GEORGETOWN UNIVERSITY

March 1, 2022

Stephen Ours
Chief, Permitting Branch
Department of Energy & Environment
Air Quality Division
1200 First Street, NE, 5th floor
Washington DC 20002

Re: Alternative NOx RACT Analysis - Georgetown University

Mr. Ours:

Enclosed is an Alternative NOx RACT Analysis for Boiler 1 at Georgetown University (GU) pursuant to 20 DCMR 805.2.

GU respectfully requests a meeting with DOEE to discuss the resulting RACT determination and the respective source-specific considerations.

Please contact Kevin Turner, Director of Engineering and Utilities, (ktt32@georgetown.edu, 202.251.9683) if you have any questions.

Sincerely,

DocuSigned by:
Lori Melendez Baldwin
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Lori Baldwin
Vice President Planning & Facilities Management and Corporate Partnerships
Georgetown University

Enclosure: Alternative NOx RACT Analysis

Alternative NOx RACT Analysis: Georgetown University

Submitted to:
District of Columbia
Department of Energy & Environment
Air Quality Permits Program

Prepared for:
Georgetown University
Planning and Facilities Management
37th and O Street, NW
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February 25, 2022

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LIST OF TABLES AND FIGURES

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

%	Percent
°F	Degrees Fahrenheit
$	U.S. Dollars (2022 value)
BTU	British Thermal Units
CEMS	Continuous Emissions Monitoring System
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPI	Consumer Price Index
CUP	Central Utility Plant
DCMR	District Code of Muncipal Regulations
DOEE	Department of Energy & Environment
EPA	Environmental Protection Agency
ERG	Eastern Research Group
FGR	Flue Gas Recirculation
GCP	Good Combustion Practices
GU	Georgetown University
H_2O	Water
HHV	Higher Heating Value
Hr	Hour
IKE	Indeck Keystone Energy
K_2CO_3	Potassium Carbonate
Kgal	Kilogallons
KNO_2	Potassium Nitrite
KNO_3	Potassium Nitrite
lb	Pounds (Mass)
LEB	Low Emission Burners
LNB	Low NOx Burners
MMBtu	Million Btu
MMscf	Million Standard Cubic Feet
MW	Megawatt (electrical)
NAAQS	National Ambient Air Quality Standards
NG	Natural Gas
NH_3	Ammonia
N_2	Nitrogen
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
O_2	Oxygen
OTR	Ozone Transport Region
$PM_{2.5}$	Particular Matter (2.5 micrometers and smaller)
PM_{10}	Particular Matter (10 micrometers to 2.5 micrometers)
ppm	Parts Per Million
RACT	Reasonably Available Control Technology

SCR	Selective Catalytic Reduction
SIP	State Implementation Plan
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulfur Dioxide
ton/yr	Tons Per year
ULSD	Ultra-Low Sulfur Diesel
VOC	Volatile Organic Compounds
yr	Year

1. INTRODUCTION

In May 2019, Georgetown University (GU) was issued construction air permits 7214 through 7217 for the construction of new Boiler 4, the retrofit of existing Boilers 1, 2 and 3 with low emission burners (LEB) and the construction of four new stacks. GU elected to undertake this voluntary project – i.e., not required by applicable federal or local regulations – as part of its ongoing commitment to reduce air emissions.

GU scheduled sequential implementation of the LEB retrofits beginning with Boiler 2. Despite repeated and ongoing efforts by GU and its contractors, retrofitting Boiler 2 with LEB has resulted in unexpectedly high emissions of carbon monoxide (CO). Cost overruns attributed to troubleshooting the issue to date are approximately $630,000.[1] GU has exhausted troubleshooting options to identify the cause of the problem and resolve it. Completion of the entire LEB project was scheduled for June 2020 and is now "to be determined" pending discussions with D.C. Department of Energy and Environment (DOEE).

With the promulgation of changes to 20 DCMR 805 in November 2021 and the unexpected Boiler 2 retrofit challenges, GU has re-evaluated the scope of the LEB project permitted in 2019. As a result, this document:

1. Provides a nitrogen oxides (NOx) "alternative Reasonably Available Control Technology (RACT)" analysis for Boiler 1[2,3].

2. Notifies the D.C. Department of Energy and Environment (DOEE) of GU's intent to request revised CO emission limits for Boiler 2.

3. Provides the following status update of the project authorized by permits 7214 through 7217:
   - Boiler 2 has been retrofitted with LEB, but commissioning is not complete.
   - Boiler 4 has been constructed.
   - Boiler 1 and Boiler 3 are currently operational and not equipped with LEB.
   - The new stacks for Boiler 2 and Boiler 4 have been constructed. (GU intends to construct the new stacks for Boiler 1 and Boiler 3.)

4. Reminds DOEE of GU's efforts to explore lower-emitting alternatives to producing thermal energy at its Central Utility Plant (CUP).[4]

Approval of revised CO emission limits will enable the use of LEB on Boiler 2 to comply with the requirements of 20 DCMR 805. Following forthcoming discussions with and direction from DOEE, GU intends submit a permit application for a revision to permits 7214 through 7217.

[1] This cost figure is in addition to nearly $2.5 million spent on the Boiler 2 LEB retrofit.

[2] Pursuant to 20 DCMR 805.2, any source subject to the requirements of 20 DCMR 805 may apply for an alternative emission limitation for a source-specific alternative RACT.

[3] The RACT analysis addresses only Boiler 1. See Section 2 for an explanation.

[4] GU submitted a NOx RACT Alternative Compliance Plan to DOEE on December 27, 2021, pursuant to 20 DCMR 805.5(g).

2. DESCRIPTION OF EMISSIONS UNITS

The following table identifies the emissions units located at GU subject to 20 DCMR 805:

Table 1 – Emissions Units Subject to 20 DCMR 805

Emission Unit	Fuel Type	NOx Emissions Control	Heat Input Capacity (MMBtu/hr $_{HHV}$)	Installation Date
Boiler 1	Natural Gas (primary) and Fuel Oil (backup)	GCP, FGR	127.0	1969
Boiler 2		GCP, FGR and LEB	127.0	1969
Boiler 3		GCP and FGR (with LEB planned)	120.6	1998
Boiler 4		GCP, FGR and LEB	119.8	2021

Note that:

1. Each boiler currently utilizes Good Combustion Practices (GCP) and Flue Gas Recirculation (FGR) to reduce NOx emissions.

2. NOx emissions from each boiler are currently monitored using a continuous emissions monitoring system (CEMS).

3. Boiler 4 was initially designed and constructed with LEB. Boiler 2 has been retrofitted with LEB. GU plans to retrofit Boiler 3 with LEB. The allowable NOx emission rate of each boiler with LEB is less than the applicable NOx RACT limits of 20 DCMR 805.5(e)(2).[5] <u>As a result, an alternative RACT is not necessary for Boilers 2, 3 and 4.</u>

4. NOx emissions from Boiler 1 typically vary from 0.06 to 0.09 lb/MMBtu (daily average).[6] <u>Therefore, it is anticipated that Boiler 1 cannot routinely and reliably comply with the new 0.05 lb/MMBtu limit (when firing natural gas) from 20 DCMR 805.5(e)(2) and must be evaluated for an alternative RACT</u>.

[5] Pursuant to Conditions II.a. through II.c. of permits 7214 through 7217, allowable NOx emissions from a boiler retrofitted with LEB is 1.7 or 1.8 pounds per hour (lb/hr) when operating at full load. These limits are based on a manufacturer emission rate of 0.0145 pounds of NOx per million British Thermal Units (lb/MMBtu).

[6] Based on CEMS data provided in requisite quarterly reports to DOEE.

3. REGULATORY BACKGROUND

On November 26, 2021, the District of Columbia Department of Energy & Environment (DOEE) issued a notice of final rulemaking regarding revisions to 20 DCMR 805, Reasonably Available Control Technology (RACT) for Major Stationary Sources of the Oxides of Nitrogen Regulations. This is the latest action stemming from a regulatory process begun by the U.S. Environmental Protection Agency (EPA) on October 26, 2015. On that date, EPA promulgated revised 8-hour primary and secondary ozone National Ambient Air Quality Standards (NAAQS). Under the Clean Air Act, states with areas designated as nonattainment for the revised ozone NAAQS and states located in the Ozone Transport Region (OTR) are required to submit, for the approval of EPA, revisions to the relevant state implementation plan (SIP) to ensure that the SIP complies with all applicable statutory and regulatory requirements[7].

The District is a part of the OTR and was designated as marginal nonattainment for the 2015 Ozone NAAQS.[8] Since the District is located within the OTR, it must comply with the EPA's RACT requirements established in 40 CFR Part 51, Subpart X.

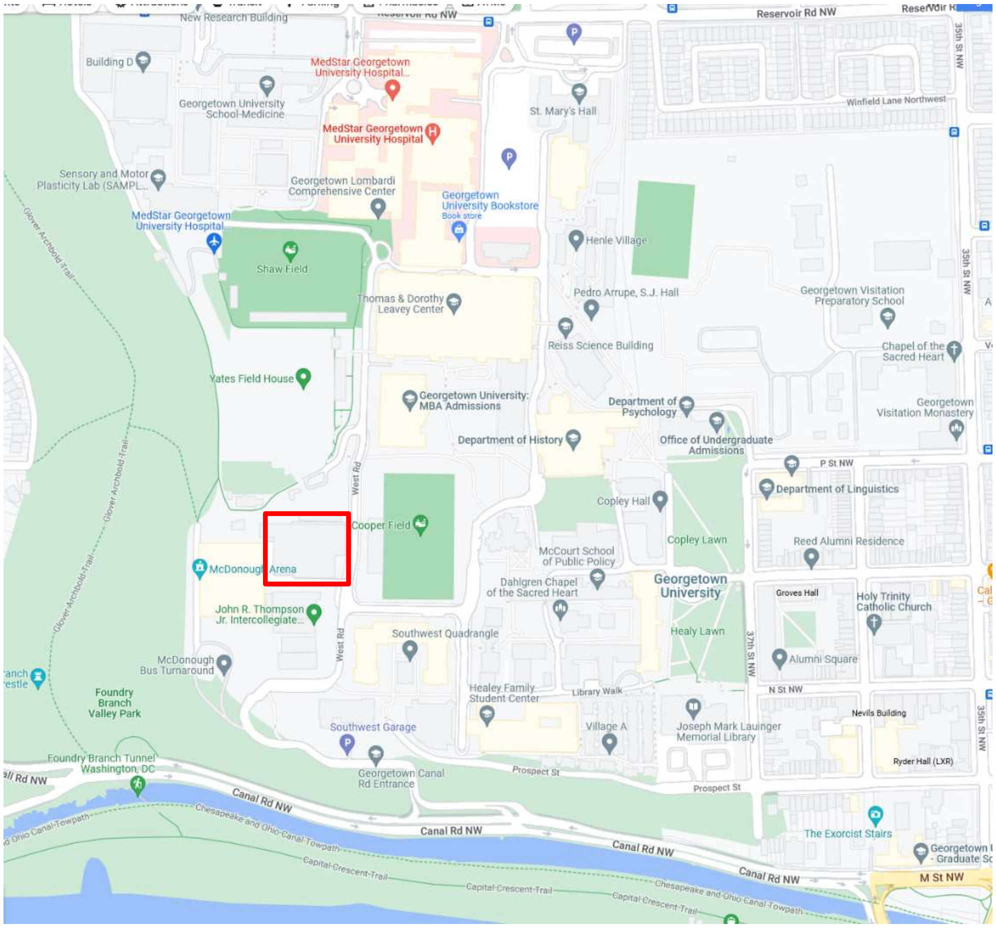
[7] 42 U.S.C. § 7502(b)

[8] 83 Federal Regulation 25776, 25795 dated June 4, 2018

4. LOCATION

GU is located at 3700 O Street NW, Washington D.C. The emission units affected by 20 DCMR 805 reside in the CUP, designated within the red rectangle in Figure 1.

Figure 1 - Map of Georgetown University[9]



9 Image credit: Google Maps (www.google/maps).

5. RESPONSIBLE OFFICIAL AND CONTACT INFORMATION

5.1 Responsible Official

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6. RACT ANALYSIS

6.1 The RACT Process

This RACT analysis, in accordance with state and federal rules and guidance, is properly conducted in a conventional "Top-Down" manner consisting of the following five steps:

- **Step 1 – Identify all potentially available control options**
  In this step, all available control options for the emission unit and the pollutant under consideration are identified. This includes technologies used throughout the world and emission reductions that may be achieved through the application of available control techniques, changes in process design, and/or operational limitations.

- **Step 2 – Eliminate technically infeasible control options**
  In this step, the technical feasibility of the various control options – from Step 1 – in relation to the specific emission unit under consideration are evaluated. If an applicant presents clear and reasonable documentation (based on physical, chemical, and engineering principles) describing technical challenges that preclude the successful implementation of the control option, it is eliminated from further consideration in this step.

- **Step 3 – Rank remaining control technologies by control effectiveness**
  In this step, the technically feasible control options are listed in order of decreasing control effectiveness. Information about each option's control efficiency and expected post-control emission rate is also presented.

- **Step 4 – Evaluate the most effective controls and document the results**
  In this step, any relevant energy, environmental, and economic impacts are considered and evaluated. If an applicant proposes to use the most effective option (from Step 3), the scope of the evaluation is typically at the discretion of the reviewer.

  A critical element in a RACT analysis is the evaluation of a control option's economic feasibility. Economic feasibility is determined according to the average cost effectiveness of the control option, expressed in dollars per ton of pollutant reduced.[10] More specifically, the cost effectiveness is the ratio of annualized control costs ($/yr) and the expected pollutant reduction (average tons per year (ton/yr)). This metric is used to determine the most cost-effective way of achieving emission reductions. The pollution reduction component requires an accurate assessment of baseline (i.e., pre-RACT) and post-RACT potential emissions, while the annualized control costs require a consideration of both capital and operating costs.

  In a 1994 memorandum to Regional Directors, the U.S. EPA provided guidance on determining NOx RACT, noting specifically that cost effectiveness for NOx technologies should cost less than $1,300 per ton of NOx removed. Escalating the cost basis from January 1994 to January 2022 using the

[10] U.S. EPA. Office of Air Quality Planning and Standards (OAQPS) Cost Control Manual, 7th Edition. Available at: https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution. Accessed January 2022.

Consumer Price index (CPI) results in a RACT cost effectiveness threshold of approximately $2,500 per ton of NOx removed.[11,12]

- **Step 5 – Select RACT**
  In Step 5, the most effective control option not eliminated in Step 4 is proposed as RACT. The specific structure and scope of the regulatory language used to describe the selected RACT is typically determined by the regulatory authority following negotiations with the source.

6.2 Pollutant Formation: NOx

Three mechanisms form NOx in combustion sources. The principal mechanism is thermal NOx, which arises from the thermal dissociation and subsequent reaction of nitrogen and oxygen molecules in the combustion air. Thermal NOx increases with temperature so combustion systems which reduce peak flame temperatures – e.g., low NOx burners – are effective NOx controls for boilers. The second mechanism is prompt NOx, which is formed from early reactions of nitrogen molecules in the combustion air and hydrocarbon radicals from the fuel. The third mechanism, fuel NOx, stems from the reaction of fuel-bound nitrogen compounds with oxygen. The relative importance of these mechanisms in contributing to overall NOx emission depends largely upon combustor operating conditions and the presence of fuel-bound nitrogen. Natural gas and distillate fuel oil have negligible chemically bound fuel nitrogen (although some molecular nitrogen is present). Most of the NOx formed from natural gas and distillate fuel oil combustion is from thermal NOx.

6.3 Resources

As a means of adhering to the prescribed RACT process, existing guidance and preceding determinations, GU used the following resources to identify possible NOx control options:

1. U.S. EPA Control Techniques Guidelines and Alternative Control Techniques Documents[13]
2. U.S. EPA AP 42, Fifth Edition Compilation of Air Pollutant Emissions Factors, Chapter 1.3 Fuel Oil Combustion, May 2010 and Chapter 1.4 Natural Gas Combustion, July 1998[14]
3. U.S. EPA RACT-BACT-LAER Clearinghouse[15]
4. Discussions with relevant manufacturers and equipment vendors
5. The requirements of 20 DCMR 805.2(c).
6. Knowledge and experience of the RACT reviewers

6.4 Step 1: Identify NOx Control Options

Using the resources identified in Section 6.3, GU determined that NOx emissions from Boiler 1 could be minimized or controlled using the control options listed in Table 2:

[11] The CPI Inflation calculator is available at: https://data.bls.gov/cgi-bin/cpicalc.pl. Accessed February 2022.

[12] GU understands EPA typically allows individual states and permitting agencies to make and defend their own determinations when establishing RACT.

[13] Available at https://www.epa.gov/ground-level-ozone-pollution/control-techniques-guidelines-and-alternative-control-techniques. Accessed January 2022.

[14] Available at: https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors. Accessed January 2022.

[15] The RACT-BACT-LAER Clearinghouse is a valuable resource used to determine what other controls have been demonstrated since 1994 when EPA control techniques and guidelines were published. Available at https://cfpub.epa.gov/rblc/. Accessed January 2022.

Table 2 – Identified Control Options

Control Option
Good Combustion Practices (GCP)
Air Staged Combustion (including Low NOx Burners)
Flue Gas Recirculation (FGR)
Selective Catalytic Reduction (SCR)
Selective Non-Catalytic Reduction (SNCR)
EMx Catalytic Absorption/Oxidation
Operational Limitations

In general, these control options fall into one of two categories, those designed to:

- Minimize the formation of a pollutant at the point of generation (i.e., "pollution prevention"), or
- Reduce the amount of pollution emitted to the atmosphere by capturing and/or destroying a portion of emissions generated (i.e., "add-on pollution control").

GCP and Air Staged Combustion are examples of pollution prevention, while SCR, SNCR, and EMx™ are examples of add-on pollution control. The remainder of this section provides concise descriptions of each control option.

Good Combustion Practices

The term "good combustion practices" (GCP) has evolved in the regulatory landscape to describe the optimal design and proper operation of process equipment, such as boilers. Optimal boiler design and operation maximizes fuel efficiency, minimizes emissions, reduces costs and improves safety. These benefits are desirable to owners of institutional, commercial, and industrial boilers. Thus, boiler manufacturers are highly incentivized to design optimized boilers and encourage customers to follow proper operation and maintenance procedures.

Air permits typically require a permittee utilize/follow GCP. For example, GU is already required to: maintain and operate each boiler, including associate air pollution control equipment and monitoring equipment, in a manner consistent with safety and good air pollution control practice for minimizing emissions; minimize the boilers start-up and shutdown periods following the manufacturer's recommended procedures; and perform boiler tune-ups. [16]

Air Staged Combustion

In a conventional boiler, all the air required for combustion is supplied to the burners. An alternative and more modern design – staged combustion – creates more than one combustion zone to optimize combustion and reduce NOx emissions. More specifically, staged combustion involves diverting a portion of the combustion air to a secondary location within the burner (aka internal staging) or to injection ports beyond the last row of burners (aka external staging). While there are several forms of staged combustion (e.g., overfire air, burners out of service, biased burner firing, low NOx burners (LNB) etc.) the most prevalent and effective approach to retrofitting an existing, natural gas fired boiler is the use of LNB.

Manufacturers of LNB typically rate the performance of the burner in terms of the maximum concentration of NOx expected to be emitted from a properly installed burner. Note that burners

[16] Conditions III.d. through III.f. from permits 7214 through 7217, issued May 7, 2019.

designed to reduce emissions of multiple pollutants – including NOx – relative to other burner configurations are often referred to as LEB.

LNB is a relative term: a "LNB" in a boiler that is several decades old may have a NOx emission rate of ~50 ppm (parts per million), whereas a LNB on a new boiler may have a NOx emission rate of 12 to 15 ppm. The term "ultra-low NOx burner" has evolved to generally refer to a burner that emits less than 9 ppm. Several ULNB designs are constructed using composite materials and designed for precise fuel and air premixing prior to injection into the furnace combustion zone. The tolerance of ultra LNB operating conditions is very tight and must be closely monitored to ensure that the produced emissions are as expected. LNB technology is available from many manufacturers and applicable to all fuels.

LNB can typically achieve NOx reductions of 30 to 60 percent (%).

Flue Gas Recirculation

Flue gas recirculation (FGR) involves the recirculation of a portion – typically 20 to 30 % – of the oxygen-deficient exhaust gases back into the boiler combustion zone to lower peak flame temperature and reduce NOx formation. Many newer boiler installations utilize FGR to optimize boiler operating parameters (e.g., turndown, capacity, efficiency) and minimize NOx and CO emissions.

The degree of NOx reductions achieved with FGR vary considerably depending on the type of fuel and the design of the system. (For the purpose of this RACT analysis, a FGR NOx reduction efficiency is not estimated since Boiler 1 already utilizes FGR.)

Selective Catalytic Reduction

Selective Catalytic Reduction (SCR) is a post-combustion flue gas treatment that reduces NOx emissions by promoting the conversion of NOx into molecular nitrogen and water vapor using a catalyst. Ammonia (NH_3), usually diluted with air or steam, is injected into the exhaust upstream of a catalyst bed. On the catalyst surface, NH_3 reacts with NOx to form molecular nitrogen (N_2) and water (H_2O) with the following basic reaction pathways:

$$2NH_3 + NO_2 + NO \rightarrow 2N_2 + 3H_2O$$
$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O$$
$$8NH_3 + 6NO_2 \rightarrow 7N_2 + 12H_2O$$

The catalyst serves to lower the activation energy of these reactions, which allows the NOx to N_2 and H2O conversions to take place at a lower temperature than the exhaust gas. The optimum temperature for this conversion can range from 350 Degrees Fahrenheit (°F) to 1,100 °F, but is typically designed to occur between 600 °F and 750 °F depending on the catalyst. Typical SCR catalysts include metal oxides (e.g., titanium oxide and vanadium), noble metals (e.g., combinations of platinum and rhodium), alumino-silicates (i.e., zeolites), and ceramics. Water vapor and elemental nitrogen are released to the atmosphere as part of the exhaust stream.

Factors affecting SCR performance include space velocity (volume per hour of flue gas divided by the volume of the catalyst bed), ammonia/NOx molar ratio, and catalyst bed temperature. Space velocity is a function of catalyst bed depth. Decreasing the space velocity (increasing catalyst bed depth) will improve NOx removal efficiency by increasing residence time but will also cause an increase in catalyst bed pressure drop. Reaction temperature is critical for proper SCR operation. Below the minimum temperature, reduction reactions will not take place. At temperatures exceeding the optimal range, oxidation of ammonia will result in an increase in NOx emissions. Loss of catalyst activity can occur from thermal degradation if the catalyst is exposed to excessive temperatures over a prolonged period.

Catalyst deactivation can also occur due to chemical poisoning. Principal poisons include arsenic, sulfur, potassium, sodium, and calcium.

NOx reductions of 70 to 90% can be achieved with SCR.

Selective Non-Catalytic Reduction (SNCR)
SNCR systems reduce NOx by injecting a reagent (ammonia or urea) into high-temperature regions (~1,600 to 2,100 °F) of a combustion system where the reagent will selectively react with NOx to produce nitrogen and water. When urea is used, it rapidly decomposes to form ammonia before reacting with NOx in the exhaust stream. Effective design and operation of a SNCR system must carefully account for operating temperature, adequate exhaust/reagent mixing, sufficient residence time (i.e., greater than 0.5 seconds), and pollutant loading. If the exhaust temperature is too low, unreacted ammonia will pass directly through the system (aka "ammonia slip") and result in increased particulate emissions. If the exhaust temperature is too high, ammonia will be oxidized to NO and emissions of NOx will increase instead of decrease. Uncontrolled NOx levels suitable for SNCR typically vary from 200 to 400 ppm according to the U.S. EPA. In addition, proper chemical storage and handling facilities must be built and operated to safely accommodate either reagent.

NOx reductions of 30 to 65% can be achieved with SNCR.

EMx™ Catalytic Absorption/Oxidation
The second-generation of the SCONOx™ NOx Absorber technology, called EMx™ Catalytic Absorption/Oxidation and currently available from EmeraChem, is based on a proprietary catalytic oxidation and absorption technology. Like SCR, EMx™ utilizes a catalyst to promote reactions at a temperature lower than what would be required otherwise. However, unlike SCR, EMx™ simultaneously reduces NOx and CO without the use of a reagent (e.g., NH_3) and thus does not potentially increase particulate emissions.

Specifically, EMx™ uses a potassium carbonate (K_2CO_3) coated catalyst to reduce NOx and CO emissions. The catalyst oxidizes carbon monoxide (CO) to carbon dioxide (CO_2), and nitric oxide (NO) to nitrogen dioxide (NO_2). The NO2 absorbs onto the catalyst to form potassium nitrite (KNO_2) and potassium nitrate (KNO_3).

Dilute hydrogen gas is periodically passed across the surface of the catalyst to regenerate the K_2CO_3 catalyst coating. The regeneration cycle converts KNO_2 and KNO_3 to K_2CO_3, water (H2O), and elemental nitrogen (N_2). This makes the K_2CO_3available for further absorption and the water and nitrogen are exhausted. Sulfur dioxide compounds in the gas quickly inactivate the EMx™ catalyst requiring the catalyst to be removed from the reactor for regeneration. To avoid this problem, EMx™ systems on natural gas fueled systems include an upstream EMx™ catalyst module that removes the sulfur compounds before they reach the EMx™ catalyst beds.

Operational Restrictions
Limiting/restricting operating status and/or schedule is a ubiquitous approach to reducing an emissions unit's potential to emit. While this technique is not a classical form of pollution prevention or add-on pollution control, it can be just as effective if not more so.

Boiler 1 is currently permitted for unrestricted operation as long as the total hourly total steam production from the CUP is less than 300,000 pounds. After careful consideration of campus projected steam demands and reliability priorities, <u>GU proposes to limit the total fuel consumption of Boiler 1 to less 166,878 MMBtu (HHV) per rolling twelve-month consecutive period.</u> (This is equivalent to a 15%

annual capacity factor.) GU also proposes to restrict operation to periods when no other boiler is available to meet steam demand. See Section 6.8 for additional information.

6.5 Step 2: Eliminate Technically Infeasible Control Options

GU has made the following determinations regarding the technical feasibility of the control options identified in Step 1:

1. **GCP**: This control option is technically feasible. GU believes various regulatory requirements to which Boiler 1 is already subject constitute the use of GCP.

2. **Air Staged Combustion**: The use of this control option – excluding the use of LEB – would require extensive modifications to the boiler's burner system and furnace. The boiler manufacturer, Indeck Keystone Energy (IKE), explained that:

    - Reducing NOx from Boiler 1 could be achieved in one of two ways: LEB retrofits or applying SCR. NOx emissions from Boiler 1 could be reduced to 12 ppm using the same LEB recently installed in Boiler 2. However, given that Boiler 1 is identical to Boiler 2, it is reasonable to conclude that the challenges (and associated cost overruns) from the Boiler 2 LEB retrofit would be encountered with Boiler 1.
    - IKE would not recommend, or guarantee the performance of, air staged combustion modifications given Boiler 1's age and design.

    Therefore, the use of air staged combustion – beyond the use of LEB – is not a technically feasible NOx control option for Boiler 1.

3. **FGR**: This control option is technically feasible. Boiler 1 already utilizes FGR.

4. **SCR**: This control option is technically feasible; however, the physical space requirements for SCR could present a design challenge if the option is evaluated more thoroughly.

5. **SNCR**: The temperature of the boiler exhaust (~410 $^{\circ}$F) is far too low to accommodate SNCR operation. While the exhaust could be heated more than a thousand degrees to the requisite SNCR operating temperature, doing so would require a significant increase in fuel consumption that would produce increased emissions of various pollutants. Therefore, SNCR is not a technically feasible NOx control option for Boiler 1.

6. **EMx™**: This control option has been demonstrated for use on relatively small combined-cycle natural gas fueled combustion turbines. The largest application is the 50 MW Unit 6 combined cycle combustion turbine at the Redding, California municipal power plant. The La Paloma Generating Project in California initially proposed to demonstrate EMx™ on a 150 megawatt (MW) turbine, but ultimately an SCR system was installed instead. Considering the lack of commercial demonstration with boilers, EMx™ is not a technically feasible NOx control option for Boiler 1.

6.6 Step 3: Rank Controls by Control Effectiveness

Each technically feasible control option from Step 2 was evaluated to determine the corresponding Total Control Efficiency and estimated post-control emission rate; see Table 3 below. (Note: In addition to restricting Boiler 1 operation, GU also proposes to continue using GCP and FGR to control

NOx emissions. As a result, each technically feasible control option was evaluated in combination with GU's proposal.)

Table 3 – Control Option Effectiveness for Boiler 1

Control Option	Control Configuration	Total Control Efficiency (Annual basis)[17]	Post-Control NOx Emission Rate
A	GCP + FGR + Restricted Operation	84%	~ 0.09 lb/MMBtu ~ 8.0 ton/yr
B	GCP + FGR + Restricted Operation **+ LEB**	97.4%	~ 0.0145 lb/MMBtu ~ 1.29 ton/yr
C	GCP + FGR + Restricted Operation **+ SCR**	97.6%	~ 0.014 lb/MMBtu ~1.2 ton/yr

6.7 Step 4: Evaluate Each Control Option

An economic analysis was completed to calculate the cost effectiveness ($ per ton of pollutant removed) of each technically feasible control option.[18] The following assumptions were used in the analysis:

- Direct and indirect annual costs were assumed equal to zero as a conservative estimate.
- Fifteen years is the estimated useful life of LEB and SCR.
- The estimated total capital investment of SCR is equal to the budgetary cost estimate from a vendor.[19]
- The estimated total capital investment of LEB is equal to actual expenditures incurred by GU to retrofit Boiler 2 with LEB.

As presented in Appendix A.3 and summarized in Table 4, the calculated cost effectiveness of Control Option B and Control Option C is much greater than the adjusted RACT threshold of $2,500 per ton of NOx removed. As a result, the use of LEB or SCR is cost prohibitive.

[17] The Total Control Efficiency accounts for the combined effect of all control measures encompassed by a specified control option. See Appendices A.1 through A.3 for supporting calculations.

[18] See Section 6.1 for a definition of cost effectiveness.

[19] See Appendix B for a copy of the budgetary cost estimate (dated February 11, 2022) obtained from CECO Environmental.

Table 4 – Calculated Cost Effectiveness

Control Option	Control Configuration	Total Capital Investment ($)[20]	Total Annualized Costs ($/yr)	Cost Effectiveness ($/ton NOx removed)
A	GCP + FGR + Restricted Operation (GU proposal)	None	None beyond what is already incurred	Not Applicable
B	GCP + FGR + Restricted Operation **+ LNB**	$2,479,000	$222,900	~ $33,100 per ton
C	GCP + FGR + Restricted Operation **+ SCR**	$2,305,000	$207,300	~ $30,400 per ton

Note: All cost figures are in terms of 2022 dollars. See Appendix A.3 for supporting calculations.

Proposed Control Option A is the only technically feasible and cost-effective control option available for reducing NOx from Boiler 1.

6.8 Step 5: Select RACT

Alternative NOx RACT for Boiler 1 has been determined to be the combined use of:

- Good combustion practices
- Flue gas recirculation
- Restricted operation, more specifically defined as:
    - Operation during periods when no other boiler is available to meet required steam demand.
    - Total fuel consumption shall not exceed 166,878 MMBtu (higher heating value) per rolling twelve consecutive month period.
    - Fuel oil consumption shall not exceed 80,616 gallons per rolling twelve consecutive month period.[21]
- Unrestricted operation during emergencies resulting from on-site disaster, local equipment failure, or public service emergencies such as flood, fire, natural disasters or severe weather conditions.

Compliance with this RACT will limit NOx emissions from Boiler 1 to less than 8.0 tons per year.

[20] The total capital investment is specific to the identified control option(s) and does not reflect other capital improvements that may be made, e.g., CEMS upgrades, new stack etc.

[21] Equal to the existing fuel oil consumption limit from Condition III.b.1. of permits 7214 through 7217.

Emissions Calculations - Georgetown University

RACT Analysis, Appendix A.1

Current Potential To Emit

Location	Unit ID	stack ID	Heat Input Capacity (MMBtu HHV/hr)
Main Plant	Boiler 1	S1	127.0

Primary Fuel: Natural Gas (NG)

1002 MMBtu/MMscf of natural gas (HHV)
83.5% Thermal Efficiency (%)
127.0 Heat Input Capacity (MMBtu HHV/hr)

Backup/Emergency Fuel: Ultra Low Sulfur Diesel (ULSD)

138.0 MMBtu/Kgal of Fuel Oil (HHV, source: 40 CFR 98, Subpart C, Table C-1)
87.5% Thermal Efficiency (%)

Current Potential Operation (Based on Permitted Limits)

1,101,395 Estimated NG consumption (MMBtu/yr)
80,616 ULSD consumption limit (gal/yr, as currently permitted)
88 Estimated ULSD Operating Schedule (hr/yr)

Emissions

Pollutant	from Natural Gas combustion: Natural Gas Emission Factor (lb/MMBtu HHV)	Potential To Emit (lb/hr)*	Potential To Emit (ton/yr)	Note	from Fuel Oil combustion: Fuel Oil Emission Factor (lb/MMBtu HHV)	Potential To Emit (lb/hr)*	Potential To Emit (ton/yr)	Note	Total (ton/yr)
CO	0.084	10.7	46.3	A	0.036	4.6	0.20	E	**46.5**
CO2	116.9	14,841	64352	C	163.0	20702	907	C	**65,259**
NOx	0.090	11.4	49.6	B	0.090	11.4	0.50	B	**50.1**
PM	0.008	1.0	4.2	A	0.002	0.3	0.01	E	**4.2**
PM_{10}	0.008	1.0	4.2	A/D	0.002	0.3	0.01	D/E	**4.2**
$PM_{2.5}$	0.008	1.0	4.2	A/D	0.002	0.3	0.01	D/E	**4.2**
SO2	0.0006	0.1	0.3	A	0.002	0.2	0.01	E/F	**0.3**
VOC	0.005	0.7	3.0	A	0.004	0.6	0.02	E	**3.0**

* Assumes 100% load
A - Emission factor from AP-42, Ch. 1.4 (Natural Gas Combustion)
B - The average measured NOx emission rate from the December 2021 CEMS Relative Accuracy Test Audit.
C - Emission factor from 40 CFR 98, Subpart C, Table C-1
D - PM10 and PM2.5 assumed equal to total PM as a conservative estimate
E - Emission factor from AP-42, Ch. 1.3 (Fuel Oil Combustion)
F - Based on a fuel oil sulfur content of 0.0015% by weight (Ultra Low Sulfur Diesel)

Methodology

Emission Factor (lb SO2/MMBtu fuel oil) = 142 (AP-42 Factor, lb/kgal) x fuel oil Higher Heating Value (kgal/MMBtu) x S, where S = fuel oil % sulfur
Potential to Emit (lb/hr) = Emission Factor (lb/MMBtu) x Heat Input Capacity (MMBtu/hr)
Potential to Emit (ton/yr) = Emission factor (lb/MMBtu) x Fuel Consumption Limit (#/yr) x Conversion Factor x 1/2000 (ton/lb)
Total PTE (ton/yr) (for each criteria pollutant) = The sum of: PTE (ton/yr, NG) and PTE (ton/yr, Fuel Oil)

Emissions Calculations - Georgetown University

RACT Analysis, Appendix A.2

Post RACT Potential To Emit

Location	Unit ID	stack ID	Heat Input Capacity (MMBtu HHV/hr)
Main Plant	Boiler 1	S1	127.0

Primary Fuel: Natural Gas (NG)

1002 MMBtu/MMscf of natural gas (HHV)
83.5% Thermal Efficiency (%)
127.0 Heat Input Capacity (MMBtu HHV/hr)

Backup/Emergency Fuel: Ultra Low Sulfur Diesel (ULSD)

138.0 MMBtu/Kgal of Fuel Oil (HHV, source: 40 CFR 98, Subpart C, Table C-1)
87.5% Thermal Efficiency (%)

Post RACT Operation (Proposed)

15% Annual Capacity Factor
166,878 Maximum Allowable NG consumption (MMBtu/yr)
80,616 ULSD consumption limit (gal/yr, as currently permitted)
88 Estimated ULSD Operating Schedule (hr/yr)

Emissions — **from Natural Gas combustion** / **from Fuel Oil combustion**

Pollutant	Natural Gas Emission Factor (lb/MMBtu HHV)	Potential To Emit (lb/hr)*	Potential To Emit (ton/yr)	Note	Fuel Oil Emission Factor (lb/MMBtu HHV)	Potential To Emit (lb/hr)*	Potential To Emit (ton/yr)	Note	Total (ton/yr)
CO	0.084	10.7	7.0	A	0.036	4.6	0.20	E	**7.2**
CO2	116.9	14,841	9750	C	163.0	20702	907	C	**10,657**
NOx	0.090	11.4	7.5	B	0.090	11.4	0.50	B	**8.0**
PM	0.008	1.0	0.6	A	0.002	0.3	0.01	E	**0.6**
PM_{10}	0.008	1.0	0.6	A/D	0.002	0.3	0.01	D/E	**0.6**
$PM_{2.5}$	0.008	1.0	0.6	A/D	0.002	0.3	0.01	D/E	**0.6**
SO2	0.0006	0.1	0.0	A	0.002	0.2	0.01	E/F	**0.1**
VOC	0.005	0.7	0.5	A	0.004	0.6	0.02	E	**0.5**

* Assumes 100% load

A - Emission factor from AP-42, Ch. 1.4 (Natural Gas Combustion)

B - The average measured NOx emission rate from the December 2021 CEMS Relative Accuracy Test Audit.

C - Emission factor from 40 CFR 98, Subpart C, Table C-1

D - PM10 and PM2.5 assumed equal to total PM as a conservative estimate

E - Emission factor from AP-42, Ch. 1.3 (Fuel Oil Combustion)

F - Based on a fuel oil sulfur content of 0.0015% by weight (Ultra Low Sulfur Diesel)

Methodology

Emission Factor (lb SO2/MMBtu fuel oil) = 142 (AP-42 Factor, lb/kgal) x fuel oil Higher Heating Value (kgal/MMBtu) x S, where S = fuel oil % sulfur

Potential to Emit (lb/hr) = Emission Factor (lb/MMBtu) x Heat Input Capacity (MMBtu/hr)

Potential to Emit (ton/yr) = Emission factor (lb/MMBtu) x Fuel Consumption Limit (#/yr) x Conversion Factor x 1/2000 (ton/lb)

Total PTE (ton/yr) (for each criteria pollutant) = The sum of: PTE (ton/yr, NG) and PTE (ton/yr, Fuel Oil)

Emissions Calculations - Georgetown University

RACT Analysis, Appendix A.3

Supporting Calculations

Baseline Operation		Note
0.09	NOx emissions (lb/MMBtu, from NOx CEMs)	
50.1	NOx emissions (ton/yr, Appendix A.1)	
8760	Allowable Operating Schedule (hr/yr)	

Option A: Use Operational Restrictions (with GCP and FGR)		
500	Proposed Maximum Operating Schedule (hr/yr)	
8.0	Post Control NOx Emission Rate (ton/yr)	
84.0%	Effective Control Efficiency (%)	
0	Associated Total Capital Investment ($)	
0	Associated Direct and Indirect Annual Costs ($/yr)	
NA	Assumed Equipment Life	
NA	Total Annualized Costs ($/yr)	
NA	**Control Effectiveness ($/ton)**	

Option B: Use LEB and Operational Restrictions (with GCP and FGR)		
0.0145	NOx emissions (lb/MMBtu, from LEB manufacturer)	
8.0	NOx PTE (ton/yr) as a result of Operating Limitation	
83.9%	Control Efficiency of LEB (%, calculated)	
1.29	Post Control NOx Emission Rate (ton/yr)	
97.4%	Total Control Efficiency (%)	
6.7	Incremental NOx Removal by LEB (ton/yr)	
15	Assumed Equipment Life (yr)	C
$ 2,479,000	Total Capital Investment of LEB ($)	A
$ -	Direct and Indirect Annual Costs ($/yr)	B
$ 222,964	Total Annualized Costs ($/yr)	E
$ 33,181	**Control Effectiveness ($/ton of NOx removed)**	

Option C: Use SCR and Operational Restrictions (with GCP and FGR)		
8.0	NOx PTE as a result of Operating Limitation (ton/yr)	
85.0%	Control Efficiency of SCR (%)	D
1.20	Post Control NOx Emission Rate (ton/yr)	
97.6%	Total Control Efficiency (%)	
6.8	Incremental NOx Removal by SCR (ton/yr)	
15	Assumed Equipment Life (yr)	C
$ 2,305,000	Total Capital Investment of SCR ($)	D
$ -	Direct and Indirect Annual Costs ($/yr)	B
$ 207,314	Total Annualized Costs ($/yr)	E
$ 30,449	**Control Effectiveness ($/ton of NOx removed)**	

(A) Equals actual Boiler 2 LEB expenditures

(B) Equals zero as a conservative estimate

(C) A longer equipment life is unreasonable given boiler age

(D) Provided by vendor (CECO Environmental)

(E) Assumes an annual interest rate of 4% over 15 years

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