY | 443 for all 3 units | 150 | -13% | -15 | -30% | -34 | 98 | 79 |
| Onondaga County Resource Recovery | NY | 684.18 | 150 | -13% | -91 | -30% | -205 | 593 | 479 |

| 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 |
|---|---|---|---|---|---|---|---|---|---|
| Onondaga County Resource Recovery | NY |  | 150 | -13% | 0 | -30% | 0 |  | 0 |
| Onondaga County Resource Recovery | NY |  | 150 | -13% | 0 | -30% | 0 |  | 0 |
| Wheelabrator Hudson Falls | NY | 145.81 | 150 | -13% | -19 | -30% | -44 | 126 | 102 |
| Wheelabrator Hudson Falls | NY | 153 | 150 | -13% | -20 | -30% | -46 | 133 | 107 |
| Wheelabrator Westchester | NY | 411.93 | 150 | -13% | -55 | -30% | -124 | 357 | 288 |
| Wheelabrator Westchester | NY | 417.23 | 150 | -13% | -56 | -30% | -125 | 362 | 292 |
| Wheelabrator Westchester | NY | 459.57 | 150 | -13% | -61 | -30% | -138 | 398 | 322 |
| 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 |
| 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 |

| 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 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 |
| Covanta Alexandria/Arlington Energy | VA | 75 | 110 | 130 ppmvd is higher |  | -5% | -3 | 75 | 72 |

| 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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | than permit | | | | | |
| 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 |
| Covanta Fairfax Energy | VA | 250 | 110 | 130 ppmvd is higher | | -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** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | than permit | | | | | |
| Covanta Fairfax Energy | VA | 250 | 110 | 130 ppmvd is higher than permit | | -5% | -11 | 250 | 239 |
| **Total** | | **22,992** | | | **(3,293)** | | **(6,742)** | **19,699** | **16,250** |

* 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 |
| MIRA | CT | Hartford | CE | 0.981 | Refuse-derived fuel combustor | 675.6 RDF; 236.4 coal | SNCR |
| MIRA | CT | Hartford | CE | 0.981 | Refuse-derived fuel combustor | 675.6 RDF; 236.4 coal | SNCR |
| MIRA | 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 | Westinghouse O-Connor | 0.665 | Mass burn rotary waterwall | 449 | |
| Covanta Delaware Valley | PA | Delaware | Westinghouse O-Connor | 0.665 | Mass burn rotary waterwall | 449 | |
| Covanta Delaware Valley | PA | Delaware | Westinghouse O-Connor | 0.665 | Mass burn rotary waterwall | 449 | |
| Covanta Delaware Valley | PA | Delaware | Westinghouse O-Connor | 0.665 | Mass burn rotary waterwall | 449 | |
| Covanta Delaware Valley | PA | Delaware | Westinghouse O-Connor | 0.665 | Mass burn rotary waterwall | 449 | |
| Covanta Delaware Valley | PA | Delaware | Westinghouse O-Connor | 0.665 | Mass burn rotary waterwall | 449 | |
| Covanta Plymouth Renewable Energy | PA | Montgomery | | 0.965 | Mass burn waterwall | 608 | 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 Plymouth Renewable Energy | PA | Montgomery |  | 0.965 | Mass burn waterwall | 608 | SNCR |
| 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 | SNCR |
| Lancaster County Resource Recovery | PA | Lancaster |  | 0.619 | Mass burn waterwall | 400 | SNCR |
| Lancaster County Resource Recovery | PA | Lancaster |  | 0.619 | Mass burn waterwall | 400 | SNCR |
| 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) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| CA | Mass burn waterwall | 400 | Ammonia Injection | 165 | 0.2835 | 438.0 |
| CA | Mass burn waterwall | 400 | Ammonia Injection | 165 | 0.2835 | 438.0 |
| CA | Mass burn waterwall w/reciprocating grate | | SNCR | 205 | 0.3522 | 148.9 |
| CA | Mass burn waterwall w/reciprocating grate | | SNCR | 205 | 0.3522 | 148.9 |
| CA | Mass burn waterwall w/reciprocating grate | | SNCR | 205 | 0.3522 | 148.9 |
| FL | Mass burn rotary waterwall | 255 | | 170 | 0.2921 | 122.3 |
| FL | Mass burn rotary waterwall | 255 | | 170 | 0.2921 | 122.3 |
| FL | Mass burn waterwall | 250 | SNCR | 205 | 0.3522 | 160.4 |

| State | Configuration | Rating (tons/day) | NOx Control | Permit NOx Limit 1* | Est NOx Rate*** (lb/MMBTU) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| FL | Mass burn waterwall | 250 | SNCR | 205 | 0.3522 | 160.4 |
| FL | Mass burn waterwall | 460 | SNCR | 205 | 0.3522 | 266.1 |
| FL | Mass burn waterwall | 460 | SNCR | 205 | 0.3522 | 266.1 |
| FL | Mass burn waterwall | 460 | SNCR | 205 | 0.3522 | 266.1 |
| FL | Mass burn waterwall | 690 | Covanta LN™, SNCR, FGR | 110 | 0.1890 | 238.0 |
| FL | Mass burn waterwall | 660 | SNCR | 180 | 0.3093 | 372.5 |
| FL | Mass burn waterwall | 660 | SNCR | 180 | 0.3093 | 372.5 |
| FL | Mass burn waterwall | 660 | SNCR & FGR | 150 | 0.2577 | 310.4 |
| FL | Mass burn waterwall | 288 | SNCR | 205 | 0.3522 | 185.1 |
| FL | Mass burn waterwall | 288 | SNCR | 205 | 0.3522 | 185.1 |
| FL | Mass burn waterwall | 288 | SNCR | 205 | 0.3522 | 185.1 |

| State | Configuration | Rating (tons/day) | NOx Control | Permit NOx Limit 1* | Est NOx Rate*** (lb/MMBTU) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| FL | Mass burn waterwall | 288 | SNCR | 205 | 0.3522 | 185.1 |
| FL | RDF Spreader Stoker | 648 | SNCR | 250 | 0.4295 | 568.9 |
| FL | RDF Spreader Stoker | 648 | SNCR | 250 | 0.4295 | 568.9 |
| FL | RDF Spreader Stoker | 648 | SNCR | 250 | 0.4295 | 568.9 |
| FL | RDF Spreader Stoker | 648 | SNCR | 250 | 0.4295 | 568.9 |
| FL | RDF | 900 | SNCR | 250 | 0.4295 | 804.3 |
| FL | RDF | 900 | SNCR | 250 | 0.4295 | 804.3 |
| FL | Stoker Mass Burn waterwall | 1000 | SCR | 50 | 0.0859 | 172.3 |
| FL | Stoker Mass Burn waterwall | 1000 | SCR | 50 | 0.0859 | 172.3 |
| FL | Stoker Mass Burn waterwall | 1000 | SCR | 50 | 0.0859 | 172.3 |
| FL | Mass burn waterwall | 350 | SNCR | 205 | 0.3522 | 216.0 |

| State | Configuration | Rating (tons/day) | NOx Control | Permit NOx Limit 1* | Est NOx Rate*** (lb/MMBTU) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| FL | Mass burn waterwall | 350 | SNCR | 205 | 0.3522 | 216.0 |
| FL | Mass burn waterwall | 350 | SNCR | 205 | 0.3522 | 216.0 |
| FL | Mass burn waterwall | 1050 | SNCR | 205 | 0.3522 | 675.7 |
| FL | Mass burn waterwall | 1050 | SNCR | 205 | 0.3522 | 675.7 |
| FL | Mass burn waterwall | 1050 | SNCR | 205 | 0.3522 | 675.7 |
| FL | Mass burn waterwall | 836 | SNCR | 205 | 0.3522 | 499.2 |
| FL | Mass burn waterwall | 836 | SNCR | 205 | 0.3522 | 499.2 |
| FL | Mass burn waterwall | 836 | SNCR | 205 | 0.3522 | 499.2 |
| IN | Mass burn waterwall | 726 | SNCR | 205 | 0.3522 | 513.4 |
| IN | Mass burn waterwall | 726 | SNCR | 205 | 0.3522 | 513.4 |
| IN | Mass burn waterwall | 726 | SNCR | 205 | 0.3522 | 513.4 |

| State | Configuration | Rating (tons/day) | NOx Control | Permit NOx Limit 1* | Est NOx Rate*** (lb/MMBTU) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| MI | Mass burn waterwall | 312.5 | SNCR | 205 | 0.3522 | 192.8 |
| MI | Mass burn waterwall | 312.5 | SNCR | 205 | 0.3522 | 192.8 |
| MN | Mass burn waterwall | 606 | Ammonia Injection | 205 | 0.3522 | 405.0 |
| MN | Mass burn waterwall | 606 | Ammonia Injection | 205 | 0.3522 | 405.0 |
| MN | Stoker mass burn waterwall | 100 |  | 500 | 0.8590 | 175.0 |
| MN | Stoker mass burn waterwall | 200 | SNCR | 150 | 0.2577 | 101.4 |
| MN | Stoker mass burn waterwall | 100 |  | 500 | 0.8590 | 175.0 |
| MN | Starved air modular | 48 |  | 500 | 0.8590 | 67.7 |
| MN | Starved air modular | 48 |  | 500 | 0.8590 | 67.7 |
| MN | RDF air swept, traveling grate | 393.6 |  | 250 | 0.4295 | 338.6 |
| MN | RDF air swept, traveling grate | 393.6 |  | 250 | 0.4295 | 338.6 |

| State | Configuration | Rating (tons/day) | NOx Control | Permit NOx Limit 1* | Est NOx Rate*** (lb/MMBTU) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| OK | Mass burn waterwall | 375 | SNCR | 205 | 0.3522 | 216.9 |
| OK | Mass burn waterwall | 375 | SNCR | 205 | 0.3522 | 216.9 |
| OK | Mass burn waterwall | 375 | SNCR & Tertiary Air | 205 | 0.3522 | 216.9 |
| OR | Mass burn waterwall | 275 | SNCR | 200 | 0.3436 | 161.0 |
| OR | Mass burn waterwall | 275 | SNCR | 200 | 0.3436 | 161.0 |
| VA | RDF Spreader Stoker | 593 |  | 250 | 0.4295 | 445.9 |
| VA | RDF Spreader Stoker | 593 |  | 250 | 0.4295 | 445.9 |
| VA | RDF Spreader Stoker | 593 |  | 250 | 0.4295 | 445.9 |
| VA | RDF Spreader Stoker | 593 |  | 250 | 0.4295 | 445.9 |
| WA** | Mass burn waterwall | 475 |  | 165 | 0.2835 | 227.6 |
| WA** | Mass burn waterwall | 475 |  | 165 | 0.2835 | 227.6 |

| State | Configuration | Rating (tons/day) | NOx Control | Permit NOx Limit 1* | Est NOx Rate*** (lb/MMBTU) | Estimated Annual PTE (tons NOx/year) |
|---|---|---|---|---|---|---|
| total | | | | | | 20,506 |

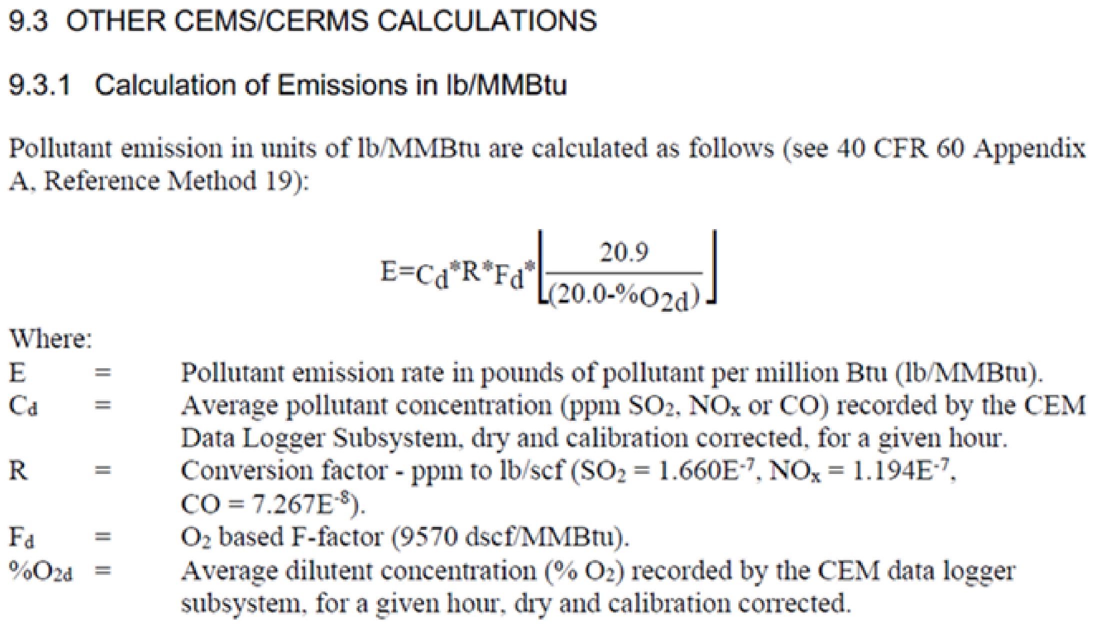
* ppmvd @12% $CO_2$.

** 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, which 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. Because the waterwall tubes form the floor of the combustion zone and effectively remove heat from that surface, peak combustion temperatures may tend to be lower than experienced with other MWC designs, helping reduce the NOx emissions relative to those other MWC designs. Also, as the watercooled surfaces require lower amounts of initial combustion zone excess air for cooling of combustor components, lower amounts of total excess air may be required for many rotary burner MWCs compared to some other MWC designs. The reduced excess air requirements may also help to reduce base NOx emissions relative to other MWC designs.

**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. However, modifications to existing plant components or system upgrades may be necessary at some facilities to optimize combustion air control for NOx reduction. 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. But it should not be overlooked that combustion air control or staging modifications may have potential NOx reduction capabilities at some facilities and may prove to be an important component in a NOx reduction strategy incorporating multiple control components.

## 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.

Existing MWC SNCR installations include both urea and ammonia-based systems. Information provided by EPA indicates that for those facilities, the group of MWCs utilizing ammonia for the reagent had a higher average NOx reduction effectiveness than the group of MWCs utilizing urea as the reagent, but that the top of the range of NOx reduction effectiveness was higher for the MWCs utilizing urea as reagent than for the MWCs using ammonia for the reagent. Many factors other than reagent type can influence the NOx reduction effectiveness of any particular SNCR installation, so these values may not be conclusive. There is also some consideration that the use of urea reagents may produce higher levels of nitrous oxide ($N_20$), a greenhouse gas, than the use of ammonia reagents. Nitrous oxide emissions will depend on the reagent feed rate and the flue gas temperature where the reduction is taking place, with higher levels on nitrous oxide emissions correlating to increased NOx reductions. The EPA indicated that there are commercially available, proprietary additives that can reduce nitrous oxide formation. The impact of the choice which reagent is most appropriate for any given MWC retrofit would be highly unit specific and it is assumed would be part of any state's case by case RACT determination.

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. Further, the ASNCR system utilizing near real time control would tend to reduce the magnitude of emission spikes associated with the combustion of a heterogeneous fuel, helping achieve a lower average emission rate over any particular averaging period.

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 for retrofit of ASNCR control 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 for the combined ASNCR and FGR technologies 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 that is more of a system of related control techniques rather than a single component control 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]

In addition to the modification of the combustion air systems and potential modification of an existing SNCR system (or installation of a new SNCR system if none existing) as part of an MWC Covanta LN™ retrofit, the Covanta LN™ may require additional modifications to other areas of the combustion zone and related components.  Not all existing MWC designs or configurations may be able to incorporate all or any of the components related to the Covanta LN™, and the NOx reduction results may also tend to vary somewhat between units that can accept all of the Covanta LN™ components.

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 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

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[19] See footnote 3 for reference.

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 facilitate 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 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, and more so in retrofit application, which may render it economically infeasible for retrofit for many existing MWCs. However, the control capability and adaptability of the SCR technology may make it desirable in certain applications.

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.

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[20] See footnote 4.

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 Fairfax 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.

### DeNOx Catalytic Filter Bags

DeNOx catalytic filter bags are a product of Gore and are designed to provide both particulate filtration and NOx reduction.  The DeNOx filter bags are similar in appearance to the bags utilized for flue gas particulate removal in baghouses, except each bag consists of both a membrane for particulate removal and a PTFE based catalytic felt for NOx and NH3 reduction.  In some instances, DeNOx bags can be made to be direct installation replacements for conventional bags in existing particular baghouses.

For retrofit installations where the combustion units already utilize SNCR for NOx control, the existing SNCR system can be operated at higher NSR levels to provide ammonia slip in the combustion flue gasses in order to provide the necessary reagent for catalytic reduction in the filter bags.

No publicly available information was found that discussed an existing installation in the US utilizing the DeNOx catalytic filter bags.  However, information was found regarding the retrofit installation of these catalytic filter bags at MWC units located in European countries.  That information indicated that addition NOx reductions of up to 60% were achieved on MWCs that were already reasonably well controlled with combustion air controls and SNCR.  It should be noted that these subject European MWCs were all small units (less than 250 ton/day rating).  No cost information was found for these European installations to enable any assessment of the cost effectiveness for the DeNOx catalytic filter bags.

Some cost information was available regarding DeNOx catalytic filter bag installation through a cost effectiveness evaluation performed by San Joaquin Valley Unified Air Pollution Control District. The cost evaluation was for two mass burn waterwall MWCs at a single facility using a 4% rate of return, 10-year equipment life, and a projected 60 ppmvd @ 12% CO2 NOx emission rate limit (roughly equivalent to 63 ppmvd @ 7% O2). The projected NOx emission rate limit was compared to the then-existing limit of 165 ppmvd @ 12% O2. The cost evaluation presented an estimated annualized capital cost of only about one sixth of the cost for full SCR, but presented an annualized O&M cost that was more than 3 times the annualized O&M cost of full SCR. The evaluation noted that much of the high annualized O&M cost was due to the need to remove high sulfur content components (such as drywall) from the waste fuel stream, as the DeNOx filter bags are susceptible to fouling at high levels of SOx. The San Joaquin evaluation estimated a cost effectiveness in excess of $88,000/ton (2020 $) of NOx removed. This estimated cost value may be lower in retrofit to a facility that has waste fuel quality restrictions or already includes sulfur emission controls.

The above-mentioned NOx control technologies are commercially available and represent a number of choices available to MWC owner/operators and state agencies in the consideration of RACT controls for NOx emissions from MWCs. From a technology standpoint, some technologies may not be technically feasible or provide significant reductions in retrofit due to the design or specific conditions of some individual MWCs. Similarly, individual unit design or operating conditions may cause a technically feasible NOx control to be economically infeasible for any specific MWC. The RACT analysis protocol of specific states would dictate whether any technically feasible NOx control technology, or group of NOx control technologies, could be considered RACT from a cost effectiveness standpoint for and specific MWC unit. For most retrofit considerations, the cost effectiveness estimates for the SCR and DENOx filter bag technology options appear to identify them as not cost-effective from a RACT standpoint. However, the workgroup felt it would be helpful to provide states with some general guidance concerning the relative cost effectiveness of all of the available NOx control technologies.

Additionally, the workgroup recognizes that MWC capacity ratings may have a significant impact on the estimated cost effectiveness of any given MWC retrofit NOx control technology. Some of the issues contributing to this are that design/engineering/modeling costs do not decrease substantially with smaller size, installation may be more difficult with smaller footprint facility and more compact combustors, and less room/time for reagent residence in the proper temperature zone for reaction. Information from EPA shows that generally the estimated magnitude of the cost effectiveness for a given retrofit NOx control technology increases (becomes less cost-effective) from higher rating units to lower rating units. Based on the EPA information, the relative cost effectiveness of several specific MWC retrofit NOx control technologies between several MWC capacity ratings are shown in the following table. For the data in the table, the estimated retrofit cost effectiveness for a 750 ton/day capacity MWC is assumed as the base with the cost effectiveness increases for the small sizes shown as percentage increases above the base.

| MWC Combustor Rating (tons/day) | SCR Control Relative Cost Effectiveness | ASNCR Control Relative Cost Effectiveness | SNCR Control Relative Cost Effectiveness |
|---|---|---|---|
| 750 | 100 | 100 | 100 |
| 400 | 123 | 149 | 131 |
| 100 | 245 | 463 | 328 |

The only cost effectiveness information associated with potential NOx reduction technologies that provides the consistency of same design and same operating characteristics for direct comparison 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 table were estimated from the data provided in the Babcock Power document, by assuming a 20-year control life with 6% interest rate, and the cost effectiveness estimates were performed using the 2019 values identified in the Babcock Power report. 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

| Control Technology | Estimated Achievable 24-hr Avg NOx Rate (ppmvd @7%O2) | Estimated Cost Effectiveness ($/ton) |
|---|---|---|
| Estimate Base | 150 | NA |
| Optimize Existing SNCR | 135 | 6941 |
| FGR & Existing SNCR | 120 | 3470 |
| ASNCR | 110 | 3883 |
| FGR & ASNCR | 105 | 4695 |
| SCR | 50 | 12779 |

The above information suggests that for this facility with these NOx control technologies, the most cost effective options are FGR&SNCR, FGR&ASNCR, and ASNCR. The associated controlled NOx emission rates are between 105 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 $4,695/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 105 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 $5,000/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.

# 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% $NO_2$

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

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

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

Est 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 )

Est 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

Est 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