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APPLICATION FOR
AIR FACILITY PERMIT

FOR

SARATOGA BIOCHAR SOLUTIONS, LLC
CARBON FERTILIZER MANUFACTURING FACILITY
MOREAU, NY

Prepared For:

Saratoga Biochar Solutions, LLC.
26F Congress Street #346
Saratoga Springs, NY 12866

Prepared By:

Sterling Environmental Engineering, P.C.
24 Wade Road
Latham, New York 12110

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STATE OF NEW YORK
ANDREW M. MILLSPAUGH
094708
LICENSED PROFESSIONAL ENGINEER

"Serving our clients and the environment since 1993"

24 Wade Road ♦ Latham, New York 12110 ♦ Tel: 518-456-4900 ♦ Fax: 518-456-3532
E-mail: sterling@sterlingenvironmental.com ♦ Website: www.sterlingenvironmental.com

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1.0 INTRODUCTION

This narrative and attached supporting documentation provide a complete application for a State Facility Air Permit under 6 NYCRR 201-5. Saratoga Biochar Solutions, LLC (SBS) is proposing to construct and operate a solid waste management facility (SWMF) to manufacture Carbon Fertilizer from biosolids and wood waste feedstock (hereinafter the "Facility") with an annual throughput up to 235,200 wet tons of received biosolids and up to 35,280 tons of wood waste. The Facility is designed to be constructed in three phases with each phase consisting of a process line capable of processing up to 10 wet tons per hour of biosolids and up to 1.5 tons per hour of wood waste. Each process line is capable of manufacturing approximately 1 ton per hour of Exceptional Quality (EQ) Class A biosolids product (i.e., "Carbon Fertilizer") in accordance with 40 CFR Part 503 and 6 NYCRR 361. The selected location is on 5.89 acres composed of Tax Parcels 50.-4-16 (3.07 acres) and 50.-4-22 (2.82 acres), on Farnan Road within the Moreau Industrial Park in the Town of Moreau, Saratoga County, New York, owned by Moreau Industrial Park, LLC. A Site Location Map on a United States Geological Survey quadrangle map is provided as Figure 1, and a Site Vicinity Map on an aerial image is provided as Figures 2.

Authorization to operate the Facility is the subject of a separate Solid Waste Management Facility Permit application to the New York State Department of Environmental Conservation (NYSDEC) pursuant to 6 NYCRR Part 360. As described in this narrative, all manufacturing activities are conducted indoors, and the Facility is maintained under negative pressure to mitigate potential fugitive odor emissions. All exhaust air is treated through engineered air pollution control devices for particulate, ammonia, sulfur dioxide, volatile organic compounds (VOCs), and odor control.

The Facility ventilation system exhausts to the atmosphere at three emission points subject to air pollution control devices (i.e., one emission point for each process line). This submittal evaluates anticipated emissions at full buildout of the Facility and is based on emission factors and performance data from bench scale testing. In practice, one process line will be constructed and operated before constructing the second and third process lines. This will allow the Facility to obtain actual full-scale emission factors to refine the emission calculations, if needed, before proceeding with construction of the additional process lines.

Table A provides a checklist of the application contents.

Table A - 6 NYCRR Part 201-5.2 State Facility Air Permit Checklist

Regulatory Requirement	Description	Location
6 NYCRR 201-5.2	**State Facility Permit Application Content**	
6 NYCRR 201-5.2(a)	Application for State Facility Permit	Attachment 1. State Facility Air Permit Forms
6 NYCRR 201-5.2(b)(1)	Identifying information, including owner name and address, facility name and address.	Attachment 1 State Facility Air Permit Forms
6 NYCRR 201-5.2(b)(2)	Facility Location Map / Site Plan drawings	Figures 1 and 2, Attachment 2
6 NYCRR 201-5.2(b)(3)	A list and description of all emission sources at the facility except those that are exempt or trivial.	Narrative Section 6.0

6 NYCRR 201-5.2(b)(4)	Listing of SIC or NAICS corresponding to the primary operations carried out at the facility.	Attachment 1 State Facility Air Permit Forms Narrative Section 6.0
6 NYCRR 201-5.2(b)(5)	A description of all processes, their associated emission sources, and products.	Narrative Section 6.0, Attachments 1-5
6 NYCRR 201-5.2(b)(6)	List of all emission points including the following parameters: stack height (ft), stack height above building (ft), internal stack diameter (in), exit temperature (degrees F), exit velocity (ft/sec), exit flow (acfm), distance from emission point to the property line (ft), and NYTM coordinates.	Attachment 1 State Facility Air Permit Forms
6 NYCRR 201-5.2(b)(7)	A Process Flow Diagram detailing which process emissions and emission sources exhaust from which emission point.	Figures 4 and 5
6 NYCRR 201-5.2(b)(8)	A list including the type, rate, and quantity of all regulated air pollutant emissions and persistent, bioaccumulative, and toxic compound emissions, as listed in Subpart 201-9.	Attachment 4, Narrative Section 6.0
6 NYCRR 201-5.2(b)(9)	List of applicable New York State and Federal air pollution control requirements applicable to the Facility.	Attachment 1 State Facility Air Permit Forms
6 NYCRR 212-2	Allowable Emissions Analysis	Narrative Section 8.0 Attachment 5 – AERMOD Outputs
CLCPA Section 7(2)	Identify each GHG and calculate the project's potential to emit GHG in units of tons per year and carbon dioxide equivalents using 20-year global warming potentials found in 6 NYCRR 496.5. Include upstream emissions using NYSDEC "preliminary interim draft emissions factors for use by state agencies and project proponents".	Narrative Section 9.0
CLCPA Section 7(3)	All state agencies, offices, authorities, and divisions shall also prioritize reductions of GHG emissions and co-pollutants in disadvantaged communities as identified pursuant to such subdivision 5 of Section 75-0101 of the Environmental Conservation Law.	Narrative Section 10.0

2.0 DESCRIPTION OF PROJECT

The Facility is designed to process biosolids and wood waste feedstock through low-temperature drying and pyrolysis to produce a marketable Carbon Fertilizer that meets specific end-use requirements. The Facility is subject to a New York State Department of Environmental Conservation (NYSDEC) SWMF permit under 6 NYCRR 362-1 (Thermal Treatment Facilities). There is no incineration or combustion of feedstock involved in the manufacturing process, and the feedstock is limited to biosolids sourced from wastewater treatment plants and wood waste consisting of land clearing debris and/or unadulterated wood, wood chips, or bark from logging operations, pulp and paper production, and wood products manufacturing; unauthorized waste that will not be accepted includes municipal solid waste, construction and demolition debris, friable asbestos-containing material (ACM), mercury-added consumer products, radioactive waste, infectious and regulated medical waste, and hazardous wastes.

All manufacturing activities are conducted indoors, and the Facility is maintained under negative pressure to mitigate potential fugitive odor emissions. All exhaust air is treated through engineered air pollution control devices for particulate, ammonia, sulfur dioxide, VOCs, and odor control.

3.0 6 NYCRR PART 201-5.2(a) APPLICATION FOR STATE FACILITY AIR PERMIT

A completed NYSDEC State Facility Air Permit Form is provided as Attachment 1. Required elements of the application are included as additional attachments as indicated in Table A.

4.0 6 NYCRR PART 201-5.2(b)(1) IDENTIFYING INFORMATION

Identifying information for the facility and facility owner is provided in the completed State Facility Air Permit Form (Attachment 1).

5.0 6 NYCRR PART 201-5.3(b)(2) FACILITY LOCATION MAP

The Facility will be located on 5.89 acres composed of Tax Parcels 50.-4-16 (3.07 acres) and 50.-4-22 (2.82 acres), on Farnan Road within the Moreau Industrial Park in the Town of Moreau, Saratoga County, New York, owned by Moreau Industrial Park, LLC. A Site Location Map on a United States Geological Survey quadrangle map is provided as Figure 1, and a Site Vicinity Map on an aerial image is provided as Figures 2. Site Plan Drawings showing the Facility layout are provided in Attachment 2.

6.0 6 NYCRR PART 201-5.2(b)(3) DETAILED DESCRIPTION OF THE OPERATIONS

The Facility uses low-temperature thermal drying and low-temperature pyrolysis to process biosolids and wood waste into a marketable EQ Class A biosolids product that meets specific end-use requirements contained in 40 CFR Part 503 and 6 NYCRR 361. Wood waste feedstock is an optional minor feedstock component that is not required for processing biosolids. Pyrolysis is a heating process in the absence of oxygen that separates volatile organic compounds (as syngas) from the inorganic solid fraction, which forms the Carbon Fertilizer. The Facility consists of the following components and processes that are shown on the Site Plan Drawings included in Attachment 2 and in the Manufacturing Equipment Process Flow Diagram (Figure 4) and Air Treatment System Process Flow Diagram (Figure 5):

A. <u>Scale House and Administrative Office</u> – The Scale House and Administrative Office includes a scale operations center, restrooms, showers, and administrative support offices. This area is a specific portion of the Carbon Manufacturing Building that is separated from process equipment.

B. Carbon Manufacturing Building – The Carbon Manufacturing Building is completely enclosed and includes a Biosolids Receiving Area, a Process Input Feed Pit, and a Carbon Manufacturing Area. Attached to the Carbon Manufacturing Building is a partially enclosed, covered Wood Feedstock Receiving, Storage, and Processing Area and an outdoor Carbon Storage and Loading Area. As shown in the Site Plan Drawings, the Facility construction is anticipated to be built out over three phases with each phase capable of processing up to 10 tons per hour of received biosolids and up to 1.5 tons per hour of wood waste. Phases two and three are planned to be constructed over a five year timeframe following completion of Phase one. Descriptions of each area and associated processes are as follows:

1. Biosolids Receiving Area – Biosolids are delivered by licensed haulers using standard hauling trucks with covers that will not require modifications. The Facility will receive biosolids Monday through Saturday at a rate of approximately 240 tons per day per processing line (i.e., approximately 283 cubic yards per day per processing line). Delivered biosolids are received inside the Carbon Manufacturing Building, which minimizes fugitive noise and odor emissions. The receiving area is isolated from the process area and is serviced by the air treatment system. Trucks back into the building through quick opening and closing garage doors and tip the biosolids into a recessed reception pit. The reception pit is equipped with a scalping grate with 8-inch square openings to separate and remove any oversized material that may be in a load (e.g., unauthorized waste). The receiving area is slightly pitched to ensure that any spillage is contained within the enclosed building. A high-pressure water source is available to wash the wheels and tailgate of delivery trucks if needed. Wash water is collected through a trench drain and for disposal to the sanitary sewer. The Facility has contracted with Casella Organics (“Casella”) for an initial 10-year term with two 5-year extensions to source and transport biosolids to the Facility. Since biosolids feedstock is being obtained from a single contracted supplier directly from wastewater treatment plants, the presence of oversized debris is expected to be minimal. If oversized debris is captured on the scalping screens, the first method of removal is manually by personnel with an extension hook. This method of removal is suitable for light debris (e.g., plastics). If large and potentially heavy oversized debris is encountered, a piece of equipment (e.g., excavator or similar) will remove the debris. All removed debris will be washed clean of biosolids using the truck wash and placed in a roll-off container for offsite disposal.

2. Process Input Feed Pit – Following biosolids reception, screw conveyors located at the bottom of the reception pit transfer the biosolids across the receiving pit into the Process Input Feed Pit. The receiving pits and storage silos are sized to provide a combined three-day storage capacity in accordance with NYSDEC regulations (6 NYCRR 362-1.5(b)(3)). The two reception pits provide a combined 855.2 cubic yards of storage capacity for the first process line. The second and third processing lines will each include a biosolids storage silo that each have a capacity of at least 850 cubic yards. Indoor storage of biosolids is necessary to provide sufficient material for continuous operation of the manufacturing process 24 hours per day while only receiving biosolids between 6:00 AM and 6:00 PM Monday through Saturday.

3. Wood Feedstock Receiving, Storage, and Processing Area – Adjacent to the Biosolids Receiving Area is a covered outdoor receiving and storage area for wood waste feedstock. Wood is used as an optional blending agent with biosolids to control moisture content and to boost energy and carbon content. Received wood waste will include land clearing debris and/or unadulterated wood, wood chips, or bark from logging operations, pulp and paper production, and wood products manufacturing material. Unauthorized

wood waste includes wood products that are painted, chemically treated (e.g., pressure-treated wood or railroad ties), or manufactured with chemicals such as glues or adhesives (e.g., plywood or particle board). Received wood will be stored in bunkers and loaded into the Process Input Feed Pit using a bucket loader or similar piece of mobile equipment. To ensure consistent particle size, all wood waste material is passed through an electric grinder to reduce oversized material. A dust hood is located above the grinder to collect any particulate emissions, and the grinder is locally shielded for noise control. The grinder will only operate during daytime hours.

4. Carbon Manufacturing Area – Biosolids and wood waste feedstock move by conveyor to the manufacturing process equipment that consist of a rotary dryer, a pyrolysis reactor, and a thermal oxidizer, among other system components as shown on the Process Flow Diagram in Figure 4. Drying high-moisture biosolids is the first step in the carbon manufacturing process, which is common in many municipalities throughout the U.S. The drying process is the only point-source of odor emissions from the Facility. Dryer emissions are ducted to the air treatment system, and dry feedstock is collected in a hopper bin for sizing prior to the second step. Sizing the dried feedstock consists of screening and milling. Only properly sized particles (i.e., the under screen fraction) are sent to the pyrolysis reactor. Oversized particles are reduced to fines through the use of a hammermill and returned to the dryer along with process dust to facilitate particle agglomeration and to reduce dust in the final product.

   The second step in the carbon manufacturing process is pyrolysis. The dried and sized feedstock is received from the dry hopper bin into an oxygen-free chamber that heats the material without direct exposure to flame. The kiln uses natural gas to indirectly heat the feedstock across four sections of the kiln to ensure uniformity of the pyrolysis process along the length of the kiln. The products of pyrolysis are the manufactured Carbon Fertilizer solids and a synthetic gas (i.e., syngas). The solid Carbon Fertilizer is cooled by an indirect heat exchanger, hydrated to 10% moisture content, and transferred by conveyor to the product storage area. The generated syngas is ducted to the thermal oxidizer to generate heat for the dryer. The drying process accounts for approximately 83% of the heat energy needed for the Facility and is expected to be supplied from the syngas generated in the pyrolysis process as renewable energy. Exhaust from the thermal oxidizer is ducted to the dryer for thermal efficiency.

   The feedstock is never directly combusted or incinerated inside the kiln, which substantially reduces the potential for air emissions. The organic constituents in the feedstock are separated as a synthetic gas (i.e., syngas), which contains methane, sulfur, VOCs, and other odor compounds. The syngas is piped to and combusted in a thermal oxidizer at a temperature that generates heat, destroys methane, VOCs, and odor compounds, and reduces the formation of nitrogen oxide emissions (i.e., NOx) through the use of low-NOx burners and a multi-stage combustion chamber. The generated syngas is a renewable energy that is burned in the thermal oxidizer to produce heat for continuous operation of the dryer. The thermal oxidizer must initiate operations using natural gas or a blend of syngas and natural gas. However, once fully operational, the drying process achieves auto-thermal operations on the generated syngas from the pyrolysis process. The thermal oxidizer is designed to achieve a destruction and removal efficiency (DRE) of 99.99%. The inorganic solids that remain after separating the syngas from the dried feedstock is the Carbon Fertilizer that is cooled and stabilized with water for storage and offsite shipment.

5. Carbon Storage and Loading Area – Manufactured Carbon Fertilizer is moved by jacketed cooling conveyor to the Carbon Storage and Loading Area for temporary storage in vertical silos. Each storage silo has a diameter of 24 feet and a height of 44 feet that provides a total storage capacity of approximately 1,230 cubic yards (~615 cubic yards per silo). Each process line has a target production rate of 1 ton of manufactured Carbon Fertilizer per hour (i.e., 2.4 cubic yards per hour at a bulk density of 0.41 tons per cubic yard). Therefore, the silos provide approximately 7 days of storage capacity at full buildout, which meets the maximum onsite storage allowed in 6 NYCRR 362.15(d). Each process line will produce up to approximately 7,840 dry tons of Carbon Fertilizer annually as agglomerated pellets with a solids content of 95 to 98%. At full buildout, the Facility will produce up to approximately 23,500 tons of Carbon Fertilizer per year. Carbon Fertilizer will be loaded directly into delivery trucks or into approximately 1 and 2 cubic yard super sacks.

   The product bagging area is located outdoors and under roof cover between the process area and storage silos. The bagging line intercepts Carbon Fertilizer that is being conveyed from the process area to the storage silos. The Carbon Fertilizer will be hydrated to 10% moisture after the jacketed cooling conveyor and prior to storage to eliminate dust throughout. In addition, a dust chute will be used at the end of the bulk loading conveyor for dust control when loading trucks. To mitigate combustion risks from combustible dusts, the process and conveyance equipment include dust ports for dust removal as well as nitrogen purging to eliminate a combustible atmosphere. Recovered dust is fed into the dryer exhaust prior to the dry cyclone for reclamation into the Carbon Fertilizer manufacturing process. The entire process area will be outfitted with sprinkler systems as a secondary form of fire control in accordance with fire protection requirements.

6. Emissions Air Treatment – Process air emissions from the Carbon Fertilizer manufacturing process, containing particulates, ammonia, sulfur dioxide, VOCs, and odors, are treated through air pollution control systems prior to exhaust to the atmosphere. The receiving area, reception pits, and process area are all maintained under negative pressure to mitigate potential for fugitive emissions. The biosolids receiving area and reception pits are ducted directly into the combustion air intake of the thermal oxidizer. Auxiliary air input into the dryer is ducted directly from the process area. Therefore, all air inside the Carbon Manufacturing Building is maintained under negative pressure induced by the air treatment system fans. When the manufacturing equipment is not operating, air is continuously pulled through the equipment and the air treatment system to ensure proper odor management at all times.

   The thermal oxidizer is integral to the Carbon Fertilizer manufacturing process and uses syngas from the pyrolysis kiln to generate heat for the biosolids dryer. The thermal oxidizer provides control of NOx emissions and destruction of VOCs, including Per-and Polyfluoroalkyl Substances (PFAS). The thermal oxidizer is designed to operate in multiple zones and temperatures to maintain a maximum NOx emission rate and minimum VOC destruction efficiency of 99.99%. Design documentation from the thermal oxidizer manufacturer is included in Attachment 3. The design documentation is a trade secret of SBS and could cause substantial injury to SBS's competitive position if made public. Therefore, Attachment 3 is appropriately marked as a trade secret and should be withheld from the public record and not subject to Freedom of Information Law (FOIL) requests.

Air treatment continues with high efficiency dry cyclones that recover most of the particulates from the air stream. After the dry cyclones, fine particulates are removed through multiple venturi heads that cool the air stream to the dew point. The cooled air stream passes through a packed bed wet scrubber where caustic or sodium bicarbonate is introduced to remove sulfur dioxide (SO_2), trace hydrofluoric acid (HF), and other odorous compounds. The effluent from the SO_2 scrubber is discharged as wastewater effluent. After SO_2 removal, the air stream passes through a second packed bed wet scrubber that uses sulfuric acid for ammonia removal. The effluent from the ammonia scrubber contains ammonium sulfate, which is either discharged as wastewater effluent or recycled into the Carbon Fertilizer to improve nutrient value. The final component of the air treatment system is a bio-scrubber that consists of two beds in series packed with microbes to polish the air by removing residual odors and SO_2 prior to release to the atmosphere.

Process water from the air treatment system that is not recycled is discharged through a direct sewer connection for treatment at the City of Glens Falls publicly owned treatment works (POTW).

6.1 Emission Sources and Emission Points

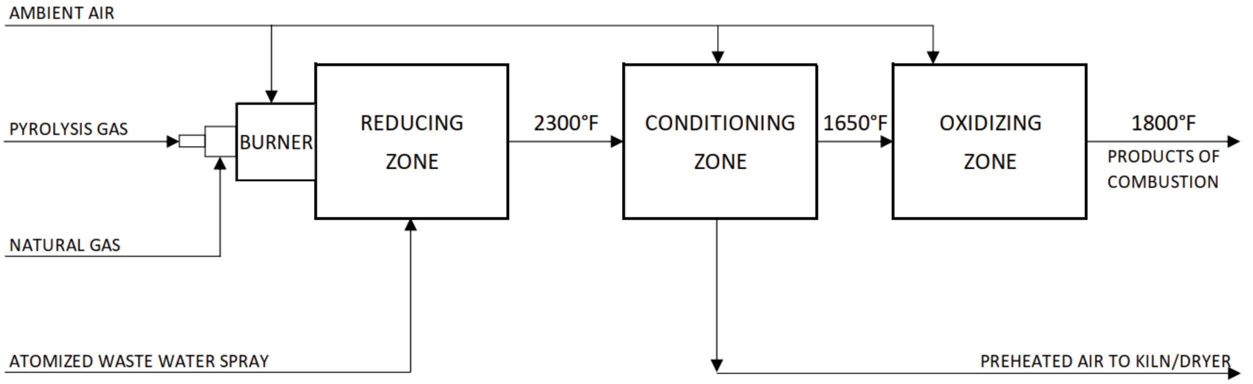
The Facility is considered a one (1) Emission Unit with three (3) stack Emission Points associated with three (3) Processes. Each Process is associated with two (2) Emission Sources that are subject to a treatment train of six (6) Emission Controls prior to discharge to the atmosphere. These are summarized as follows and identified on the Process Flow Diagrams included as Figures 3 and 4:

- Emission Unit: (1) U-00SBS – Carbon Fertilizer manufacturing facility
- Process: (1) CM1 – Carbon Fertilizer manufacturing processing line 1
  (2) CM2 – Carbon Fertilizer manufacturing processing line 2
  (3) CM3 – Carbon Fertilizer manufacturing processing line 3
- Emission Points: (1) SBS01 – Stack from first process line
  (2) SBS02 – Stack from second process line
  (3) SBS03 – Stack from third process line
- Emission Source: (1) DRY01 – Biosolids Dryer for processing line 1
  (2) DRY02 – Biosolids Dryer for processing line 2
  (3) DRY03 – Biosolids Dryer for processing line 3
  (4) CONV1 – Biosolids Conversion (pyrolysis) for processing line 1
  (5) CONV2 – Biosolids Conversion (pyrolysis) for processing line 2
  (6) CONV3 – Biosolids Conversion (pyrolysis) for processing line 3
- Emission Controls: (1) CYCL1 – Dry Cyclone for processing line 1
  (2) CYCL2 – Dry Cyclone for processing line 2
  (3) CYCL3 – Dry Cyclone for processing line 3
  (4) VCYC1 – Venturi Cyclone for processing line 1
  (5) VCYC2 – Venturi Cyclone for processing line 2
  (6) VCYC3 – Venturi Cyclone for processing line 3
  (7) NH3S1 – Ammonia Scrubber for processing line 1
  (8) NH3S2 – Ammonia Scrubber for processing line 2
  (9) NH3S3 – Ammonia Scrubber for processing line 3
  (10) SO2S1 – SO2 Scrubber for processing line 1

(11) SO2S2 – SO2 Scrubber for processing line 2
(12) SO2S3 – SO2 Scrubber for processing line 3
(13) THOX1 – Thermal Oxidizer for processing line 1
(14) THOX2 – Thermal Oxidizer for processing line 2
(15) THOX3 – Thermal Oxidizer for processing line 3
(16) BIOS1 – Biological Scrubber for processing line 1
(17) BIOS2 – Biological Scrubber for processing line 2
(18) BIOS3 – Biological Scrubber for processing line 3

6.2 Emission Controls

To control emissions associated with generated syngas from the pyrolysis reactor, a multi-staged thermal oxidizer will be used. The multi-stage thermal oxidizer includes a reducing zone, oxidizing zone, and a conditioning zone to achieve reductions of NOx compounds. In particular, multi-stage thermal oxidizers have the ability to reduce N_2O concentrations by up to 99%. N_2O, and to a lesser extent NO_2, are converted to N_2 and NO in the reducing zone. Products of incomplete combustion are fully oxidized in the oxidizing zone to CO_2 and H_2O. The exhaust air is then conditioned by blending with ambient air to achieve the target temperature for use in the rotary dryer.

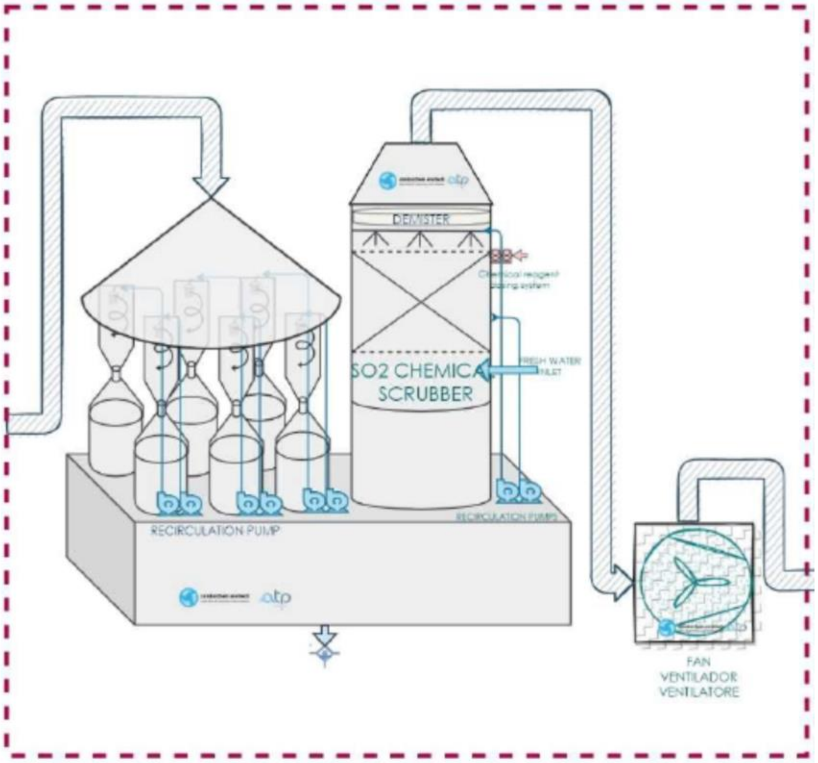


Multi-Stage Thermal Oxidizer Schematic

To control process emissions, the following 2-stage treatment process will treat all exhaust air from the Facility. The described air treatment will be integral to each process line and emission point:

<u>Stage 1 – Pre-Treatment:</u>

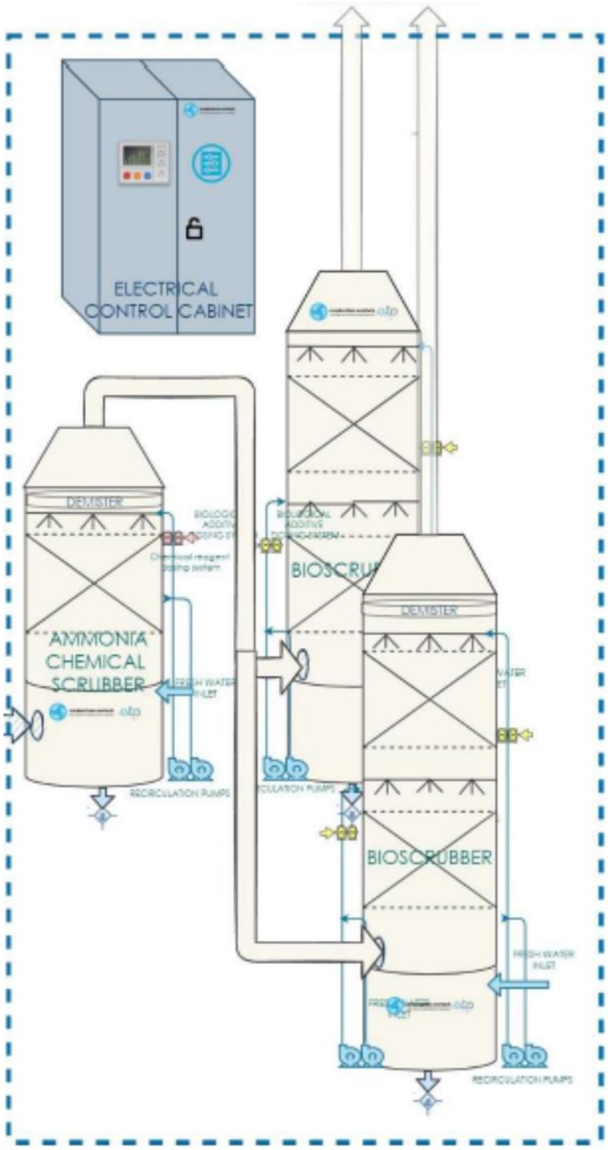
1. Dry cyclones that are integral to the process dryer perform bulk particulate removal (not pictured).
2. Cooling of the air stream with the venturi cyclone. The venturi stage performs pre-treatment conditioning of the air stream with cooling, and fine particulate removal through the strong turbulence created in the throat by high velocity.
3. SO_2 and odor removal with a packed bed wet chemical scrubber. A basic washing occurs in the wet chemical scrubber using an alkaline chemical solution to eliminate SO_2. The air is washed at low speed in a large contact surface for intimate contact with the washing solution. The minimum pH is 7.0 and the minimum washing flow rate is 500 gallons per minute.



Stage 1: Pre-Treatment With Venturi Cyclone and SO_2 Chemical Scrubber

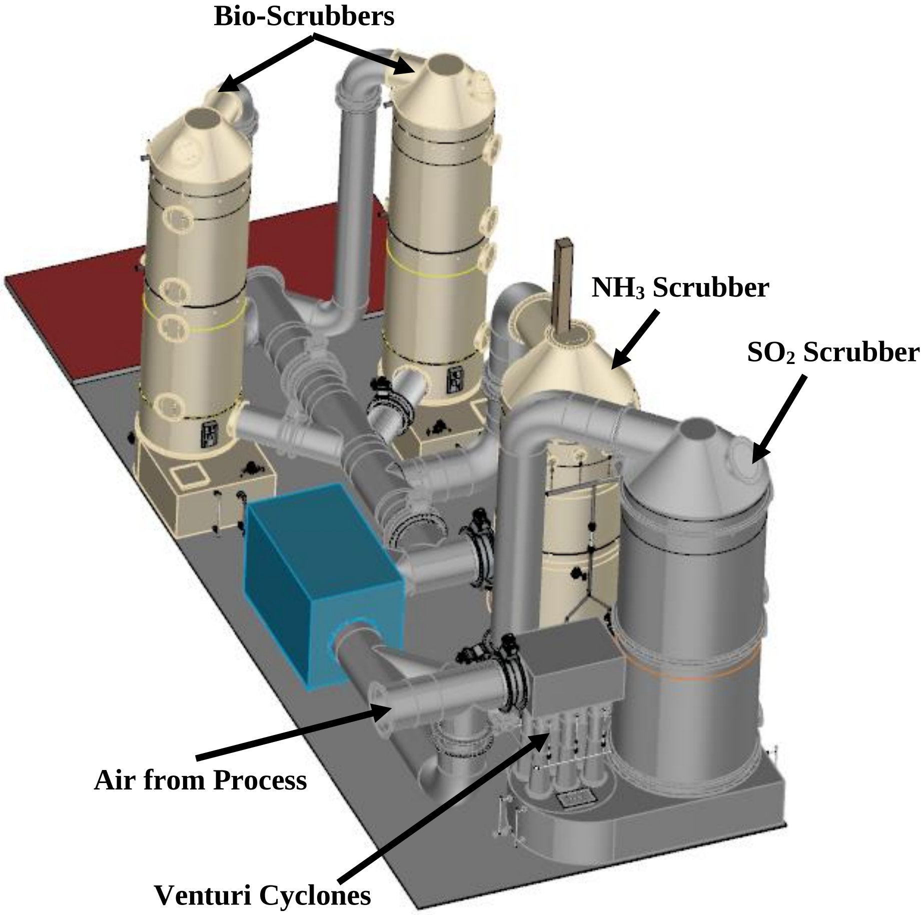
Stage 2 – Main Deodorizing System:

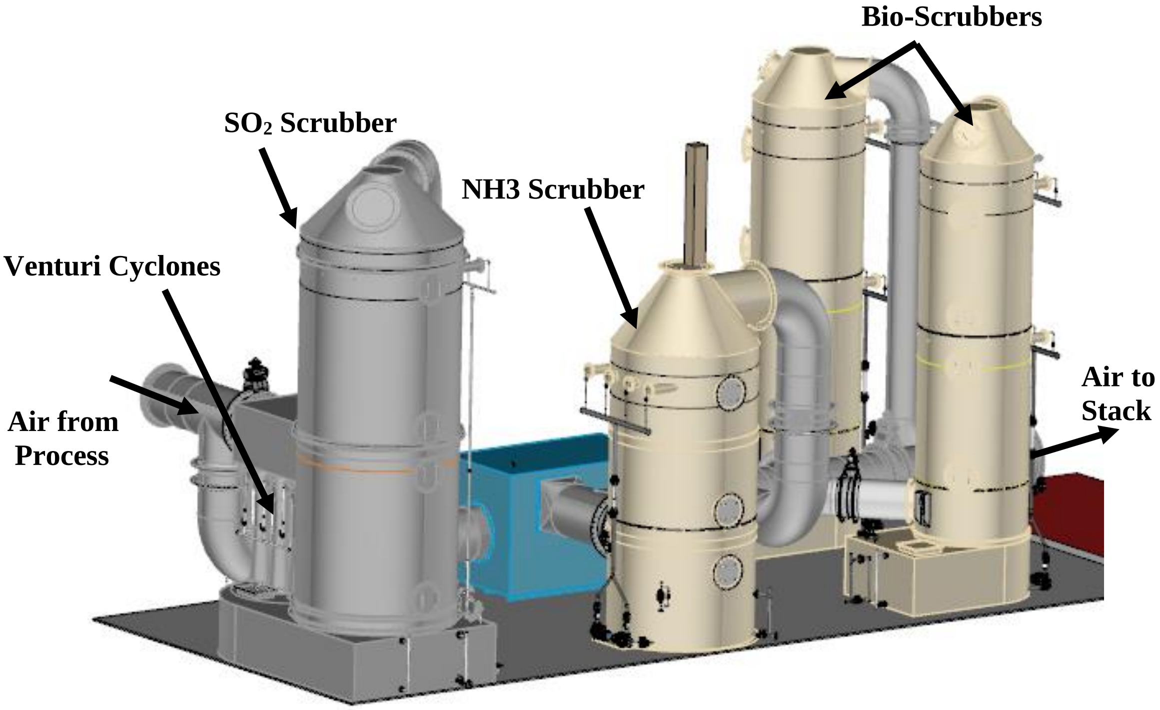
4. Ammonia removal with a packed bed wet chemical scrubber. Ammonia is eliminated in the wet chemical scrubber using an acidic chemical solution with sulfuric acid. The air is washed at a low speed in a large contact surface for intimate contact with the washing solution. The maximum pH is 4.5 and the minimum washing flow rate is 350 gallons per minute.
5. Odor and SO_2 removal with a double-stage bio-scrubber. Two overlapped bio-scrubbing towers will be the last treatment step for odor removal prior to discharge to the atmosphere.



Stage 2: Main Deodorizing System

The air treatment system is shown in the following 3-D renderings and in the Process Flow Diagram in Figure 5.


Bio-Scrubbers
NH_3 Scrubber
SO_2 Scrubber
Air from Process
Venturi Cyclones


Bio-Scrubbers
SO_2 Scrubber
NH3 Scrubber
Venturi Cyclones
Air from Process
Air to Stack

7.0 6 NYCRR PART 201-5.2(b)(4) LISTING OF SIC OR NAICS CODES

Applicable SIC and NAICS codes are included in the Air State Facility Permit Application (Attachment 1) and listed below:

- SIC: 3999 – Manufacturing Industries, Not Elsewhere Classified
- NAICS: 339999 – All Other Miscellaneous Manufacturing

8.0 6 NYCRR PART 201-5.2(b)(8) LIST OF EMITTED REGULATED POLLUTANTS

8.1 Emission Factors and Potential to Emit

Emission Factors are included in Attachment 4 and were provided by the technology provider based on bench scale testing with representative biosolids and using the following assumptions:

- Biosolids at 77% moisture content (23% solids) and 10 wet ton per hour feed rate.
- Wood waste at 40% moisture content (60% solids) and 1 ton per hour feed rate.
- 100% natural gas use in the Pyrolysis Reactor.
- 100% syngas use for the dryer with a heating value of 8,616 BTU/lb.

This is considered the base operational case based on the anticipated and target biosolids solid content of 23%. The Facility will perform frequent moisture content testing of received biosolids to ensure the process stays at or closely around the target solids content.

The Facility will operate up to three identical process lines. Each process line consists of a biosolids dryer, pyrolysis reactor, kiln, and air pollution control devices. Each process line will have an independent emissions stack.

Emissions were calculated as Emission Rate Potential (ERP) and Potential to Emit (PTE) based on the following methodology and assumptions included in Attachment 4.

Emission Rate Potential:

- Facility emissions were assumed to occur 24 hours per day, 365 days per year.
- Facility emissions were assumed to occur with no pollution controls.

Potential to Emit:

- Facility emissions were assumed to occur 24 hours per day, 365 days per year.
- Facility emissions were assumed to occur with full emissions controls.

Based on the calculations provided in Attachment 4, the Facility emissions are expected to be below the Major Source thresholds contained in 6 NYCRR Part 201 at full buildout. The Facility intends to construct and operate one process line prior to constructing and operating the second and third process lines. Once the first process line is operational, stack tests will be performed to verify the actual emission factors to refine the emissions estimates for the second and third process lines.

8.2 AERMOD Dispersion Modeling Protocol

Refined emissions modeling was performed to map the pollutant dispersion plumes in relations to surrounding communities. Modeling was performed in accordance with the following protocol in coordination with NYSDEC.

Air Dispersion Model:

- USEPA AERMOD version 21112 using Lakes Environmental AERMOD View version 11.2.0.

Emission Source:

Table B – AERMOD Emission Point Summary

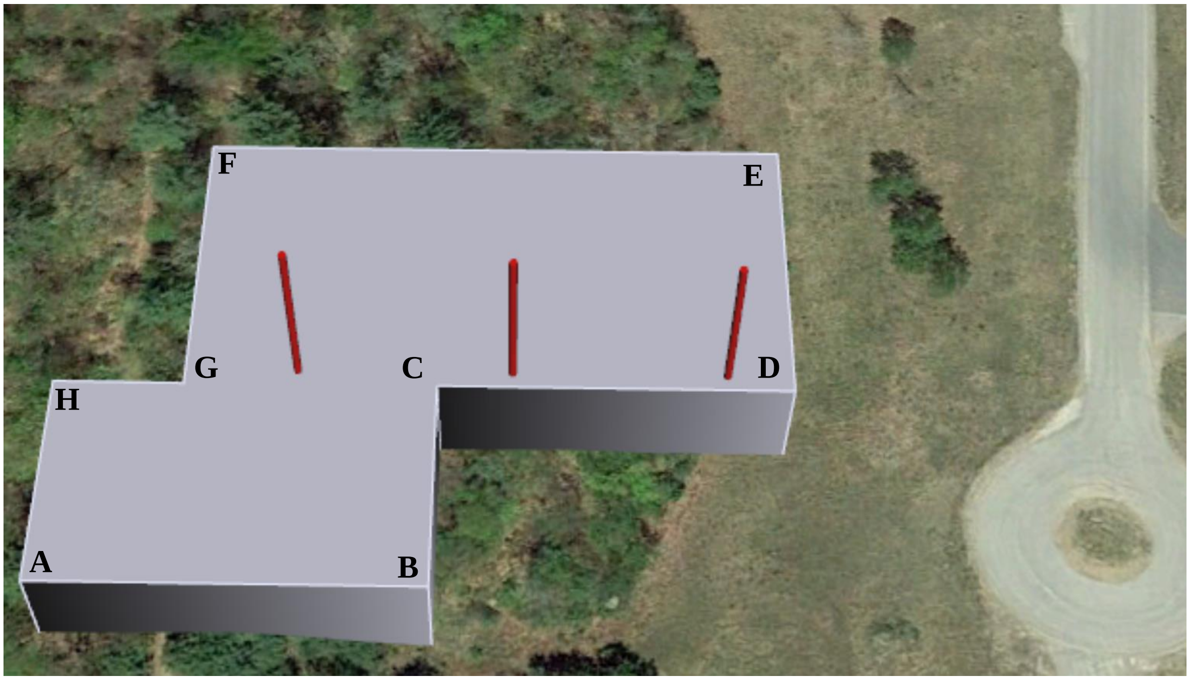
Emission Point	X-Coordinate (m)	Y-Coordinate (m)	Diameter (ft)	Release Height Above Ground (ft)	Gas Exhaust Temperature	Gas Exit Velocity
Stack #1	613155.02	4793191.36	2.75	115	166.1ºF (74.5ºC)	95.8 fps (34,146 acfm)
Stack #2	613181.02	4793191.36	2.75	115	166.1ºF (74.5ºC)	95.8 fps (34,146 acfm)
Stack #3	613207.02	4793191.36	2.75	115	166.1ºF (74.5ºC)	95.8 fps (34,146 acfm)

Building Options:

- Single tier polygonal building at a height of 45.75 ft. See the model schematic below. Building downwash calculations were performed using USEPA Building Profile Input Program (BPIP) to obtain the building downwash zone of influence for use in AERMOD.

Table C – AERMOD Building Profile Dimensions

Segment	Length (ft)	Segment	Length (ft)
A-B	152	E-F	242
B-C	91	F-G	124
C-D	142	G-H	52
D-E	124	H-A	91



Building Schematic and Stack Emission Points for AERMOD Emissions Model

Emission Rate:

- Constant emission rate from three (3) stack emission points using the Potential to Emit (PTE) emission rates in the emission estimate tables included in Attachment 4. Note that the modeled condition conservatively assumed constant emissions occurring 365 days per year with no downtime.

Pollutants:

- Emissions were modeled for the following:
    - Criteria Pollutants: Particulate Matter, Nitrogen Dioxide, Sulfur Dioxide, Carbon Monoxide, and Lead.
    - Non-Criteria Pollutants: Naphthalene, Hydrogen Sulfide, Arsenic, Cadmium, Mercury, Methyl Di/Trisulfides, Ammonia, Methyl/Ethyl Amines, Hydrogen Chloride, Acetic Acid, Perfluorooctanoic Acid (PFOA), and Hydrogen Fluoride.

Receptors:

The model domain extended 10 km from the Facility fence line to the north, south, east, and west. The following receptor spacing was used:

- Fence line receptors along the property line at a 25 m spacing.
- Multi-tier receptor grid spacing at:
    - 70 m grid to 1,000 m from the Facility fence line.
    - 100 m grid from 1,000 m to 2,000 m from the Facility fence line.
    - 250 m grid from 2,000 m to 5,000 m from the Facility fence line.
    - 500 m grid from 5,000 m to 10,000 m from the Facility fence line.

Meteorology:

The following meteorology was used based on the source files provided by NYSDEC.

- Surface File: GFL1721.sfc
- Profile File: GFL1721.pfl
- Data Period: 01/01/2017 to 12/31/2021
- Surface Air Station: No. 14750
- Upper Air Station: No. 54775

Terrain:

AERMAP was used to process terrain elevations for the entire model domain, and elevations were applied to the source stacks and receptor locations.

- Terrain Option: Elevated
- Terrain Data: glens_falls-w.dem USGS DEM file with 1-Degree resolution
- AERMAP: DEM data file processed through AERMAP and applied to source stack emission points and all receptor locations.

8.3 Allowable Emissions Analysis (6 NYCRR 212-2)

Facility emissions are restricted pursuant to the following requirements:

- 6 NYCRR Part 212-2.3(a) Table 3 Degree of Air Cleaning Required for criteria air contaminants (i.e., particulate matter, sulfur dioxide, and nitrogen dioxide)
- 6 NYCRR Part 212-2.3(b) Table 4 Degree of Air Cleaning Required for remaining non-criteria air contaminants.

Emissions are evaluated for the Degree of Air Cleaning Required (6 NYCRR 212-2.3), Ambient Air Quality Standards (6 NYCRR 257), and Annual and Short-term Guideline Concentrations (AGC/SGC) established in NYSDEC Program Policy DAR-1 “Guidelines for the Evaluation and Control of Ambient Air Contaminants under Part 212.”

Model output are summarized in the attached Table 1. Background concentrations are summarized in the attached Table 2. Emission factors are summarized in Attachment 4. A wind rose diagram, summary tables of each model run, and corresponding plume contour plots are included in Attachment 5. The predominant wind direction is from the south-southwest. Each modeled pollutant is described in more detail in the following sections.

8.3.1 Particulate Matter

Particulate Matter is a Criteria Contaminant under the National Ambient Air Quality Standards (NAAQS) of the Clean Air Act. In accordance with DAR-1, particulate matter consisting primarily of nuisance particles is assigned an Environmental Rating of "B" and emissions are restricted by the following:

- The Degree of Air Cleaning Required must limit particulate emissions to less than 0.05 grains per cubic foot of exhaust gas.

- 6 NYCRR 212-2.3(a) Table 3 requires a degree of air cleaning of 90% for an ERP between 10 and 20 lb/hr and an Environmental Rating of B.
- The primary NAAQS for particulate matter (PM-2.5) is an annual mean of 12 µg/m^3 and a 24-hour 98th percentile of 35 µg/m^3.
- The primary NAAQS for particulate matter (PM-10) is a 24-hour mean of 150 µg/m^3.

Model output for PM-2.5 are summarized in the following table:

Table D - PM-2.5 Modeled Maximum Concentrations (µg/m^3)

	24-hour 98th Percentile	**Annual**
AERMOD Output	1.50	0.30
Background	15.70	5.78
Total Concentration	17.20	6.08

- The primary NAAQS for particulate matter (PM-10) is a 24-hour mean of 150 µg/m^3.

Model output for PM-10 are summarized in the following table:

Table E - PM-10 Modeled Maximum Concentrations (µg/m^3)

	24-hour
AERMOD Output	3.53
Background	42.30
Total Concentration	45.83

The modeled PM emission factor was conservatively assumed to be all PM-2.5 for comparison to the PM-2.5 NAAQS and all PM-10 for comparison to the PM-10 NAAQS. The PM concentrations achieve the applicable primary NAAQS. As indicated in Attachment 4, the air pollution control devices provide a control efficiency of 90% for particulate matter. By providing the minimum control efficiency and achieving the NAAQS, the Facility achieves the necessary Degree of Air Cleaning Required. The PM emission rate of 1.82 lb/hr for all particulate matter emissions corresponds to 0.007 grains per cubic foot of exhaust gas, which achieves the Degree of Air Cleaning Required.

8.3.2 Nitrogen Oxides (NOx)

The Facility has potential to emit NOx from the use of natural gas in the carbon manufacturing process and the nitrogen released from biosolids in the pyrolysis reactor. Pyrolysis is a low-emission technology where the generation of NOx varies based on feedstock type and process temperature. Ammonia-rich feedstocks such as municipal sewage sludge (i.e., biosolids), poultry litter, animal manure, etc. impart an inherent benefit to the pyrolysis process for limiting NOx emissions.

Biosolids, like all animal manures, contains ammonia and other nitrogen-laden compounds that are released simultaneously in the pyrolysis reactor and combusted in the combustion chamber. Combusting ammonia and nitrogen-laden compounds together replicates a selective non-catalytic reduction (SNCR) principle, which is commonly used to reduce NOx emissions in conventional power plants and other industries that burn biomass waste, coal, etc. Typically, SNCR reduces NOx emissions by injecting either ammonia or urea to react with the nitrogen oxides to form molecular nitrogen (N_2), carbon dioxide (CO_2), and water (H_2O).

In the Facility’s pyrolysis process, the ammonia and nitrogen-laden compounds present in the biosolids feedstock are released simultaneously in the pyrolysis reactor and pneumatically conveyed into the combustion chamber as a component of the generated syngas. The syngas is combusted at a temperature ranging from 1,650°F to 2,300°F, as required for a SNCR, which reacts any remaining ammonia with the nitrogen oxides formed in the combustion process to further reduce NOx.

The term NOx refers to multiple oxides of nitrogen, including NO_2 (nitrogen dioxide), which is designated as a Criteria Contaminant under the NAAQS of the Clean Air Act, and N_2O (nitrous oxide), which is a greenhouse gas with a carbon dioxide equivalent (CO_2e) of 264 (6 NYCRR Part 496.5). For the purposes of this emissions analysis, all NOx is conservatively assumed to be released as NO_2 for assessing compliance with the NAAQS. Alternatively, for assessing consistency with the Climate Leadership and Community Protection Act (CLCPA), all NOx is conservatively assumed to be released as N_2O (see Section 9.0). In practice, the generated syngas will include a mixture of NO_2, N_2O, and other NOx compounds at varying proportions.

The Facility will employ the use of a multi-stage thermal oxidizer to combust the syngas, which will reduce NOx stack emissions and will be capable of reducing N_2O concentrations by up to 99%. The exact speciation and concentration of NOx compounds in Facility emissions will be determined through a stack test after commencing operation of the first process line.

Nitrogen dioxide is designated as a Criteria Contaminant under the NAAQS of the Clean Air Act. NOx emissions are restricted by the following:

- 6 NYCRR 212-2.3(a) Table 3 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable NAAQS for an ERP between 1 and 10 lb/hr and an Environmental Rating of B.
- The primary NAAQS for nitrogen dioxide is an annual mean of 53 ppb (100 $\mu g/m^3$) and a 1-hour 98th percentile maximum of 100 ppb (188 $\mu g/m^3$).

Model output are summarized in the following table:

Table F - NO_2 Modeled Maximum Concentrations (µg/m^3)

	1-hour 98th Percentile	**Annual (Year 4 Max)**
AERMOD Output	27.15	1.60
Background	61.0	12.70
Total Concentration	88.15	14.30

The modeled concentrations meet the NAAQS. The Facility is employing the use of low-NOx thermal oxidizers that have a control efficiency for NOx based on the construction and operation of the burners. The following design features are included that provide NOx control:

1. Off-Stoichiometric Combustion (i.e., staged combustion) – The thermal oxidizers are multi-staged consisting of a reducing zone, a conditioning zone, and an oxidizing zone. Oxygen is restricted in the reducing zone to maintain a high temperature, destroy N_2O, and limit NOx formation. Excess oxygen is provided in the oxidizing zone to ensure complete oxidation. According to Cooper & Alley[1], staged combustion reduce NOx emissions by 34% compared to single stage combustion.
2. Water Injection – The thermal oxidizers include a conditioning zone where water is injected to the gas stream to lower the temperature prior to the oxidizing stage. According to Cooper & Alley, water injection for temperature control can reduce NOx emissions by 80%.
3. Selective Noncatalytic Reduction (SNR) – While not an intentional design component of the thermal oxidizers, the syngas will contain ammonia, which is commonly used for NOx control by SNR. According to Cooper & Alley, the presence of ammonia, when combusted at temperatures of 900 to 1000°C (1652 to 1832°F), can reduce NOx emissions by 40 to 60% depending on the molar ration of ammonia to NOx. The conditioning and oxidizing zones of the Facility thermal oxidizers will operate at design temperatures of 1,650°F and 1,800°F, respectively; therefore, NOx control through SNR is expected.

The thermal oxidizer designer evaluated the scenario where the syngas is fired in a single chamber thermal oxidizer under oxidizing conditions only. In this scenario, the estimated NOx emission is 153 lb/hr. Therefore, the Facility's multi-chamber thermal oxidizer minimizes NOx formation by 98%. By achieving the NAAQS, the Facility achieves the necessary Degree of Air Cleaning Required.

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[1] Cooper, David C., and F.C. Alley, "Air Pollution Control, A Design Approach", Third Edition, ISBN 1-57766-218-0

8.3.3 Sulfur Dioxide (SO_2)

Sulfur dioxide is designated as a Criteria Contaminant under the NAAQS of the Clean Air Act. In accordance with DAR-1, SO_2 emissions are restricted by the following:

- 6 NYCRR 212-2.3(a) Table 3 requires a degree of air cleaning of 94% for an ERP between 100 and 500 lb/hr and an Environmental Rating of B.
- The primary NAAQS for sulfur dioxide is a 1-hour 99th percentile daily maximum of 75 ppb (195 $\mu g/m^3$).
- The 6 NYCRR Part 257 standard for sulfur dioxide is:
    - 99th percentile of 3-hour average of 0.25 ppm (650 $\mu g/m^3$) and 3-hour maximum average of 0.5 ppm (1,300 $\mu g/m^3$) during a 12 month period.
    - 99th percentile of 24-hour hour average of 0.10 ppm (260 $\mu g/m^3$) and 24-hour maximum average of 0.14 ppm (365 $\mu g/m^3$) during a 12 month period.
    - Annual 24-hour average of 0.03 ppm (80 $\mu g/m^3$) during a 12 month period.

Model output are summarized in the following table:

Table G - SO_2 Modeled Maximum Concentrations ($\mu g/m^3$)

	1-hour 99th Percentile	3-hour	24-hour	Annual (Year 4 Max)
AERMOD Output	39.55	38.56	24.13	2.19
Background	1.57	1.57	1.57	0.157
Total Concentration	41.12	40.13	25.70	2.35

The modeled concentrations meet the NAAQS and 6 NYCRR 257 ambient air quality standards. As indicated in Attachment 4, the air pollution control device provides a control efficiency of 95% for SO_2. By providing the minimum control efficiency and achieving the NAAQS, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.4 Carbon Monoxide (CO)

Carbon Monoxide is designated as a Criteria Contaminant under the NAAQS of the Clean Air Act. In accordance with DAR-1, CO emissions are restricted by the following:

- 6 NYCRR 212-2.3(a) Table 3 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable NAAQS for an ERP between 1 and 10 lb/hr and an Environmental Rating of B.
- The primary NAAQS for carbon monoxide is a 1-hour maximum of 35 ppm (40,000 $\mu g/m^3$) and an 8-hour maximum of 9 ppm (10,000 $\mu g/m^3$).

Model output are summarized in the following table:

Table H – Carbon Monoxide Modeled Maximum Concentrations (µg/m^3)

1-hour	8-hour
19.68	15.27

The maximum 1-hour and 8-hour concentration meet the NAAQS for all process lines. By achieving the NAAQS, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.5 Naphthalene

In accordance with DAR-1, naphthalene is designated as "M" for medium toxicity and is assigned an Environmental Rating of "B". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning of 90% for an ERP exceeding 25 lb/hr and an Environmental Rating of B.
- The AGC is 3.0 µg/m^3.
- The SGC is 7,900.0 µg/m^3.

Model output are summarized in the following table:

Table I - Naphthalene Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
7.04	0.34

The maximum 1-hour concentration meets the SGC, and the maximum annual concentration meets the AGC for all process lines. As indicated in Attachment 4, the air pollution control device provides a control efficiency of 99.5% for naphthalene. By providing the minimum control efficiency and achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.6 Hydrogen Sulfide (H_2S)

In accordance with DAR-1, hydrogen sulfide is designated as "M" for medium toxicity and is assigned an Environmental Rating of "B". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP between 1 and 10 lb/hr and an Environmental Rating of B.
- The 6 NYCRR Part 257 ambient air quality standard for hydrogen sulfide is a 1-hour average of 0.01 ppm (14 µg/m^3) due to the potential to cause odors that unreasonably interfere with the comfortable enjoyment of life and property.
- The AGC is 2.0 µg/m^3. There is no SGC.

Model output are summarized in the following table:

Table J - H_2S Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
1.25	0.06

The maximum 1-hour concentration meets the 6 NYCRR 257 ambient air quality standard, and the maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.7 Arsenic

In accordance with DAR-1, arsenic is designated as "H" for high toxicity and is assigned an Environmental Rating of "A". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP less than 0.1 lb/hr and an Environmental Rating of A.
- The AGC is 2.3×10^{-4} µg/m^3.
- There is no SGC.

Casella has provided representative arsenic data collected from municipalities within Casella's operating footprint. These facilities are representative of those that will generate biosolids ultimately destined for management at the SBS Facility. Average and maximum concentrations for samples collected in 2023 are summarized in the table below.

Table K – Feedstock Arsenic Concentrations

Source Location	Average	Maximum
	mg/kg, ppm	mg/kg, ppm
1	4.6	5.3
2	ND	ND
3	4.36	5.36
4	1.22	1.22
5	ND	ND
6	1.61	1.82
7	ND	ND
8	2.23	2.5
Overall Average or Max	**2.8**	**5.36**

The untreated emission rate was conservatively calculated using the overall maximum concentration and assuming that the entire metal concentration enters the gas stream. This is a conservative assumption because a portion of the metal concentration will remain in the solid phase. The project team reviewed the article included in Attachment 9 (Liaw et al.) from the peer reviewed research journal Energy & Fuels about the release of trace elements, including arsenic, during the fast pyrolysis of biosolids. The article indicated that 40% of the arsenic concentration is retained in the char after pyrolysis at 900°C, which is higher than Facility design pyrolysis temperature of 482°C to 621°C. The emission factor for the untreated emission rate potential is calculated as follows:

$$Arsenic\ Release\ from\ Biosolids = 10\ \frac{mg}{kg}\ on\ dry\ weight\ basis$$

$$Biosolids\ Processing\ Rate = 20{,}000\ \frac{lb}{hr}\ (wet\ weight) = 4{,}600\ \frac{lb}{hr}\ (dry\ weight) = 2{,}086\ \frac{kg}{hr}$$

$$Process\ Line\ Air\ Flow = 34{,}146\ acfm = 58{,}006\ \frac{m^3}{hr}$$

$$Arsenic\ Emission\ Rate\ Potential\ =\ 5.4\ \frac{mg}{kg} \times 2{,}086\ \frac{kg}{hr} \div 58{,}006\frac{m^3}{hr} = 0.193\frac{mg}{m^3}$$

The process equipment and air treatment designers indicate that metals will condense to particulates when the exhaust temperature drops prior to entering the air treatment train. The venturi cyclones and wet scrubbers are estimated to provide at least 99% DRE. The emission factor for the potential to emit is calculated as follows:

$$Arsenic\ Potential\ to\ Emit\ =\ 0.193\frac{mg}{m^3} \times (1 - 0.99) = 0.0019\ \frac{mg}{m^3}$$

Model output are summarized in the following table:

Table L - Arsenic Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
2.4 x 10^{-3}	1.1 x 10^{-4}

The maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentration, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.8 Cadmium

In accordance with DAR-1, cadmium is designated as "H" for high toxicity and is assigned an Environmental Rating of "A". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP less than 0.1 lb/hr and an Environmental Rating of A.
- The AGC is 2.4 x 10^{-4} µg/m^3.
- There is no SGC.

Casella has provided representative cadmium data collected from municipalities within Casella's operating footprint. These facilities are representative of those that will generate biosolids ultimately destined for management at the SBS Facility. Average and maximum concentrations for samples collected in 2023 are summarized in the table below.

Table M – Feedstock Cadmium Concentrations

Source Location	Average	Maximum
	mg/kg, ppm	mg/kg, ppm
1	0.79	1.1
2	0.87	1.0
3	0.88	1.76
4	ND	ND
5	ND	ND
6	1.06	1.22
7	ND	ND
8	2.65	4.5
Overall Average or Max	**1.3**	**4.5**

The untreated emission rate was conservatively calculated using the overall maximum concentration and assuming that the entire metal concentration enters the gas stream. This is a conservative assumption because a portion of the metal concentration will remain in the solid phase. The project team reviewed the article included in Attachment 9 (Liaw et al.) from the peer reviewed research journal Energy & Fuels about the release of trace elements, including cadmium, during the fast pyrolysis of biosolids. The article indicated that 40% of the cadmium concentration is retained in the char after pyrolysis at 900°C, which is higher than Facility design pyrolysis temperature of 482°C to 621°C. The emission factor for the untreated emission rate potential is calculated as follows:

$$Cadmium\ Release\ from\ Biosolids = 4.5\ \frac{mg}{kg}\ on\ dry\ weight\ basis$$

$$Biosolids\ Processing\ Rate = 20{,}000\ \frac{lb}{hr}\ (wet\ weight) = 4{,}600\ \frac{lb}{hr}\ (dry\ weight) = 2{,}086\ \frac{kg}{hr}$$

$$Process\ Line\ Air\ Flow = 34,146\ acfm = 58{,}006\ \frac{m^3}{hr}$$

$$Cadmium\ Emission\ Rate\ Potential\ =\ 5.5\ \frac{mg}{kg} \times 2{,}086\ \frac{kg}{hr} \div 58{,}006 \frac{m^3}{hr} = 0.162 \frac{mg}{m^3}$$

The process equipment and air treatment designers indicate that metals will condense to particulates when the exhaust temperature drops prior to entering the air treatment train. The venturi cyclones and wet scrubbers are estimated to provide at least 99% DRE. The emission factor for the potential to emit is calculated as follows:

$$Cadmium\ Potential\ to\ Emit\ =\ 0.162 \frac{mg}{m^3} \times (1 - 0.99) = 0.0016\ \frac{mg}{m^3}$$

Model output are summarized in the following table:

Table N - Cadmium Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
2.0 x 10^{-3}	1.0 x 10^{-4}

The maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentration, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.9 Lead

Lead is designated as a Criteria Contaminant under the NAAQS of the Clean Air Act. In accordance with DAR-1, lead is designated as "H" for high toxicity and is assigned an Environmental Rating of "A". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning of 90% for an ERP between 0.1 and 1 lb/hr and an Environmental Rating of A.
- The primary NAAQS for lead is a 3-month maximum of 0.15 µg/m^3.
- The AGC is 3.8 x 10^{-2} µg/m^3.
- There is no SGC.

Casella has provided representative lead data collected from municipalities within Casella's operating footprint. These facilities are representative of those that will generate biosolids ultimately destined for management at the SBS Facility. Average and maximum concentrations for samples collected in 2023 are summarized in the table below.

Table O – Feedstock Lead Concentrations

Source Location	Average	Maximum
	mg/kg, ppm	mg/kg, ppm
1	28.2	40
2	9.8	9.8
3	18.38	43.4
4	14	19.3
5	31	33
6	22.3	23
7	36	54
8	25.5	33
Overall Average or Max	**23.1**	**54**

The untreated emission rate was conservatively calculated using the overall maximum concentration and assuming that the entire metal concentration enters the gas stream. This is a conservative assumption because a portion of the metal concentration will remain in the solid phase. The project team reviewed the article included in Attachment 9 (Liaw et al.) from the peer reviewed research journal Energy & Fuels about the release of trace elements, including lead, during the fast pyrolysis of biosolids. The article indicated that 10% of the lead concentration is retained in the char after pyrolysis at 900°C, which is higher than Facility design pyrolysis temperature of 482°C to 621°C. The emission factor for the untreated emission rate potential is calculated as follows:

$$Lead\ Release\ from\ Biosolids = 54\ \frac{mg}{kg}\ on\ dry\ weight\ basis$$

$$Biosolids\ Processing\ Rate = 20{,}000\ \frac{lb}{hr}\ (wet\ weight) = 4{,}600\ \frac{lb}{hr}\ (dry\ weight) = 2{,}086\ \frac{kg}{hr}$$

$$Process\ Line\ Air\ Flow = 34,146\ acfm = 58{,}006\ \frac{m^3}{hr}$$

$$Lead\ Emission\ Rate\ Potential\ =\ 54\ \frac{mg}{kg} \times 2{,}086\ \frac{kg}{hr} \div 58{,}006 \frac{m^3}{hr} = 1.94 \frac{mg}{m^3}$$

The process equipment and air treatment designers indicate that metals will condense to particulates when the exhaust temperature drops prior to entering the air treatment train. The venturi cyclones and wet scrubbers are estimated to provide at least 99% DRE. The emission factor for the potential to emit is calculated as follows:

$$Lead\ Potential\ to\ Emit\ =\ 1.94 \frac{mg}{m^3} \times (1 - 0.99) = 0.019\ \frac{mg}{m^3}$$

Model output are summarized in the following table:

Table P - Lead Modeled Maximum Concentrations (μg/m^3)

1-hour	Month	Annual
0.024	0.002	1.15 x 10^{-3}

The maximum annual concentration meets the AGC for all process lines and the maximum monthly average meets the NAAQS. As indicated in Attachment 4, the air pollution control device provides a control efficiency of 99% for lead. By providing the minimum control efficiency and achieving the Guideline Concentration and NAAQS, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.10 Mercury

In accordance with DAR-1, mercury is designated as "H" for high toxicity and is assigned an Environmental Rating of "A". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP less than 0.1 lb/hr and an Environmental Rating of A.
- The AGC is 0.30 μg/m^3.
- The SGC is 0.60 μg/m^3.

Model output are summarized in the following table:

Table Q - Mercury Modeled Maximum Concentrations (μg/m^3)

1-hour	Annual
0.028	0.0014

The maximum 1-hour concentration meets the SGC, and the maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.11 Methyl Disulfides and Trisulfides

This pollutant category includes dimethyl disulfide (CAS# 624-92-0) and dimethyl trisulfide (CAS# 3658-80-8). Only dimethyl disulfide is listed in DAR-1 with a corresponding AGC and SGC. NYSDEC Air Toxics has reviewed these two compounds and found that they are similar in chemical composition; therefore, the AGC and SGC for dimethyl disulfide can also be used for dimethyl trisulfide. In accordance with DAR-1, dimethyl disulfide is designated as "M" for medium toxicity and is assigned an environmental rating of "B". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP between 1 and 10 lb/hr and an Environmental Rating of B.

- The AGC is 4.8 μg/m^3.
- The SGC is 14.0 μg/m^3.

Model output are summarized in the following table:

Table R - Dimethyl Disulfide & Dimethyl Trisulfide Modeled Maximum Concentrations (μg/m^3)

1-hour	Annual
1.25	0.06

The modeled emission factor was conservatively assumed to be all dimethyl disulfide or all dimethyl trisulfide for comparison to the AGC and SGC. The maximum 1-hour concentration meets the SGC, and the maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.12 Ammonia (NH_3)

In accordance with DAR-1, ammonia is designated as "L" for low toxicity and is assigned an Environmental Rating of "C". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning of 75% for an ERP exceeding 25 lb/hr and an Environmental Rating of C.

- The AGC is 100.0 μg/m^3. There is no SGC.

Model output are summarized in the following table:

Table S - Ammonia Modeled Maximum Concentrations (μg/m^3)

1-hour	Annual
6.17	0.30

The modeled annual concentration meets the AGC for all process lines. As indicated in Attachment 4, the air pollution control device provides a control efficiency of 95.5% for ammonia. By providing the minimum control efficiency and achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.13 Methyl and Ethylamines

The pollutant category includes methylamine, dimethylamine, trimethylamine, ethylamine, diethylamine, and triethylamine. The only compound in the category with a toxicity rating is methylamine, which is designated as “M” for medium toxicity and is assigned an environmental rating of “B”. Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP between 1 and 10 lb/hr and an Environmental Rating of B.

- The AGC and SGC for the individual compounds are summarized in the following table:

Table T – Methyl and Ethylamine AGCs and SGCs

Compound	AGC (μg/m^3)	SGC (μg/m^3)
Methylamine	15.0	1,900
Dimethylamine	22.0	2,800
Trimethylamine	29.0	3,600
Ethylamine	22.0	2,800
Diethylamine	23.0	--
Triethylamine	7.0	2,800

The modeled emission factor for this group of compounds was conservatively assumed to be entirely one compound for comparison to the corresponding AGC and SGC.

Model output are summarized in the following table:

Table U - Methyl and Ethylamines Modeled Maximum Concentrations (μg/m^3)

1-hour	Annual
2.51	0.121

The maximum 1-hour concentration meets the SGC for each compound, and the maximum annual concentration meets the AGC for each compound. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.14 Hydrogen Chloride

In accordance with DAR-1, hydrogen chloride is designated as "M" for medium toxicity and is assigned an Environmental Rating of "B". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP between 0.1 and 1 lb/hr and an Environmental Rating of B.

- The AGC is 20.0 μg/m^3.
- The SGC is 2,100 μg/m^3.

Model output are summarized in the following table:

Table V - Hydrogen Chloride Modeled Maximum Concentrations (μg/m^3)

1-hour	Annual
1.16	0.06

The maximum 1-hour concentration meets the SGC, and the maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.15 Acetic Acid

In accordance with DAR-1, acetic acid does not have a designated toxicity and is assigned an environmental rating of "C". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP between 0.1 and 1 lb/hr and an Environmental Rating of C.

- The AGC is 60.0 μg/m^3.
- The SGC is 3,700 μg/m^3.

Model output are summarized in the following table:

Table W - Acetic Acid Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
0.772	0.037

The maximum 1-hour concentration meets the SGC, and the maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

8.3.16 Perfluorooctanoic Acid (PFOA)

PFAS compounds are known to be present in municipal biosolids. PFAS compounds that may be in the source biosolids will pass through the dryer, will be separated from the solids in the pyrolysis process, and are not expected to be present in the final manufactured Carbon Fertilizer. The current understanding of the fate of PFAS compounds during thermal treatment of biosolids is evolving and is described in the proceedings from the 2021 WEF Residuals and Biosolids Conference[2], which confirmed the removal of between 98.9% and 100% of all PFAS compounds analyzed from the solid phase (i.e., biosolids to biochar) when thermally treated through pyrolysis at 500°C to 700°C. The study analyzed concentrations of 28 PFAS compounds in the source biosolids and in the resulting biochar, oils, and syngas following pyrolysis. 31 PFAS compounds were analyzed in the syngas based on the ability of the analytical method for this media. The results indicated that remaining PFAS compounds after pyrolysis were detected primarily in the syngas. The study supports the conclusion that PFAS compounds are first desorbed from the solids phase (i.e., the biosolids) and then transformed and/or destroyed when in the gas or oil phase, with greater desorption and transformation/destruction occurring at higher pyrolysis temperature.

The findings of the WEF conference proceedings are supported by independent testing performed by SBS during design of the Facility. SBS performed a small-scale thermal treatment test using biosolids from the North Shore Water Reclamation District's Zion Wastewater Treatment Plant located on the north shore of Chicago. The dried biosolids were tested for 21 PFAS compounds prior to thermally treating in a pyrolysis kiln at approximately 450°C for 20 minutes and then testing the resulting biochar. The raw dried biosolids had detections of 15 PFAS compounds, while the small-scale thermal treatment test resulted in the removal of all PFAS compounds to below quantification limits except for PFOS, which was reduced by 72%. A copy of the laboratory analytical results is included in Attachment 6.

The Facility design intends to operate the pyrolysis kiln to achieve a material temperature of 900°F to 1,150°F (482°C to 621°C), which is higher than SBS's small-scale test and within the range evaluated in the WEF conference proceedings. The residence time within the pyrolysis kiln will be a minimum of 20 minutes, which is consistent with the small-scale test. The higher temperature during full-scale operation is expected to result in greater removal of PFAS compounds from the solid phase. As indicated in the WEF conference proceedings, desorbed PFAS compounds are expected to be present in the syngas. The Facility will conduct PFAS testing on produced biochar during startup to confirm the operating temperature and residence time in the pyrolysis kiln results in removal of PFAS compounds from the solid phase. The Facility's objective is to operate at a temperature and residence time that maximizes biochar production and minimizes residual PFAS in the biochar.

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[2] WEF Residuals and Biosolids Conference Proceedings, 2021, Water Environment Federation, "Removal and Transformation of PFAS from Biosolids in a High Temperature Pyrolysis System – A Bench Scale Evaluation."

Casella has provided representative data of per- and polyfluoroalkyl substances (PFAS) collected from municipalities within Casella's operating footprint over the past 4+ years. These facilities are representative of those that will generate biosolids ultimately destined for management at the SBS Facility. Average and maximum concentrations for six PFAS compounds are summarized in the table below:

Table X – Representative PFAS Concentrations in Source Biosolids

	Average Concentrations (ng/g, ppb)					
Year	**PFBS**	**PFOA**	**PFOS**	**PFNA**	**HFPO-DA**	**PFHxS**
2019	0.83	7.8	19.39	--	--	--
2020	2.2	7.76	20.6	1.4	--	<0.35
2021	3.04	6.94	20.04	--	--	--
2022	2.81	4.62	16.41	1.12	--	1.2
2023	2.24	3.42	12.61	1.31	ND	<1.8
Overall Average	**2.22**	**6.11**	**17.81**	**1.28**	**ND**	**1.2**
	Maximum Concentrations (ng/g, ppb)					
Year	**PFBS**	**PFOA**	**PFOS**	**PFNA**	**HFPO-DA**	**PFHxS**
2019	1.9	63	77	--	--	--
2020	2.71	30.6	63	1.4	--	<0.35
2021	4.8	40	48	--	--	--
2022	7.3	38.9	66	2.2	--	1.2
2023	2.24	14.3	48.3	2.54	ND	<1.8
Overall Max	**7.3**	**63**	**77**	**2.54**	**ND**	**1.2**

NOTE: PFBS = Perfluorobutanesulfonic acid
PFOA = Perfluorooctanoic acid
PFOS = Perfluorooctanesulfonic acid
PFNA = Perfluorononanoic acid
HFPO-DA = Hexafluoropropylene oxide-dimer acid
PFHxS = Perfluorohexane sulfonate

Currently only PFOA has an established air guideline concentration, and is therefore used as a surrogate for other PFAS compounds by summing all detected PFAS compounds and assessing the total potential emission as PFOA. Based on the data provided in Table Q, the sum of the maximum concentrations for each PFAS compound results in a total PFAS concentration of 151 parts per billion (ppb), which is assessed as PFOA emissions. The following calculations provide an estimate of an untreated PFOA emission rate for a single process line:

$$PFOA\ Release\ from\ Biosolids = 151\ \frac{ng}{g} = 151\frac{\mu g}{kg}\ on\ dry\ weight\ basis$$

$$Biosolids\ Processing\ Rate = 20{,}000\ \frac{lb}{hr}\ (wet\ weight) = 4{,}600\ \frac{lb}{hr}\ (dry\ weight) = 2{,}086\ \frac{kg}{hr}$$

$$Process\ Line\ Air\ Flow = 34,146\ acfm = 58{,}006\ \frac{m^3}{hr}$$

$$PFOA\ Emission\ Factor = 151\ \frac{\mu g}{kg} \times 2{,}086\ \frac{kg}{hr} \div 58{,}006 \frac{m^3}{hr} = 5.4 \frac{\mu g}{m^3} = 5.4 \times 10^{-3} \frac{mg}{m^3}$$

The SBS Facility will thermally oxidize the syngas for heat recovery at a temperature of 1,650°F to 2,300°F (871°C to 982°C), which has an estimated DRE of 99.99% for PFAS compounds. NYSDEC has indicated that the Facility will be subject to a PFOA emission limit of 0.001 lb/hr per process line. The estimated untreated PFOA emission factor is 5.4 x 10^{-3} mg/m^3 (i.e., 6.95 x 10^{-4} lb/hr) per process line, which is less than the 0.001 lb/hr emission limit. The AERMOD assessment conservatively used the higher emission rate of 0.001 lb/hr per process line to assess potential impacts.

In accordance with DAR-1, the only PFAS compound with an established emission limit is PFOA, which is designated as "H" for high toxicity and is assigned an Environmental Rating of "A". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP less than 0.1 lb/hr and an Environmental Rating of A.

- The AGC is 5.3 x 10^{-3} µg/m^3. There is no SGC.

Model output are summarized in the following table:

Table Y - PFOA Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
0.0097	4.7 x 10^{-4}

The maximum annual concentration meets the AGC for all process lines at the conservative emission rate of 0.001 lb/hr. Actual emissions are expected to be significantly lower due to the 99.99% destruction efficiency provided by the thermal oxidizer. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

The Facility will perform a stack test upon startup to determine the actual emission factor for PFOA to demonstrate compliance with the AGC. If the stack test indicates concentrations of PFOA that do not meet the AGC, the Facility has included space in the floor plan to install carbon treatment.

8.3.17 PFAS Products of Incomplete Combustion

NYSDEC requested supporting information regarding the potential formation of tetrafluoromethane (CF4) and hydrofluoric acid (HF) from the combustion of PFAS compounds. The Facility thermal oxidizer designer, PCC, provided the article included in Attachment 8 (Sheilds, et al.) from the peer reviewed research journal Environmental Science and Technology (ES&T) regarding the thermal destruction of PFAS compounds. The article presents results from pilot-scale thermal treatment of legacy aqueous film forming foam (AFFF) with a total PFAS concentration of 10,008,550 ppb. The pilot-scale test calculated the %DRE for 10 PFAS compounds at temperatures ranging from 810°C to 1,180°C (1,490°F to 2,156°F). 99.99% DRE was achieved for all PFAS compounds at a temperature of 1,090°C (1,994°F), which is below the operating temperature of reducing zone for the thermal oxidizer in the SBS

Facility. The study also tested for volatile products of incomplete combustion (PICs), which found very few PICs at temperatures above 1,090°C (1,994°F).

One of the monitored PICs was CF4, which was not detected above detection limits at all test temperatures. HF was also monitored with concentrations ranging from 227 ppm at 810°C (1,490°F) to 340 ppm at 1,180°C (2,156°F). The Facility's air treatment system designer, Condorchem, confirmed that the hydrated lime scrubber will also provide removal of HF in addition to SO_2 control. Further, review of the USEPA Compilation of Air Emissions Factors (AP-42) Chapter 8.7 for Hydrofluoric Acid indicates that caustic scrubbers can provide a control efficiency of 99%.

The ES&T pilot-scale results are based on a feedstock total PFAS concentration of 10,008,550 ppb with a single-stage combustion unit. The SBS Facility will use a multi-stage thermal oxidizer with temperatures exceeding the pilot-study and with significantly lower PFAS concentrations in the feedstock (i.e., 151 ppb in biosolids versus 10,008,550 ppb in AFFF). Therefore, the SBS facility is expected to achieve the following:

- 99.99% DRE for PFAS compounds.
- No formation of CF4 as a PIC.
- Formation of HF during the complete mineralization of PFAS compounds that will be removed from the exhaust gas by the hydrated lime scrubber.

8.3.18 Hydrofluoric Acid (HF)

As indicated in Section 8.3.17, the HF formation will occur during the complete mineralization of PFAS compounds. The project team reviewed the article (Zhang, et al.) from the peer reviewed research journal Science of the Total Environment about the formation of byproducts during the thermal destruction of PFAS in biosolids. A copy of the article is included as Attachment 10. The article reviews various operating conditions and the influence on the formation of byproducts, including HF, during the pyrolysis of biosolids and the combustion of the resulting syngas. The article found that HF concentrations, as a percentage of initial total PFAS concentration, increased as processing temperatures increased.

An HF emission factor was conservatively estimated assuming 100% of the initial total PFAS concentration is converted to HF. This results in an untreated HF emission factor of 5.4×10^{-3} mg/m^3 (i.e., 6.95×10^{-4} lb/hr) per process line. The air treatment designer estimates that the hydrated lime scrubber will provide at least 85% DRE for HF. NYSDEC has indicated that the Facility will be subject to a PFOA emission limit of 0.001 lb/hr per process line; therefore, the AERMOD assessment conservatively used the 0.001 lb/hr emission limit as the emission rate.

In accordance with DAR-1, HF is designated as "M" for high toxicity and is assigned an Environmental Rating of "B". Emissions are restricted by the following:

- 6 NYCRR 212-2.3(b) Table 4 requires a degree of air cleaning that demonstrates the maximum offsite air concentration is less than the applicable AGC and SGC for an ERP less than 0.1 lb/hr and an Environmental Rating of B.

- The AGC is 7.1×10^{-2} µg/m^3.
- The SGC is 5.6 µg/m^3.

Model output are summarized in the following table:

Table Z - HF Modeled Maximum Concentrations (µg/m^3)

1-hour	Annual
0.0097	4.7 x 10^{-4}

The maximum 1-hour concentration meets the SGC, and the maximum annual concentration meets the AGC for all process lines. By achieving the Guideline Concentrations, the Facility achieves the necessary Degree of Air Cleaning Required.

9.0 CLCPA CONSISTENCY ASSESSMENT

As required by the Climate Leadership and Community Protection Act (CLCPA) and set out in Article 75 of the Environmental Conservation Law (ECL), the NYSDEC must consider whether this project is inconsistent with, or will interfere with, the attainment of the statewide greenhouse gas (GHG) emission limits. The CLCPA includes economy-wide requirements to reduce GHG emissions in New York State by 40% below 1990 levels by 2030 and 85% below 1990 levels by 2050. NYSDEC has promulgated GHG emission limits in 6 NYCRR 496. This assessment has been prepared consistent with NYSDEC Program Policy DAR-21 "The Climate Leadership and Community Protection Act and Air Permit Applications" dated December 14, 2022.

9.1 GHG Emissions

The following table identifies the Facility's potential GHG emissions including calculated carbon dioxide equivalent (CO_2e) using 20-year global warming potentials (GWP20) established in 6 NYCRR Part 496.5.

Table AA – Potential GHG Emissions

Greenhouse Gas	Greenhouse Gas Emission Rate (ton/yr)	Carbon Dioxide Equivalent Multiplier (6 NYCRR 496.5)	20-Year Global Warming Potential CO_2e (ton/yr)
Carbon Dioxide (CO_2)	83,420	1	83,420
Methane (CH_4)	0	84	0
Nitrous Oxide (N_2O)	0.58	264	153
Hydrofluorocarbons	0	NA	0
Perfluorocarbons	0	NA	0
Sulfur Hexafluoride	0	NA	0
Total GWP20 CO2e Emission Rate (ton/yr)			**83,573**

Note: N_2O emissions conservatively assumes 100% of NOx emitted as N_2O with 99% reduction in multi-stage thermal oxidizer.

The upstream out-of-state emissions associated with extraction, production, and transmission of natural gas as the plant's fuel source is summarized in the following table per NYSDEC presumptive values contained in the 2022 NYS Statewide Greenhouse Gas Emissions Report:

Table AB – Potential Upstream GHG Emissions

Greenhouse Gas	Greenhouse Gas Emission Rate (g/mmbtu)	Carbon Dioxide Equivalent Multiplier (6 NYCRR 496.5)	20-Year Global Warming Potential CO2e Emission Rate (g/mmbtu)
Natural Gas			
Carbon Dioxide (CO_2)	12,206	1	12,206
Methane (CH_4)	350	84	29,400
Nitrous Oxide (N_2O)	0.14	264	36.96
Total GWP20 CO2 Equivalent Emission Rate (g/mmbtu)			41,643
Total GWP20 CO2 Equivalent Emission Rate (lb/mmbtu)			91.81
Total GWP20 CO2 Equivalent Emission Rate (ton/mmbtu)			0.0459
Plant Annual Natural Gas Energy Demand			126,776 mmbtu/yr
Total GWP20 CO2e Upstream Emission Rate (ton/yr)			**5,819 ton/yr**

9.2 GHG Emission Reductions

The annual quantity of biosolids requiring management is based on population. The NYSDEC March 2018 Report "Biosolids Management in New York State" indicates that New York State currently generates in excess of 377,000 dry tons of biosolids annually requiring management. It is important to note that the SBS Facility is not going to generate any new or additional biosolids than currently requires management. Instead, the SBS Facility will divert up to 15% of New York State's existing biosolids from current management methods that have larger GHG emission footprints (e.g., landfilling). Currently in New York State, the primary biosolids management method is through landfill disposal, which accounts for 68% of all biosolids generated. By diverting existing biosolids from current management practices, the SBS Facility will not contribute additional GHG emissions associated with biosolids management.

The most appropriate comparison to the projected Facility GHG emissions footprint is to the current practice of landfilling. In respects to landfilling biosolids, a relevant study was performed by the North East Biosolids and Residuals Association (NEBRA) to evaluate GHG emissions from landfill disposal of biosolids generated in Merrimack, NH[3]. The landfill referenced in the study is an advanced landfill that captures methane for generating electricity. In this example, the GHG emissions are accounted for as debits (i.e., emissions) and credits (i.e., offsets) typical of a lifecycle GHG accounting method. The lifecycle landfill GHG emissions are offset by: 1) carbon sequestration credits, and 2) electric generation from methane. This is an exemplary landfill that is suitable for comparison to the SBS Facility with the goal of minimizing the generation and emission of methane, which is a much more potent GHG compared to CO_2. Landfills have significant fugitive emissions from the open working face, and biosolids quickly decompose to create fugitive methane emissions.

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[3] "A Greenhouse Gas Emissions Analysis of Biosolids Management Options for Merrimack, NH", North East Biosolids Residuals Association, Tamworth, NY, April 2008.

The following table represents the GHG emissions from the studied landfill:

Table AC – GHG Emissions from Biosolids Landfill Disposal

Activity	CO_2e (metric tons/year)
Biosolids Transport to Landfill	72
Landfill Operations	7.1
Fugitive Methane Emissions	4,018.2
Gross Total	**4,097.3**
Biosolids, Dry tons/year	1,841
Gross Landfill GHG Emissions, MT CO2e per Dry ton	**2.23**
Carbon Sequestration Credit	-132.3
Electric Generation Credit	-294.79
Net Total	**3,670.21**
Biosolids, Dry tons/year	1,841
Net Landfill GHG Emissions MT CO2e per Dry ton	**1.99**

The gross GHG emissions divides the gross total CO_2e emissions by the total annual biosolids disposal quantity, which results in 2.23 metric tons of CO_2e emissions for each dry ton of landfilled biosolids. GHG emissions can be assessed on a lifecycle basis by accounting for credits from carbon sequestration and electrical energy generation. The net GHG emissions divides the net total CO_2e emissions by the total annual biosolids disposal quantity, which results in 1.99 metric tons of CO_2e emissions for each dry ton of landfilled biosolids.

The gross GHG emissions estimate for the SBS Facility is similarly assessed in the following table.

Table AD - GHG Emissions from SBS Facility

Activity	CO2e/year
Carbon Dioxide Emissions	83,420 US Ton/year
Carbon Dioxide Emissions	75,677 MT/year
Biosolids Transportation (allowance)	2,247 MT/year
Gross Total	77,924
Biosolids, Dry Tons/year	57,463.2
Gross SBS Facility GHG Emissions CO2e (MT) per Dry Ton	**1.36**

Note: Transportation allowance based on Table T on a per dry ton basis and adjusted for the SBS Facility biosolids design quantity.

Dividing the total gross GHG emissions by the annual disposal capacity at the SBS Facility results in 1.36 metric tons of CO_2e emissions for each dry ton of processed biosolids. By comparing the “per ton” gross GHG emissions in Tables T and U, the SBS Facility emits 39% less GHG emissions for each dry ton of biosolids diverted from a landfill. Even comparing the gross GHG emissions from the SBS Facility to the net emissions from the studied landfill results in 31.6% less GHG emissions for each dry ton of diverted biosolids. Therefore, each ton of existing biosolids that is diverted to the SBS Facility directly meets the goals of the CLCPA by reducing overall GHG emissions.

This basic gross GHG emission comparison does not take into account any GHG credits associated with the SBS Facility due to carbon sequestration from land application of the manufactured Carbon Fertilizer or avoided emissions from the manufacturing of synthetic chemical fertilizers that Carbon Fertilizer displaces.

SBS retained the services of EcoEngineers to perform a life cycle analysis (LCA) on the manufactured Carbon Fertilizer to obtain a carbon intensity (CI) to quantify the greenhouse gas (GHG) footprint of the Facility for comparison to baseline disposal methods for biosolids. The LCA was performed using standard practices that are adopted under many carbon crediting programs, and a copy of the report is included in Attachment 7. The Facility has direct GHG emissions associated with feedstock transportation, energy use (i.e., electricity and natural gas), chemical use (i.e., air treatment scrubbers), and final product transportation. The carbon sequestration value of the manufactured Carbon Fertilizer alone exceeds the Facility's direct GHG emissions, yielding a carbon negative GHG footprint. The Facility also directly offsets GHG emissions associated with avoided biosolids disposal and displaced chemical fertilizer production. As indicated in the report, the Facility is expected to result in a gross GHG reduction of 235% and a net GHG reduction of 135% on a life cycle basis after deducting the Facility's direct GHG emissions. As the Facility diverts biosolids from current higher GHG emitting management practices, the net statewide GHG emissions will decrease.

9.3 Alternatives

This Facility is being proposed to meet an existing demand for alternative practices to manage biosolids. Applicable alternatives include the following:

1. No Action: Under this alternative, the proposed Facility is not constructed. Biosolids continue to be managed under current practices, which relies largely on landfilling. This alternative is inconsistent with New York State strategies to reduce GHG emissions associated with landfill disposal of biosolids. Under this alternative, other management practices may grow to achieve the goal of landfill diversion, such as land application and composting. These management practices have negative impacts including uncontrolled odors. In addition, these practices result in the reintroduction of contaminants (e.g., PFAS compounds) into the human food chain since there is no processing of the biosolids for their removal. Biosolids that are directly land applied or used to create compost are documented to have concentrations of PFAS compounds that will continue to bioaccumulate if used in agriculture. The SBS process is documented to remove PFAS from the solid phase in the manufactured Carbon Fertilizer.

   Similarly, under this alternative, less preferred management practices may continue, such as incineration. Currently, approximately 16% of the total biosolids generated in New York State is incinerated. Compared to the SBS Facility, incinerators have higher emissions due to the full combustion of biosolids. The SBS Facility recovers Carbon Fertilizer as a manufactured product. The carbon and nutrient content retained in the Carbon Fertilizer are avoided emissions that are otherwise emitted to the atmosphere if incinerated.

2. Modify the proposed plant equipment: The proposed plant is incorporating state-of-the-art equipment to operate predominantly on syngas generated at the Facility. A small amount of clean burning natural gas is used for the rotary calciner to provide consistent operating conditions to produce Carbon Fertilizer. If new technology becomes available in the future to reduce or

eliminate the use of natural gas, the plant will consider incorporating the technology as part of ongoing maintenance and operational review.

3. Modify the proposed plant size: The proposed capacity is based on a combination of pilot scale testing and the known local and regional biosolids market. These factors have resulted in an optimal design that can be constructed in phases. Following startup of Phase 1, actual GHG emissions will be determined and reviewed prior to receiving NYSDEC approval to construct Phases 2 and 3. This review will include confirming that this CLCPA consistency assessment remains valid.

9.4 Mitigation

In accordance with Section 7(3) of the CLCPA and with DAR-21, actions that are consistent with the CLCPA do not need to evaluate or implement mitigation measures. The LCA in Attachment 7 demonstrates that the SBS Facility will result in a net GHG reduction of 135% compared to landfill disposal, which is currently the predominant biosolids management practice in New York State. In essence, the SBS Facility provides GHG mitigation for the current statewide practice of biosolids landfill disposal. Specifically, the SBS Facility provides the following mitigation measures for reducing statewide GHG emissions associated with biosolids management:

- Bioenergy/Renewable Energy – The biogenic energy available in the biosolids and waste wood feedstock is recovered in the thermal treatment process and used as a fuel source to reduce fossil fuel consumption from natural gas. The heat generated in the thermal treatment process is recovered for use in the drying process, which accounts for 83% of the heat energy needed for the Facility. Recovered heat from the biogenic energy content of the biosolids and wood waste minimizes the fossil fuel energy demand of the Facility.
- Carbon Sequestration – The recovered Carbon Fertilizer represents avoided GHG emissions that are transformed into solid “fixed” carbon that becomes sequestered in soil. The Facility is specifically designed to manufacture a granular Carbon Fertilizer that can be used directly in existing commercially available fertilizer spreading equipment. The carbon sequestration mitigation alone exceeds the Facility’s direct GHG emissions, yielding a carbon negative GHG footprint.

Therefore, SBS Facility is consistent with the CLCPA and supports New York State’s ability to meet the statewide GHG emissions limits.

9.5 DAC Assessment

The Facility is located within the Moreau Industrial Park with no sensitive receptors in close proximity. The following table identifies potentially sensitive receptors within 1.0 mile of the Facility:

Table AE – Potentially Sensitive Receptors

Receptor	Distance (Miles)
Hudson Falls DAC (closest boundary)	0.75
Home of Good Shepherd (assisted living center)	0.5
Fort Hudson Health System (healthcare provider)	0.8

Section 7(3) of the CLCPA states that:

> *"In considering and issuing permits, licenses, and other administrative approvals and decisions, including but not limited to the execution of grants, loans, and contracts, pursuant to article 75 of the environmental conservation law, all state agencies, offices, authorities, and divisions shall not disproportionately burden disadvantaged communities as identified pursuant to subdivision 5 of section 75-0101 of the environmental conservation law. All state agencies, offices, authorities, and divisions shall also prioritize reductions of greenhouse gas emissions and co-pollutants in disadvantaged communities as identified pursuant to such subdivision 5 of section 75-0101 of the environmental conservation law."*

The SBS Facility is located within 0.5 miles of the Fort Edward Village and within 2 miles of the Glens Falls City DACs. The Climate Justice Working Group has identified the following indicators of environmental burdens associated with DACs:

- Land Use and Facilities Associated with Historical Discrimination or Disinvestment
- Potential Pollution Exposures

The Facility itself is not located within a DAC and is sited within the zoned Moreau Industrial Park that was the subject of a Generic Environmental Impact Statement (GEIS) at the park's creation. Therefore, the land use indicator is not relevant, and the potential burden to the DACs from the Facility would be potential pollution exposures. As a stationary Facility, potential pollution exposures for assessment are mobile sources including truck traffic and air emissions from the Facility stacks.

Truck Traffic

All truck traffic for biosolids delivery, wood waste delivery, carbon fertilizer distribution, and service deliveries will access the Facility from Farnan Road within the Moreau Industrial Park and will be restricted to delivery hours of 6:00 AM to 6:00 PM Monday through Saturday. The travel route is the truck route established in the GEIS for the Moreau Industrial Park, as described below:

- Exit Interstate 87 via Exit 17N onto Route 9 north. Right (east) turn onto Route 197 (Reynolds Rd.). Left (north) turn onto Fort Edward Road. Right (east) turn onto Bluebird Road. Right (south) turn onto Farnan Road at the Moreau Industrial Park entrance. Right turn into the Facility entrance.

Trucks will not travel through residential neighborhoods or on Town roads that are not part of the identified, pre-approved truck route for the Moreau Industrial Park. Condition Number 6 of the Town of Moreau Planning Board Site Plan Approval Resolution includes specific requirements related to Facility truck traffic, including that trucks must follow the established truck route from the GEIS. The truck route does not travel into the identified DACs of Fort Edward or Glens Falls; therefore, there is no disproportionate burden on the draft DACs from truck traffic.

Air Emissions

The Facility will discharge process air emissions to the atmosphere from up to three stacks, which is the subject of the Air State Facility Permit Application. Refined emissions modeling was performed using AERMOD to map the pollutant dispersion plumes in relation to the DACs. As indicated in the AERMOD output in Attachment 5, emissions achieve the necessary air standards, quickly dissipate in close proximity to the Facility, and do not result in a disproportionate burden on the DACs.

Section 7(3) of the CLCPA also requires prioritizing reductions of GHG emissions and co-pollutants in DACs. The CLCPA states that “the department shall prioritize measures to maximize **net** reductions of greenhouse gas emissions and co-pollutants in DACs” (emphasis added). Biosolids are currently managed daily throughout New York State with a baseline GHG emission. As the Facility diverts biosolids from current higher GHG emitting management practices, the net statewide GHG emissions will decrease. DACs are identified across New York State; therefore, the net decrease in GHG emissions will have a benefit on the entire State, including draft DACs.

Co-pollutants are defined as HAPs produced by GHG emission sources. The Facility may emit HAPs associated with the generated syngas from the pyrolysis process. Naphthalene is used as a surrogate in the emissions modeling as the primary expected HAP from the syngas. The emission rate for naphthalene is conservatively based on a 99.5% destruction efficiency of the thermal oxidizer; however, the Thermal Oxidizer is expected to achieve a destruction efficiency of 99.99%. As shown in the attached AERMOD output for naphthalene, the ambient air standards are expected to be achieved beyond the facility property line at full buildout with all three process lines operating. The plume dispersion plots show negligible impact on the DACs.

As described in this section, the Facility will not disproportionately impact or burden DACs, and the Facility prioritizes reductions in GHG emissions and co-pollutants. The Facility will include engineered air pollution control devices to mitigate potential impacts from air emissions and no additional mitigation is required. Therefore, the assessment required by Section 7(3) of the CLCPA is complete and the intent of the CLCPA is satisfied.

9.6 CLCPA Consistency

Biosolids management is an essential service that is integral to daily waste management for municipalities across New York State. In December 2022, the New York State Climate Action Council issued its Final Scoping Plan for how to achieve the goals of the CLCPA. Chapter 16 specifically reviews the waste management sector. The Scoping Plan acknowledges that current market conditions and regulations favor the landfilling of biosolids over beneficial reuse. An identified strategy is for the State to support beneficial use of biosolids and renewable biogas. The SBS Facility is directly consistent with this strategy in that the Facility will: 1) divert biosolids from landfill disposal; 2) beneficially use biosolids to manufacture Carbon Fertilizer, 3) use renewable syngas in Facility operations. Further, the SBS Facility is a private merchant facility and does not require municipalities to make capital investments to realize this positive benefit. As soon as the SBS Facility is operational, their contract with an established biosolids hauler will immediately start diverting biosolids from landfills.

Based on the provided information, the proposed plant is consistent with the CLCPA by:

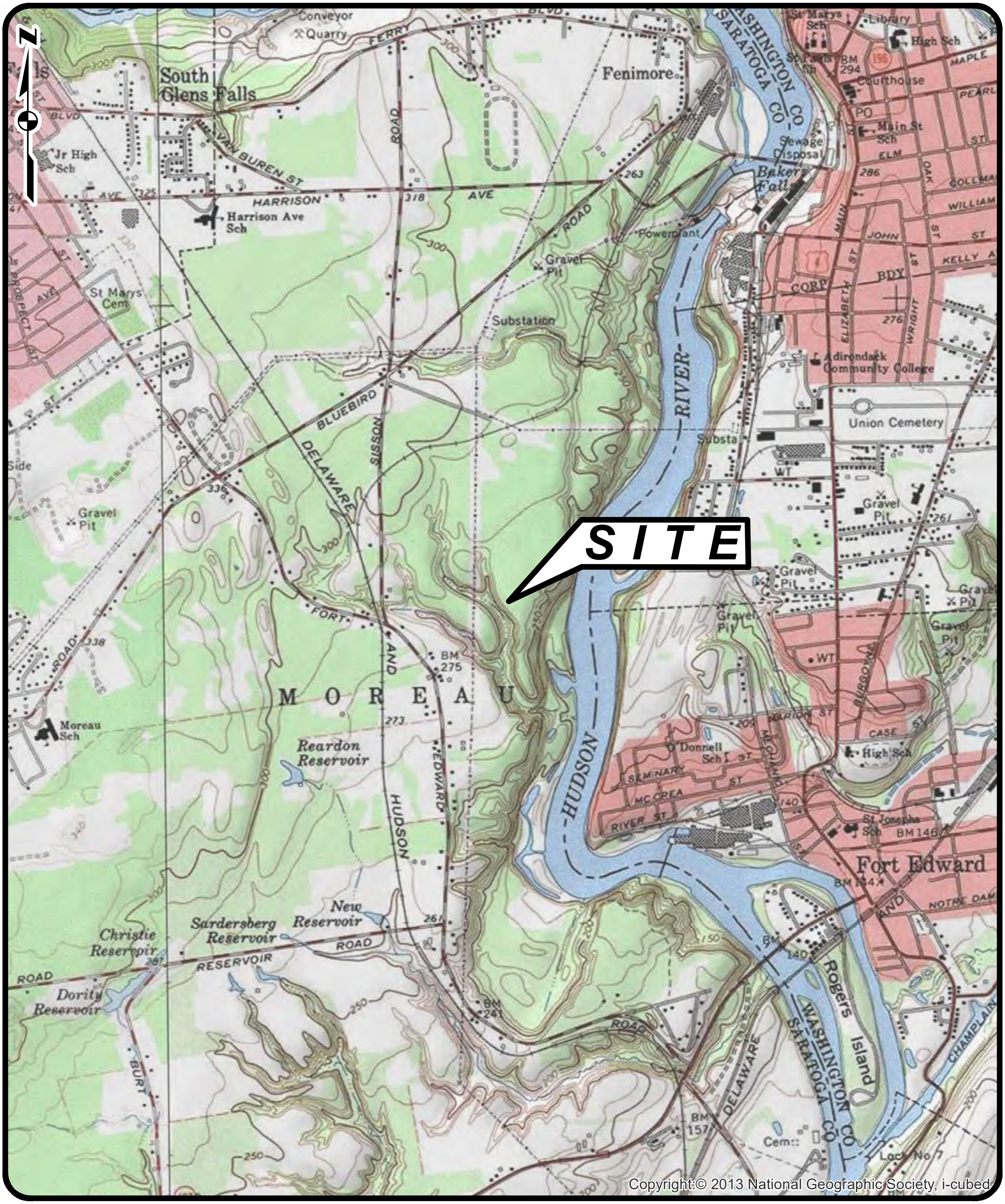
1. Reducing statewide GHG emissions.
2. Reducing biosolids disposal in landfills.
3. Not disproportionately burdening DACs.

10.0 CONCLUSIONS

Based on the emissions assessment described in this narrative and supporting attachments, the proposed Facility is expected to operate in compliance with regulatory emissions restrictions and the CLCPA. The emission factors and assumptions used in the assessment are generally conservative for the full buildout of the proposed Facility. Following startup of the Facility's first process line, a stack test will be performed for compliance verification and to refine emission estimates for future construction of a second and third process line.

FIGURES

S:\Sterling\Projects\2020 Projects\Saratoga Biochar Solutions - 2020-20\Drawings-Maps-Figures\GIS\2020-20001G- FIG 1 SITE LOC MAP.mxd\



STERLING

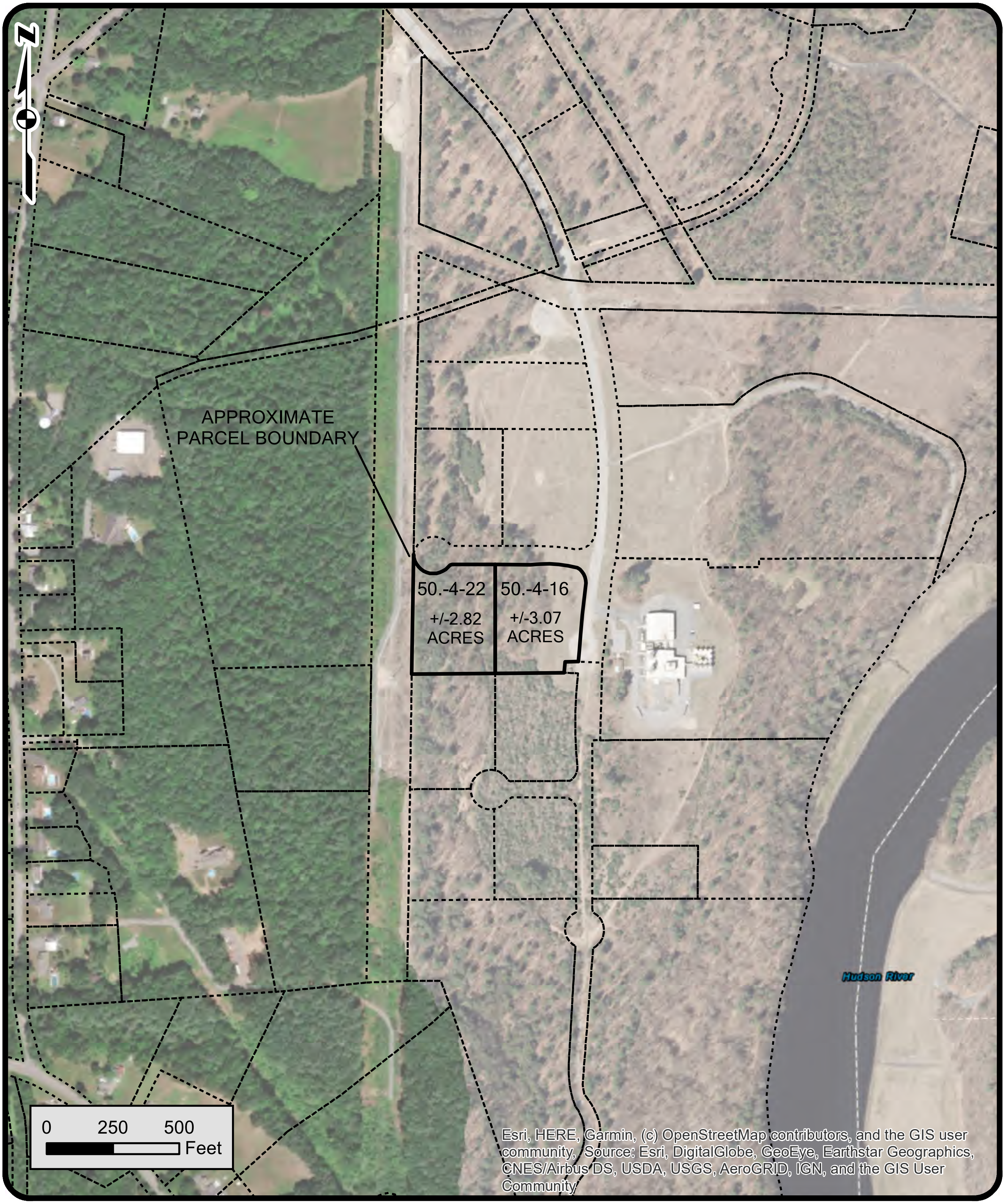
Sterling Environmental Engineering, P.C.
24 Wade Road • Latham, New York 12110

SITE LOCATION MAP
SARATOGA BIOCHAR SOLUTIONS, LLC
CARBON FERTILIZER MANUFACTURING FACILITY

TOWN OF MOREAU SARATOGA CO., NY

PROJ.NO. 2020-20	DATE: 10/25/2021	SCALE: 1 " = 2,000 '	DWG.NO. 2020-20001G	FIGURE 1

S:\Sterling\Projects\2020 Projects\Saratoga Biochar Solutions - 2020-20\Drawings-Maps-Figures\GIS\2020-20003G- FIG 2 SITE LAYOUT.mxd\



Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community, Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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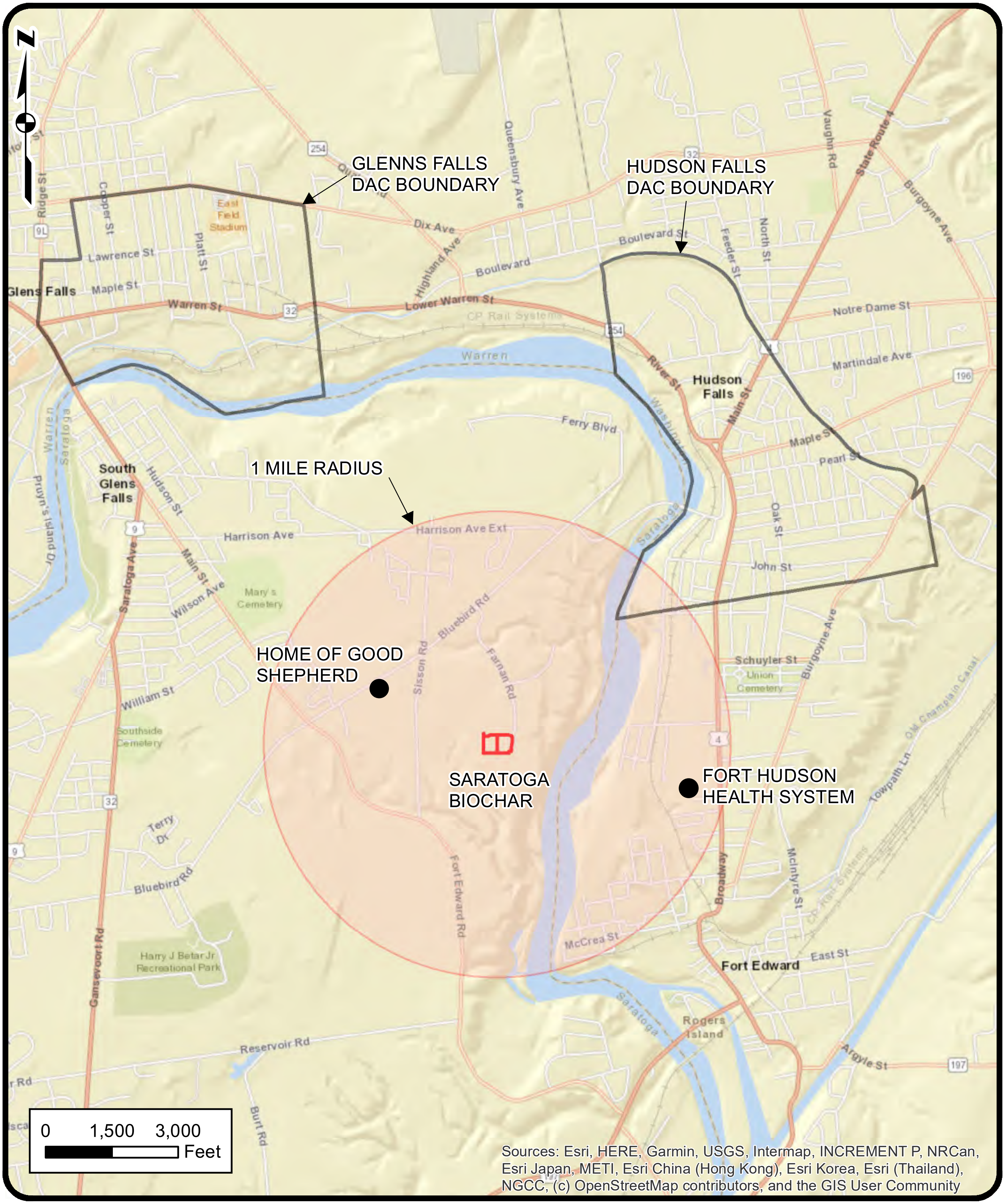
SITE VICINITY MAP
SARATOGA BIOCHAR SOLUTIONS, LLC
CARBON FERTILIZER MANUFACTURING FACILITY

TOWN OF MOREAU
SARATOGA CO., NY

PROJ.NO. 2020-20	DATE: 10/14/2021	SCALE: 1 " = 500 '	DWG.NO. 2020-20003G	FIGURE 2



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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POTENTIALLY SENSITIVE RECEPTORS

SARATOGA BIOCHAR SOLUTIONS, LLC

CARBON FERTILIZER MANUFACTURING FACILITY

TOWN OF MOREAU SARATOGA CO., NY

PROJ.NO. 2020-20	DATE: 5/12/2023	SCALE: 1 " = 3,000 '	DWG.NO. 2020-20005G	FIGURE 3

EMISSION UNIT: U-00SBS
PROCESS ID: CMF (CARBON FERTILIZER MANUFACTURING)

NOTES:

1. THIS DRAWING IS PRELIMINARY AND SUBJECT TO CHANGE UNTIL DRAWINGS ARE "ISSUED FOR CONSTRUCTION" REVISION 0.
2. STREAM PROPERTIES AND COMPOSITIONS ARE SHOWN IN EXCEL FILE THAT ACCOMPANIES THIS DRAWING.

PROCESS FLOW DIAGRAM

REV.	MADE	CHKD.	APPR.	DATE	DESCRIPTION
E	MCG			9/23/22	ADDED THERMAL OXIDIZER HEAT EXCHANGER
D	MCG			8/18/22	ADDED DUCT HEATER REMOVED SECOND SCREENER RENUMBERED STREAMS
C	CMR			3/18/22	REDIRECT EXCESS TO HEAT TO AFTER CYCLONE
G	MCG			5/9/23	REVISED TO MATCH CURRENT LAYOUT
F	MCG			12/15/22	REMOVED DRYER BYPASS AND ADDED QUENCH WATER LINE TO DRYER INLET

BIOSOLIDS SYSTEM
PROCESS FLOW DIAGRAM

ELEMENT CARBON HUDSON VENTURES

FIGURE 4

HPTP PROJECT NO. 7031
CUSTOMER PROJECT NO.

HEYL PATTERSON
CPEG THERMAL PROCESSING

DWG. NO. **7031-2401**
REV. **G**
SCALE 12"=1'–0"
DIV. NO. 24

EMISSION UNIT: U-00SBS
PROCESS ID: CMF (CARBON FERTILIZER MANUFACTURING)

LEGEND	
―	Spent liq. Line
―	Reagents Line
―	Scrubbing liq. Line
―	Industrial Water Line
―	Air Line
―	Hot air
―	Dust Line
⬭	Temperature (°C)
⬡	Pressure (atm)
⋈	Mass Flow Rate (kg/h)

SOURCE NOTE:
PROCESS FLOW DIAGRAM PROVIDED BY CONDORCHEM ENVITECH.

NO.	DATE	RECORD OF WORK	DRN	CKD	APPR

PROJECT	
PROJ. ENGR.:	AMM
PROJ. NO.:	2020-20

0
N.T.S

AIR TREATMENT SYSTEM
PROCESS FLOW DIAGRAM
SARATOGA BIOCHAR SOLUTIONS, LLC
CARBON FERTILIZER MANUFACTURING FACILITY
TOWN OF MOREAU SARATOGA CO., NY

STERLING
Sterling Environmental Engineering, P.C.
24 Wade Road ● Latham, New York 12110

DATE: 10/29/2021	SCALE: N.T.S.	DWG. NO. 2020-20001	FIGURE 5

TABLES

Table 1
AERMOD Calculated Concentrations
Saratoga Biochar Solutions, LLC
Carbon Fertilizer Manufacturing Facility

CAS Number	Pollutant	Averaging Time	Limit ($\mu g/m^3$)	Modeled Concentration ($\mu g/m^3$)	Background Concentration ($\mu g/m^3$)	Total Concentration ($\mu g/m^3$)
NY075-02-5	PM-2.5	Annual	12	0.30	5.78	6.08
		24 Hr 98th Percentile	35	1.50	15.70	17.20
NY075-00-5	PM-10	24 Hr	150	3.53	42.30	45.83
0NY210-00-0	Nitrogen Dioxide	Annual[3]	100	1.60	12.70	14.30
		1 Hr 98th Percentile	188	27.15	61.0	88.15
007446-09-5	Sulfur Dioxide	Annual[3]	80	2.19	0.157	2.35
		24 Hr[2]	365	24.13	1.57	25.70
		24 Hr 99th Percentile[1,2]	260	24.13	1.57	25.70
		3 Hr[2]	1,300	38.56	1.57	40.13
		3 Hr 99th Percentile[1,2]	650	38.56	1.57	40.13
		1 Hr 99th Percentile	195	39.55	1.57	41.12
00630-08-0	Carbon Monoxide	8 Hr	10,000	15.27	--	15.27
		1 Hr	40,000	19.68	--	19.68
00091-20-3	Naphthalene	Annual	3.0	0.34	--	0.34
		1 Hr	7,900	7.04	--	7.04
07783-06-4	Hydrogen Sulfide	Annual	2.0	0.06	--	0.06
		1 Hr	14	1.25	--	1.25
07440-38-2	Arsenic	Annual	2.30E-04	1.10E-04	--	1.10E-04
		1 Hr	--	2.40E-03	--	2.40E-03
07440-43-9	Cadmium	Annual	2.40E-04	1.00E-04	--	1.00E-04
		1 Hr	--	2.00E-03	--	2.00E-03
07439-92-1	Lead	Annual	3.80E-02	1.15E-03	--	1.15E-03
		Month	0.15	0.002	--	0.002
		1 Hr	--	0.024	--	0.024
07439-97-6	Mercury	Annual	0.30	0.0014	--	0.0014
		1 Hr	0.60	0.028	--	0.028
00624-92-0	Dimethyl Disulfide	Annual	4.8	0.06	--	0.06
		1 Hr	14	1.25	--	1.25
3658-80-8	Dimethyl Trisulfide	Annual	4.8	0.06	--	0.06
		1 Hr	14	1.25	--	1.25
07644-41-7	Ammonia	Annual	100	0.30	--	0.30
		1 Hr	--	6.17	--	6.17
00074-89-5	Methylamine	Annual	15	0.121	--	0.12
		1 Hr	1,900	2.51	--	2.51
00124-40-3	Dimethylamine	Annual	22	0.121	--	0.12
		1 Hr	2,800	2.51	--	2.51
00075-50-3	Trimethylamine	Annual	29	0.121	--	0.12
		1 Hr	3,600	2.51	--	2.51
00075-04-7	Ethylamine	Annual	22	0.121	--	0.12
		1 Hr	2,800	2.51	--	2.51
00109-89-7	Diethylamine	Annual	23	0.121	--	0.12
		1 Hr	--	2.51	--	2.51
00121-44-8	Triethylamine	Annual	7.0	0.121	--	0.12
		1 Hr	2,800	2.51	--	2.51
07647-01-0	Hydrogen Chloride	Annual	20	0.06	--	0.06
		1 Hr	2,100	1.16	--	1.16
00064-19-7	Acetic Acid	Annual	60.0	0.037	--	0.04
		1 Hr	3,700	0.772	--	0.772
00335-67-1	PFOA	Annual	5.30E-03	4.70E-04	--	4.70E-04
		1 Hr	--	0.0097	--	0.0097
07664-39-3	Hydrogen Fluoride	Annual	7.10E-02	4.70E-04	--	4.70E-04
		1 Hr	5.6	0.0097	--	0.0097

NOTES:

1. The maximum modeled concentration is also compared to 99th percentile limit.
2. The 1-Hour Background Concentration is applied to this averaging time.
3. Modeled concentration reported as the maximum single year from modeled 5-year period.
4. -- = Not Applicable

Table 2
Calculated Background Concentrations
Saratoga Biochar Solutions, LLC
Carbon Fertilizer Manufacturing Facility

Station ID	Station City	Station State	Parameter	Concentrations (μg/m3)				Background Standard
				2021	2020	2019	Background	
500030004	Bennington	VT	PM2.5 Annual	6.11	5.62	5.62	5.78	Average of the annual concentrations over most recent 3 years
500030004	Bennington	VT	PM2.5 24-HR	15.5	18.0	13.7	15.7	Average of the 98th percentile concentration over most recent 3 years
500210002	Rutland	VT	PM10 24-HR	44	30	53	42.3	Average of highest 24-hr concentrations over most recent 3 years
500210002	Rutland	VT	NO2 Annual	11.2	10.8	12.7	12.7	Highest annual concentration over the most recent 3 years
500210002	Rutland	VT	NO2 1-HR	57.2	59.8	65.9	61.0	Average of the 98th percentile concentation over most recent 3 years
360410005	Piseco Lake	NY	SO2 Annual	0.157	0.079	0.131	0.157	Highest annual concentration over the most recent 3 years
360410005	Piseco Lake	NY	SO2 1-HR	1.57	1.57	1.57	1.57	Average of the 99th percentile concentration over most recent 3 years

NOTES:

1. Background Standards from Table 3 of DAR-10 NYSDEC Guidelines on Dispersion Modeling Procedures for Air Quality Impact Analysis
2. Background data obtained from USEPA Air Quality Systems Annual Summary Data
3. Background data for NO_2 and SO_2 were provided in ppb and converted to ug/m^3.

ATTACHMENT 1

STATE FACILITY AIR PERMIT FORMS

New York State Department of Environmental Conservation
Air Permit Application

DEC ID	Application ID	Application Type
- -	5 - 4 1 4 4 - 0 0 1 8 7 / 0 0 0 0 1	☒ State Facility ☐ Title V

Section I - Certification

Certification

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information required to complete this application, I believe the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

Responsible Official Raymond Apy	Title President
Signature	Date 09/06/2023

Professional Engineer Certification

I certify under penalty of law that I have personally examined, and am familiar with, the statements and information submitted in this document and all its attachments as they pertain to the practice of engineering. I am aware that there are significant penalties for submitting false information, including the possibility of fines and imprisonment for knowing violations.

Professional Engineer Andrew Millspaugh	NYS License No. 094708
Signature	Date 09/06/2023

Section II - Identification Information

Type of Permit Action Requested

☒ New ☐ Renewal ☐ Significant Modification ☐ Administrative Amendment ☐ Minor Modification

☒ Application for the construction of a new facility ☐ Application involves the construction of new emission unit(s)

Facility Information

Name Saratoga Biochar Solutions, LLC	
Location Address 55 Farnan Road	
☐ City / ☒ Town / ☐ Village Moreau	Zip 12828

Owner/Firm Information

Name Saratoga Biochar Solutions, LLC			Business Taxpayer ID 8 4 4 0 8 7 3 0 7
Street Address 26F Congress Street #346			
City Saratoga Springs	State/Province New York	Country USA	Zip 12866

Owner Classification: ☐ Federal ☐ State ☐ Municipal ☒ Corporation/Partnership ☐ Individual

Owner/Firm Contact Information

Name Raymond Apy			Phone 518-391-0566
E-mail Address rapy@northeasternbiochar.com			Fax
Affiliation Saratoga Biochar Solutions, LLC			Title President
Street Address 26F Congress Street #346			
City Saratoga Springs	State/Province New York	Country USA	Zip 12866

Facility Contact Information

Name Raymond Apy			Phone
E-mail Address rapy@northeasternbiochar.com			Fax
Affiliation Saratoga Biochar Solutions, LLC			Title
Street Address 26F Congress Street #346			
City Saratoga Springs	State/Province New York	Country USA	Zip 12866

New York State Department of Environmental Conservation
Air Permit Application

NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

DEC ID
_ - _ _ _ _ - _ _ _ _ _

Project Description ☐ Continuation Sheet(s)

Saratoga Biochar Solutions, LLC (SBS) is proposing to construct and operate a solid waste management facility (SWMF) to manufacture carbon fertilizer from biosolids and wood waste feedstock (hereinafter the "Facility") with an annual throughput up to 235,200 wet tons of received biosolids and up to 35,280 tons of wood waste. The Facility is designed to be constructed in three phases with each phase consisting of a process line capable of processing up to 10 wet tons per hour of biosolids and up to 1.5 tons per hour of wood waste. The Facility will have three stack emission points associated with emissions from each process line. Refer to supporting narrative.

Section III - Facility Information

Facility Classification

☐ Hospital ☐ Residential ☐ Educational/Institutional ☒ Commercial ☐ Industrial ☐ Utility

Affected States (Title V Applications Only)

☐ Vermont ☐ Massachusetts ☐ Rhode Island ☐ Pennsylvania Tribal Land: ____________________

☐ New Hampshire ☐ Connecticut ☐ New Jersey ☐ Ohio Tribal Land: ____________________

SIC Code(s)			NAICS Code(s)			
3999			339999			

Facility Description ☐ Continuation Sheet(s)

The Facility will operate up to three identical process lines. Each process line consists of a biosolids dryer, pyrolysis reactor, thermal oxidizer, and air pollution control devices. The Facility is considered a 1 Emission Unit with 3 stack Emission Points associated with 3 Processes. Each Process is associated with 2 Emission Sources that are subject to a treatment train of 6 Emission Controls prior to discharge to the atmosphere. Refer to supporting narrative.

Compliance Statements (Title V Applications Only)

I certify that as of the date of this application the facility is in compliance with all applicable requirements. ☐ Yes ☐ No

If one or more emission units at the facility are not in compliance with all applicable requirements at the time of signing this application (the 'NO' box must be checked), the noncomplying units must be identified in the "Compliance Plan" block on page 8 of this form along with the compliance plan information required. For all emission units at the facility that are operating <u>in compliance</u> with all applicable requirements, complete the following:

☐ This facility will continue to be operated and maintained in such a manner as to assure compliance for the duration of the permit, except those emission units referenced in the compliance plan portion of this application.

☐ For all emission units subject to any applicable requirements that will become effective during the term of the permit, this facility will meet such requirements on a timely basis.

☐ Compliance certification reports will be submitted at least once per year. Each report will certify compliance status with respect to each applicable requirement, and the method used to determine the status.

Facility Applicable Federal Requirements ☒ Continuation Sheet(s)

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	200.5							
6	NYCRR	200.6							
6	NYCRR	200.7							
6	NYCRR	201	1.2						

Facility State Only Requirements ☒ Continuation Sheet(s)

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	201	1.5						
6	NYCRR	201	1.10	a					
6	NYCRR	201	5						
	ECL	19	0301						

DEC ID
- -

Facility Compliance Certification	☒ Continuation Sheet(s)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	201	7.1						

		CAS Number	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping	0NY210-00-0	Oxides of Nitrogen

Monitoring Information

☐ Work Practice Involving Specific Operations ☐ Ambient Air Monitoring ☒ Record Keeping/Maintenance Procedures

Compliance Activity Description

Facility-wide emissions of Nitrogen Oxides (NOx) shall not exceed 97.5 tons per year as determined by summing monthly NOx emissions during any 12-month period. Records shall be maintained onsite which demonstrate compliance with the NOx cap. These records shall include the mass emissions over each rolling 12 month period. Emissions are calculated by multiplying the tons of biosolids and wood waste processed (tons per month) by the emission factor for NOx (pounds of NOx per ton of material processed). The emission rate will be determined by stack testing.

Work Practice Type Code	Process Material		Reference Test Method
	Code	Description	

Monitored Parameter		Manufacturer's Name/Model Number
Code	Description	
	Oxides of Nitrogen	

Limit		Limit Units	
Upper	Lower	Code	Description
97.5		38	Tons Per Year

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description
17	Annual Rolling Avg	05	Monthly	15	Annually

Facility Emissions Summary	☒ Continuation Sheet(s)

CAS Number	Contaminant Name	Potential to Emit (tons/yr)	Actual Emissions (pounds/yr)
0NY075 - 00 - 5	PM-10	8.40	
0NY750 - 02 - 5	PM-2.5	8.40	
007446 - 09 - 5	Sulfur Dioxide	57.6	
0NY210 - 00 - 0	Oxides of Nitrogen	42.0	
000630 - 08 - 0	Carbon Monoxide	26.8	
007439 - 92 - 1	Lead (elemental)	0.0326	
0NY998 - 00 - 0	Total Volatile Organic Compounds	9.5	
0NY100 - 00 - 0	Total Hazardous Air Pollutants	14.44	
0NY750 - 00 - 0	Carbon Dioxide Equivalents	83,573	
07644-41-7	Ammonia	8.4	
07783-06-4	Hydrogen Sulfide	1.7	
00074-89-5	Methylamine	3.4	
00124-40-3	Dimethylamine	3.4	

DEC ID
- -

Section IV - Emission Unit Information

Emission Unit Description	☐ Continuation Sheet(s)
Emission Unit	U-00SBS

The emission unit consists of the Carbon Manufacturing Facility with an annual throughput up to 235,200 wet tons of received biosolids and up to 35,280 tons of wood waste. The Facility is designed to be constructed in three phases with each phase consisting of a process line capable of processing up to 10 wet tons per hour of biosolids and up to 1.5 tons per hour of wood waste. the Facility is maintained under negative pressure to mitigate potential fugitive odor emissions. All exhaust air is treated through engineered air pollution control devices for particulate, ammonia, sulfur dioxide, and odor control. Refer to supporting narrative.

Building Information ☐ Continuation Sheet(s)

Building ID	Building Name	Length (ft)	Width (ft)	Orientation
1	Carbon Manufacturing Building	272	180	90

Emission Unit Emissions Summary ☒ Continuation Sheet(s)

Emission Unit U-00SBS

CAS Number	Contaminant Name			
NY075-00-0	Particulate Matter			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
169,745	1.92	16,806		
CAS Number	Contaminant Name			
0NY210-00-0	Nitrogen Dioxide			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
84,096	9.60	84,096		
CAS Number	Contaminant Name			
007446-09-5	Sulfur Dioxide			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
2,302,313	13.14	115,116		
CAS Number	Contaminant Name			
00124-38-9	Carbon Dioxide			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
166,839,720	19,046	166,839,720		

DEC ID												
	-					-						

Emission Point Information						☐ Continuation Sheet(s)
Emission Point	SBS01					
Ground Elevation (ft)	Height (ft)	Height Above Structure (ft)	Inside Diameter (in)	Exit Temp. (°F)	Cross Section	
					Length (in)	Width (in)
280	115	65	33	166.1		
Exit Velocity (FPS)	Exit Flow (ACFM)	NYTM (E) (KM)	NYTM (N) (KM)	Building	Distance to Property Line (ft)	Date of Removal
95.8	34,146	613.155	4793.191	1	170	
Emission Point	SBS02					
Ground Elevation (ft)	Height (ft)	Height Above Structure (ft)	Inside Diameter (in)	Exit Temp. (°F)	Cross Section	
					Length (in)	Width (in)
280	115	65	33	166.1		
Exit Velocity (FPS)	Exit Flow (ACFM)	NYTM (E) (KM)	NYTM (N) (KM)	Building	Distance to Property Line (ft)	Date of Removal
95.8	34,146	613.181	4793.191	1	170	
Emission Point	SBS03					
Ground Elevation (ft)	Height (ft)	Height Above Structure (ft)	Inside Diameter (in)	Exit Temp. (°F)	Cross Section	
					Length (in)	Width (in)
280	115	65	33	166.1		
Exit Velocity (FPS)	Exit Flow (ACFM)	NYTM (E) (KM)	NYTM (N) (KM)	Building	Distance to Property Line (ft)	Date of Removal
95.8	34,146	613.207	4793.191	1	160	

Emission Source/Control Information							☒ Continuation Sheet(s)	
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model Number	
ID	Type				Code	Description		
DRY01	I							
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
240	37	Tons Per Day			04	Conveyor	05	Sewage Sludge
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model Number	
ID	Type				Code	Description		
DRY02	I							
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
240	37	Tons Per Day			04	Conveyor	05	Sewage Sludge
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model Number	
ID	Type				Code	Description		
DRY03	I							
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
240	37	Tons Per Day			04	Conveyor	05	Sewage Sludge

New York State Department of Environmental Conservation
Air Permit Application

NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

DEC ID
- -

Process Information ☐ Continuation Sheet(s)

Emission Unit	U-00SBS	Process	CMF

Process Description

Refer to supporting narrative Section 6.0

Source Classification Code (SCC)	Total Throughput		Throughput Quantity Units	
	Quantity/Hr	Quantity/Yr	Code	Description
2399000000	30	235,200	0365	Tons Processed

	Operating Schedule		Building	Floor/Location
☐ Confidential ☐ Operating at Maximum Capacity	Hours/Day	Days/Year		
	24	365	1	1

Emission Point Identifier(s)

SBS01	SBS02	SBS03				

Emission Source/Control Identifier(s)

DRY01,2,3	CONV1,2,3					
CYCL1,2,3	VCYC1,2,3	NH3S1,2,3	SO2S1,2,3	THOX1,2,3	BIOS1,2,3	

Emission Unit	-	Process	

Process Description

Source Classification Code (SCC)	Total Throughput		Throughput Quantity Units	
	Quantity/Hr	Quantity/Yr	Code	Description

	Operating Schedule		Building	Floor/Location
☐ Confidential ☐ Operating at Maximum Capacity	Hours/Day	Days/Year		

Emission Point Identifier(s)

Emission Source/Control Identifier(s)

New York State Department of Environmental Conservation
Air Permit Application

NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

DEC ID
☐ - ☐☐☐☐ - ☐☐☐☐☐

Process Emissions Summary

☐ Continuation Sheet(s)

Emission Unit	☐ - ☐☐☐☐☐				Process	☐☐☐
CAS Number	Contaminant Name	% Thruput	% Capture	% Control	ERP (lbs/hr)	ERP How Determined
Potential to Emit			Standard Units	Potential to Emit How Determined	Actual Emissions	
(lbs/hr)	(lbs/yr)	(standard units)			(lbs/hr)	(lbs/yr)
Emission Unit	☐ - ☐☐☐☐☐				Process	☐☐☐
CAS Number	Contaminant Name	% Thruput	% Capture	% Control	ERP (lbs/hr)	ERP How Determined
Potential to Emit			Standard Units	Potential to Emit How Determined	Actual Emissions	
(lbs/hr)	(lbs/yr)	(standard units)			(lbs/hr)	(lbs/yr)
Emission Unit	☐ - ☐☐☐☐☐				Process	☐☐☐
CAS Number	Contaminant Name	% Thruput	% Capture	% Control	ERP (lbs/hr)	ERP How Determined
Potential to Emit			Standard Units	Potential to Emit How Determined	Actual Emissions	
(lbs/hr)	(lbs/yr)	(standard units)			(lbs/hr)	(lbs/yr)

Emission Source Emissions Summary

☐ Continuation Sheet(s)

Emission Source	☐☐☐☐☐				Process	☐☐☐
CAS Number	Contaminant Name	% Thruput	% Capture	% Control	ERP (lbs/hr)	ERP How Determined
Potential to Emit			Standard Units	Potential to Emit How Determined	Actual Emissions	
(lbs/hr)	(lbs/yr)	(standard units)			(lbs/hr)	(lbs/yr)
Emission Source	☐☐☐☐☐				Process	☐☐☐
CAS Number	Contaminant Name	% Thruput	% Capture	% Control	ERP (lbs/hr)	ERP How Determined
Potential to Emit			Standard Units	Potential to Emit How Determined	Actual Emissions	
(lbs/hr)	(lbs/yr)	(standard units)			(lbs/hr)	(lbs/yr)
Emission Source	☐☐☐☐☐				Process	☐☐☐
CAS Number	Contaminant Name	% Thruput	% Capture	% Control	ERP (lbs/hr)	ERP How Determined
Potential to Emit			Standard Units	Potential to Emit How Determined	Actual Emissions	
(lbs/hr)	(lbs/yr)	(standard units)			(lbs/hr)	(lbs/yr)

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Emission Unit	Emission Point	Process	Emission Source	Emission Unit Applicable Federal Requirements							☐ Continuation Sheet(s)		
				Title	Type	Part	Subpart	Section	Subdiv.	Parag.	Subparag.	Cl.	Subcl.

Emission Unit	Emission Point	Process	Emission Source	Emission Unit State Only Requirements							☐ Continuation Sheet(s)		
				Title	Type	Part	Subpart	Section	Subdiv.	Parag.	Subparag.	Cl.	Subcl.

Emission Unit Compliance Certification

☐ Continuation Sheet(s)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause

☐ Applicable Federal Requirement ☐ State Only Requirement ☐ Capping

Emission Unit	Emission Point	Process	Emission Source	CAS Number	Contaminant Name

Monitoring Information

☐ Continuous Emission Monitoring ☐ Monitoring of a Process or Control Device Parameters as a Surrogate
☐ Intermittent Emission Testing ☐ Work Practice Involving Specific Operations
☐ Ambient Air Monitoring ☐ Record Keeping/Maintenance Procedures

Compliance Activity Description

Work Practice Type Code	Process Material		Reference Test Method
	Code	Description	

Monitored Parameter		Manufacturer's Name/Model Number
Code	Description	

Limit		Limit Units	
Upper	Lower	Code	Description

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description

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Determination of Non-Applicability (Title V Applications Only)

☐ Continuation Sheet(s)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause

Emission Unit	Emission Point	Process	Emission Source	
				☐ Applicable Federal Requirement ☐ State Only Requirement

Non-Applicability Description

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause

Emission Unit	Emission Point	Process	Emission Source	
				☐ Applicable Federal Requirement ☐ State Only Requirement

Non- Applicability Description

Compliance Plan

☐ Continuation Sheet(s)

For any emission units which are <u>not in compliance</u> at the time of permit application, the applicant shall complete the following:

Consent Order		Certified progress reports are to be submitted every 6 months beginning / /

Emission Unit	Process	Emission Source	Applicable Federal Requirement									
			Title	Type	Part	Subpart	Section	Subdiv.	Parag.	Subparag.	Clause	Subcl.

Remedial Measures and Intermediate Milestones	R/I	Date Scheduled

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Request for Emission Reduction Credits

☐ Continuation Sheet(s)

Emission Source	☐☐☐☐☐

Emission Reduction Description

Contaminant Emission Reduction Data

		Reduction	
Baseline Period ____ /____ /________ to ____ / ____ / ________		Date	Method
CAS Number	Contaminant Name	ERC (lbs/yr)	
		Netting	Offset

Facility to Use Future Reduction

Name	Application ID ☐ - ☐☐☐☐ - ☐☐☐☐☐ / ☐☐☐☐☐	
Location Address		
☐ City/ ☐ Town / ☐ Village	State	Zip

Use of Emission Reduction Credits

☐ Continuation Sheet(s)

Emission Source	☐☐☐☐☐

Proposed Project Description

Contaminant Emissions Increase Data

CAS Number	Contaminant Name	Project Emission Potential (lbs/yr)

Statement of Compliance

☐ All facilities under the ownership of this "owner/firm" are operating in compliance with all applicable requirements and state regulations including any compliance certification requirements under Section 114(a)(3) of the Clean Air Act Amendments of 1990, or are meeting the schedule of a consent order.

Source of Emission Reduction Credit - Facility

Name	Permit ID ☐ - ☐☐☐☐ - ☐☐☐☐☐ / ☐☐☐☐☐	
Location Address		
☐ City/ ☐ Town / ☐ Village	State	Zip

Emission Source	CAS Number	Contaminant Name	ERC (lbs/yr)	
			Netting	Offset

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Supporting Documentation and Attachments

Required Supporting Documentation	Date of Document
☐ List of Exempt Activities (attach form)	
☒ Plot Plan	5/15/23
☒ Process Flow Diagram	5/15/23
☐ Methods Used to Determine Compliance (attach form)	
☒ Emissions Calculations	9/06/23
Optional Supporting Documentation	**Date of Document**
☒ Air Quality Model	9/06/23
☐ Confidentiality Justification	
☐ Ambient Air Quality Monitoring Plan or Reports	
☐ Stack Test Protocol	
☐ Stack Test Report	
☐ Continuous Emissions Monitoring Plan	
☐ Lowest Achievable Emission Rate (LAER) Demonstration	
☐ Best Available Control Technology (BACT) Demonstration	
☐ Reasonably Available Control Technology (RACT) Demonstration	
☐ Toxic Impact Assessment (TIA)	
☐ Environmental Rating Demonstration	
☐ Operational Flexibility Protocol/Description of Alternate Operating Scenarios	
☐ Title IV Permit Application	
☐ Emission Reduction Credit (ERC) Quantification (attach form)	
☐ Baseline Period Demonstration	
☐ Use of Emission Reduction Credits (attach form)	
☐ Analysis of Contemporaneous Emissions Increase/Decrease	
Other Supporting Documentation	**Date of Document**

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Section III - Facility Information

Facility Applicable Federal Requirements (continuation)									
Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	201	1.7						
6	NYCRR	201	1.8						
6	NYCRR	201	3.2	a					
6	NYCRR	201	3.3	a					
6	NYCRR	202	1.1						
6	NYCRR	215.2							
	ECL	19	0305						
40	CFR	70.6	b						
6	NYCRR	201	7.1						

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Section III - Facility Information

Facility State Only Requirements (continuation)									
Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	201	1.4						
6	NYCRR	201	5						
6	NYCRR	201	5.2	c					
6	NYCRR	201	5.3	c					
6	NYCRR	211.1							
6	NYCRR	212	2.4	b					
6	NYCRR	212	2.1	a					

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	202	1						

☒ Applicable Federal Requirement
☐ State Only Requirement

☐ Capping

CAS No.	Contaminant Name

Monitoring Information

☐ Continuous Emission Monitoring
☐ Intermittent Emission Testing
☐ Ambient Air Monitoring
☐ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Work Practice Involving Specific Operations
☒ Record Keeping/Maintenance Procedures

Description

CAS no: 007439-92-1 Lead; 007440-43-9 Cadmium; 007439-97-6 Mercury

Stack test to establish emission rate.

Work Practice Type	Process Material Code	Process Material Description	Reference Test Method
			Method 29

Parameter Code	Parameter Description	Manufacturer Name/Model No.

Limit Upper	Limit Lower	Limit Units Code	Limit Units Description
0.001		3	Pounds Per Hour

Averaging Method Code	Averaging Method Description	Monitoring Frequency Code	Monitoring Frequency Description	Reporting Requirements Code	Reporting Requirements Description
21	Arithmetic	14	As Required	01	Per Monitoring Event

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	202	1						

		CAS No.	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping	000335-67-1	PFOA

Monitoring Information

☐ Continuous Emission Monitoring
☐ Intermittent Emission Testing
☐ Ambient Air Monitoring
☐ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Work Practice Involving Specific Operations
☒ Record Keeping/Maintenance Procedures

Description

Stack test to establish emission rate.

Work Practice Type	Process Material Code	Process Material Description	Reference Test Method
			PFAS

Parameter Code	Parameter Description	Manufacturer Name/Model No.

Limit Upper	Limit Lower	Limit Units Code	Limit Units Description
0.001		3	Pounds Per Hour

Averaging Method Code	Averaging Method Description	Monitoring Frequency Code	Monitoring Frequency Description	Reporting Requirements Code	Reporting Requirements Description
21	Arithmetic	14	As Required	01	Per Monitoring Event

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	202	1						

		CAS No.	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping		

Monitoring Information

☐ Continuous Emission Monitoring
☐ Intermittent Emission Testing
☐ Ambient Air Monitoring
☐ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Work Practice Involving Specific Operations
☒ Record Keeping/Maintenance Procedures

Description

CAS No: 000630-08-0 Carbon Monoxide; 007446-09-5 Sulfur Dioxide; 0NY998-00-0 VOC; 0NY210-00-0 Oxides of Nitrogen.

Stack test to establish emission rate.

Work Practice	Process Material		Reference Test Method
Type	Code	Description	

Parameter		Manufacturer Name/Model No.
Code	Description	

Limit		Limit Units	
Upper	Lower	Code	Description
		3	Pounds Per Hour

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description
21	Arithmetic	14	As Required	01	Per Monitoring Event

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	212	1.6	a					

		CAS No.	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping		Opacity

Monitoring Information

☐ Continuous Emission Monitoring
☐ Intermittent Emission Testing
☐ Ambient Air Monitoring
☐ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Work Practice Involving Specific Operations
☒ Record Keeping/Maintenance Procedures

Description

Record keeping to demonstrate compliance with requirement for emissions to have an average opacity less than 20% during any 6 consecutive minutes.

Work Practice	Process Material		Reference Test Method
Type	Code	Description	
			Method 9

Parameter		Manufacturer Name/Model No.
Code	Description	

Limit		Limit Units	
Upper	Lower	Code	Description
20		136	Percent

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description
44	6-Minute Average	14	As Required	10	Upon Request

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	212	1.7	b					

		CAS No.	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping	007664-41-7	Ammonia

Monitoring Information

☐ Continuous Emission Monitoring	☒ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Intermittent Emission Testing	☐ Work Practice Involving Specific Operations
☐ Ambient Air Monitoring	☐ Record Keeping/Maintenance Procedures

Description

Scrubber pH will be monitored and recorded on a continuous basis. Scrubber pH must be maintained at or below the maximum value established during the most recent stack test. If there has been no stack test, the maximum pH will be the manufacturer's recommended maximum of 4.5.

Scrubber water recirculation flow will be monitored and recorded on a continuous basis. Scrubber recirculation flow must be maintained at or above the minimum level established during the most recent stack test. If there has been no stack test, the minimum flow will be the manufacturer's recommended minimum of 350 gallons per minute.

Work Practice	Process Material		Reference Test Method
Type	Code	Description	

Parameter		Manufacturer Name/Model No.
Code	Description	

Limit		Limit Units	
Upper	Lower	Code	Description

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description
47	3-Hour Average	14	As Required	10	Upon Request

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	212	1.7	b					

		CAS No.	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping	007446-09-5	Sulfur Dioxide

Monitoring Information

☐ Continuous Emission Monitoring
☐ Intermittent Emission Testing
☐ Ambient Air Monitoring
☒ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Work Practice Involving Specific Operations
☐ Record Keeping/Maintenance Procedures

Description

Scrubber pH will be monitored and recorded on a continuous basis. Scrubber pH must be maintained at or above the minimum value established during the most recent stack test. If there has been no stack test, the minimum pH will be the manufacturer's recommended minimum of 7.0.

Scrubber water recirculation flow will be monitored and recorded on a continuous basis. Scrubber recirculation flow must be maintained at or above the minimum level established during the most recent stack test. If there has been no stack test, the minimum flow will be the manufacturer's recommended minimum of 500 gallons per minute.

Work Practice	Process Material		Reference Test Method
Type	Code	Description	

Parameter		Manufacturer Name/Model No.
Code	Description	

Limit		Limit Units	
Upper	Lower	Code	Description

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description
47	3-Hour Average	14	As Required	10	Upon Request

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	212	1.7	b					

☒ Applicable Federal Requirement
☐ State Only Requirement
☐ Capping

CAS No.	Contaminant Name

Monitoring Information

☐ Continuous Emission Monitoring	☒ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Intermittent Emission Testing	☐ Work Practice Involving Specific Operations
☐ Ambient Air Monitoring	☐ Record Keeping/Maintenance Procedures

Description

The thermal oxidizers will be monitored and recorded on a continuous basis whenever the process equipment is operating. Chamber temperature must be maintained at or above the minimum temperature established during the most recent stack test. If there has been no stack test, the minimum temperature will be the manufacturer's recommended minimum of 1650 degrees fahrenheit.

Work Practice	Process Material		Reference Test Method
Type	Code	Description	

Parameter		Manufacturer Name/Model No.
Code	Description	

Limit		Limit Units	
Upper	Lower	Code	Description
	1650	44	Degrees Fahrenheit

Averaging Method		Monitoring Frequency		Reporting Requirements	
Code	Description	Code	Description	Code	Description
47	3-Hour Average	14	As Required	10	Upon Request

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Section III - Facility Information

Facility Compliance Certification (continuation)

Rule Citation

Title	Type	Part	Subpart	Section	Subdivision	Paragraph	Subparagraph	Clause	Subclause
6	NYCRR	212	2.4	b					

		CAS No.	Contaminant Name
☒ Applicable Federal Requirement ☐ State Only Requirement	☐ Capping	0NY075-00-0	Particulates

Monitoring Information

☐ Continuous Emission Monitoring
☒ Intermittent Emission Testing
☐ Ambient Air Monitoring
☐ Monitoring of Process or Control Device Parameters as a Surrogate
☐ Work Practice Involving Specific Operations
☐ Record Keeping/Maintenance Procedures

Description

Intermittent emission testing to demonstrate compliance with particulate limit of 0.050 grains per cubic foot of exhaust gas.

Work Practice Type	Process Material Code	Process Material Description	Reference Test Method
			Method 5

Parameter Code	Parameter Description	Manufacturer Name/Model No.

Limit Upper	Limit Lower	Limit Units Code	Limit Units Description
0.05		12	Grains per DSCF

Averaging Method Code	Averaging Method Description	Monitoring Frequency Code	Monitoring Frequency Description	Reporting Requirements Code	Reporting Requirements Description
08	1-Hour Average	10	Upon Request	10	Upon Request

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Section III - Facility Information

Facility Emissions Summary (continuation)

CAS No.	Contaminant Name	Potential to Emit		Actual Emissions (lbs/yr)
		(lbs/yr)	Range	
00075-50-3	Trimethylamine	6,723		
00075-04-7	Ethylamine	6,723		
00109-89-7	Diethylamine	6,723		
00121-44-8	Triethylamine	6,723		
07647-01-0	Hydrogen Chloride	3,025		
00064-19-7	Acetic Acid	2,017		
00624-92-0	Dimethyl Disulfide	3,361		
3658-80-8	Dimethyl Trisulfide	3,361		
00091-20-3	Naphthalene	19,092		
07439-97-6	Mercury	76		
00335-67-1	PFOA	0.00183		
07440-38-2	Arsenic	0.00074		
07440-43-9	Cadmium	0.00062		
07664-39-3	Hydrogen Fluoride	0.00183		

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Section IV - Emission Unit Information

Emission Source/Control (continuation)

Emission Unit U - 0 0 S B S

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
CONV1	I							
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
240	37	Tons Per Day			04	Conveyor	05	Sewage Sludge
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
CONV2	I							
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
240	37	Tons Per Day			04	Conveyor	05	Sewage Sludge
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
CONV2	I							
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
240	37	Tons Per Day			04	Conveyor	05	Sewage Sludge
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
CYLC1	K				075	Cyclone		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
CYCL2	K				075	Cyclone		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
CYCL3	K				075	Cyclone		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						

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Section IV - Emission Unit Information

Emission Source/Control (continuation)

Emission Unit U-00SBS

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.
ID	Type				Code	Description	
VCYC1	K				111	Venturi	

Design Capacity	Design Capacity Units		Waste Feed		Waste Type	
	Code	Description	Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute				

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.
ID	Type				Code	Description	
VCYC2	K				111	Venturi	

Design Capacity	Design Capacity Units		Waste Feed		Waste Type	
	Code	Description	Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute				

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.
ID	Type				Code	Description	
VCYC3	K				111	Venturi	

Design Capacity	Design Capacity Units		Waste Feed		Waste Type	
	Code	Description	Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute				

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.
ID	Type				Code	Description	
NH3S1	K				001	Wet Scrubber	

Design Capacity	Design Capacity Units		Waste Feed		Waste Type	
	Code	Description	Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute				

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.
ID	Type				Code	Description	
NH3S2	K				001	Wet Scrubber	

Design Capacity	Design Capacity Units		Waste Feed		Waste Type	
	Code	Description	Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute				

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.
ID	Type				Code	Description	
NH3S3	K				001	Wet Scrubber	

Design Capacity	Design Capacity Units		Waste Feed		Waste Type	
	Code	Description	Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute				

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Section IV - Emission Unit Information

Emission Source/Control (continuation)

Emission Unit: U-00SBS

Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
SO2S1	K				001	Wet Scrubber		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
SO2S2	K				001	Wet Scrubber		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
SO2S3	K				001	Wet Scrubber		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
THOX1	K				127	Thermal Oxidizer		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
THOX2	K				127	Thermal Oxidizer		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						
Emission Source		Date of Construction	Date of Operation	Date of Removal	Control Type		Manufacturer's Name/Model No.	
ID	Type				Code	Description		
THOX3	K				127	Thermal Oxidizer		
Design Capacity	Design Capacity Units				Waste Feed		Waste Type	
	Code	Description			Code	Description	Code	Description
34,146	39	Cubic Feet Per Minute						

Continuation Sheet 14 of 18

New York State Department of Environmental Conservation
Air Permit Application Form

NEW YORK STATE OF OPPORTUNITY | Department of Environmental Conservation

DEC ID
_ - _ _ _ _ - _ _ _ _ _

Section IV - Emission Unit Information

Emission Source/Control (continuation)

Emission Unit: U-00SBS

Emission Source ID	Emission Source Type	Date of Construction	Date of Operation	Date of Removal	Control Type Code	Control Type Description	Manufacturer's Name/Model No.
BIOS1	K				001	Wet Scrubber	

Design Capacity	Design Capacity Units Code	Design Capacity Units Description	Waste Feed Code	Waste Feed Description	Waste Type Code	Waste Type Description
34,146	39	Cubic Feet Per Minute				

Emission Source ID	Emission Source Type	Date of Construction	Date of Operation	Date of Removal	Control Type Code	Control Type Description	Manufacturer's Name/Model No.
BIOS2	K				001	Wet Scrubber	

Design Capacity	Design Capacity Units Code	Design Capacity Units Description	Waste Feed Code	Waste Feed Description	Waste Type Code	Waste Type Description
34,146	39	Cubic Feet Per Minute				

Emission Source ID	Emission Source Type	Date of Construction	Date of Operation	Date of Removal	Control Type Code	Control Type Description	Manufacturer's Name/Model No.
BOIS3	K				001	Wet Scrubber	

Design Capacity	Design Capacity Units Code	Design Capacity Units Description	Waste Feed Code	Waste Feed Description	Waste Type Code	Waste Type Description
34,146	39	Cubic Feet Per Minute				

Emission Source ID	Emission Source Type	Date of Construction	Date of Operation	Date of Removal	Control Type Code	Control Type Description	Manufacturer's Name/Model No.

Design Capacity	Design Capacity Units Code	Design Capacity Units Description	Waste Feed Code	Waste Feed Description	Waste Type Code	Waste Type Description

Emission Source ID	Emission Source Type	Date of Construction	Date of Operation	Date of Removal	Control Type Code	Control Type Description	Manufacturer's Name/Model No.

Design Capacity	Design Capacity Units Code	Design Capacity Units Description	Waste Feed Code	Waste Feed Description	Waste Type Code	Waste Type Description

Emission Source ID	Emission Source Type	Date of Construction	Date of Operation	Date of Removal	Control Type Code	Control Type Description	Manufacturer's Name/Model No.

Design Capacity	Design Capacity Units Code	Design Capacity Units Description	Waste Feed Code	Waste Feed Description	Waste Type Code	Waste Type Description

Continuation Sheet 15 of 18

DEC ID
- -

Section IV - Emission Unit Information

Emission Unit	Emission Unit Emissions Summary (continuation)			
U - 0 0 S B S				
CAS Number	Contaminant Name			
07644-41-7	Ammonia			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
378,144	1.9	16,806		
CAS Number	Contaminant Name			
07783-06-4	Hydrogen Sulfide			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
84,032	0.4	3,361		
CAS Number	Contaminant Name			
00074-89-5	Methylamine			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
37,982	0.8	6,723		
CAS Number	Contaminant Name			
00124-40-3	Dimethylamine			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
37,982	0.8	6,723		
CAS Number	Contaminant Name			
00075-50-3	Trimethylamine			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
37,982	0.8	6,723		
CAS Number	Contaminant Name			
00075-04-7	Ethylamine			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
37,982	0.8	6,723		
CAS Number	Contaminant Name			
00109-89-7	Diethylamine			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
37,982	0.8	6,723		

Continuation Sheet 16 of 18

DEC ID
- -

Section IV - Emission Unit Information

Emission Unit	Emission Unit Emissions Summary (continuation)			
U-00SBS				
CAS Number	Contaminant Name			
00121-44-8	Triethylamine			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
37,982	0.8	6,723		
CAS Number	Contaminant Name			
07647-01-0	Hydrogen Chloride			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
3,025	0.3	3,025		
CAS Number	Contaminant Name			
00064-19-7	Acetic Acid			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
2,017	0.2	2,017		
CAS Number	Contaminant Name			
00624-92-0	Dimethyl Disulfide			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
22,184	0.4	3,361		
CAS Number	Contaminant Name			
3658-80-8	Dimethyl Trisulfide			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
22,184	0.4	3,361		
CAS Number	Contaminant Name			
00091-20-3	Naphthalene			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
3,818,484	2.18	19,092		
CAS Number	Contaminant Name			
07439-97-6	Mercury			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
76.1	0.01	76		

DEC ID
- -

Section IV - Emission Unit Information

Emission Unit	Emission Unit Emissions Summary (continuation)			
U-00SBS				
CAS Number	Contaminant Name			
00335-67-1	PFOA			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
18.26	2.08x10-7	1.83x10-3		
CAS Number	Contaminant Name			
07440-38-2	Arsenic			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
648	7.4x10-4	6.48		
CAS Number	Contaminant Name			
07440-43-9	Cadmium			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
544	6.21x10-4	5.44		
CAS Number	Contaminant Name			
07664-39-3	Hydrogen Fluoride			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
18.26	1.20x10-4	1.05		
CAS Number	Contaminant Name			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
CAS Number	Contaminant Name			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)
CAS Number	Contaminant Name			
ERP (lbs/yr)	Potential to Emit		Actual Emissions	
	(lbs/hr)	(lbs/yr)	(lbs/hr)	(lbs/yr)

Continuation Sheet 18 of 18

ATTACHMENT 2

FACILITY SITE PLAN AND ENGINEERING DRAWINGS

SARATOGA BIOCHAR SOLUTIONS, LLC

2-12 ELECTRIC DRIVE
MOREAU, NEW YORK

SHEET INDEX

L-0.00	COVER SHEET
L-0.10	EROSION & SEDIMENT CONTROL PLAN
L-1.10	LAYOUT PLAN
L-2.10	GRADING & DRAINAGE PLAN
L-3.10	UTILITIES PLAN
L-4.10	CONSTRUCTION DETAILS
L-5.10	CONSTRUCTION DETAILS
L-5.11	CONSTRUCTION DETAILS
L-6.10	PLANTING PLAN
L-7.10	LIGHTING PLAN

PREPARED FOR

SARATOGA BIOCHAR SOLUTIONS, LLC

26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

ZONING STATISTICS

TAX MAP ID: 50.-4-22 & 50.-4-16

ZONE: GENERAL MANUFACTURING & INDUSTRIAL (M-1)

ZONE ABBREV.: M-1

LOT SIZE:5.89 ACRES(TOTAL)

	REQUIRED	PROPOSED
FRONT YARD SETBACK	40 FT. MIN	±265 FT. (±134 FT PHASE 2/3)
SIDE YARD SETBACK	50 FT. MIN	±70 FT.
REAR YARD SETBACK	50 FT. MIN	±201 FT.
MAX LOT COVERAGE:	60%	43% (PHASE 1) 52% (PHASE 2/3 BUILD OUT)
MAX BLDG HEIGHT	60' FT.	±45 FT.

PARKING STATISTICS

PROPOSED USE: GENERAL MANUFACTURING/INDUSTRIAL
PARKING REQUIREMENTS: 1 PARKING SPACE / 400 SF GROSS FLOOR AREA

REQUIRED SPACES: 80 SPACES FOR PROPOSED PHASE 1 BUILDING GFA

PROPOSED SPACES: 80 SPACES (BASED ON ANTICIPATED EMPLOYEE USE)

PROJECT LOCATION

PROJECT TEAM

CIVIL ENGINEERING & LANDSCAPE ARCHITECT:

STUDIO A | LANDSCAPE ARCHITECTURE, D.P.C.
38 HIGH ROCK AVE SUITE 3 | P.O. BOX 272
SARATOGA SPRINGS, NY 12866
CONTACT: MATTHEW HUNTINGTON, PE/ KIRSTEN CATELLIER, RLA
PHONE: 518.450.4030

GENERAL NOTES

1. PRIOR TO COMMENCING ANY WORK, CONTRACTOR SHALL CONTACT U.F.P.O. AND THE PROPER LOCAL AUTHORITIES TO CONFIRM THE LOCATION OF ALL EXISTING UTILITIES. ANY COSTS INCURRED BY THE CONTRACTOR FOR FAILURE TO CONTACT THE PROPER AUTHORITIES SHALL BE SOLELY THE RESPONSIBILITY OF THE CONTRACTOR.
2. THE GENERAL CONTRACTOR SHALL VERIFY ALL SITE CONDITIONS AND REPORT ANY DISCREPANCY BETWEEN THE PLANS AND THE FIELD CONDITIONS TO THE OWNER'S REPRESENTATIVE.
3. CONTRACTOR SHALL VERIFY AND COORDINATE LOCATION OF ALL UTILITIES, INCLUDING BY NOT LIMITED TO LINES, DUCTS, CONDUITS, SLEEVES, FOOTINGS, ETC., WITH LOCATIONS OF PROPOSED SITE ELEMENTS. EXCAVATION REQUIRED PROXIMATE TO UTILITY LINES SHALL BE DONE BY HAND. ANY DAMAGE AND INCURRED COSTS DUE TO FAILURE OF THE CONTRACTOR TO ADHERE TO THESE GUIDELINES SHALL BE RESPONSIBILITY OF THE CONTRACTOR.
4. CONTRACTOR SHALL ESTABLISH PERMANENT BENCHMARKS PRIOR TO THE START OF CONSTRUCTION. ALL SECONDARY BENCHMARKS SHALL BE LOCATED SO THAT THEY WILL NOT BE DISTURBED DURING CONSTRUCTION.
5. LIMITS OF DISTURBANCE IS NOTED ON DRAWINGS. CONTRACTOR IS RESPONSIBLE FOR ALL DAMAGE DUE TO OPERATIONS INSIDE AND OUTSIDE THE LIMITS OF DISTURBANCE. ANY AREAS OUTSIDE THE LIMITS OF DISTURBANCE THAT ARE DISTURBED SHALL BE RESTORED TO THE ORIGINAL CONDITION AT NO ADDITIONAL COST TO THE OWNER. IF NO LIMITS OF DISTURBANCE IS SHOWN, PROPERTY LINE SHALL BE THE LIMITS OF DISTURBANCE.
6. CONTRACTOR SHALL EMPLOY CARE IN SCHEDULING CONSTRUCTION SO AS TO MAINTAIN EXISTING VEHICULAR TRAFFIC PATTERNS AND MINIMIZE DISRUPTION TO SURROUNDING PEDESTRIAN TRAFFIC. CONTRACTOR SHALL EMPLOY SPECIAL CARE TO PROTECT SAFETY OF PEDESTRIANS INSIDE AND OUTSIDE OF THE LIMITS OF DISTURBANCE.
7. VARIOUS PERMITS ARE REQUIRED FOR THIS PROJECT. IT IS THE CONTRACTOR'S RESPONSIBILITY TO ENSURE ALL REQUIRED PERMITS FROM ALL JURISDICTIONS AFFECTED BY THIS WORK ARE IN PLACE PRIOR TO CONSTRUCTION.
8. ALL ALTERATIONS TO THESE DRAWINGS MADE IN THE FIELD DURING CONSTRUCTION SHALL BE RECORDED BY THE CONTRACTOR ON "AS-BUILT DRAWINGS," AS SPECIFIED.
9. CONTRACTOR SHALL MAINTAIN THE INTEGRITY OF ALL EXISTING INFRASTRUCTURE FOR THE DURATION OF CONSTRUCTION.

APPROVAL SET
DOCUMENTS
03/30/2022

STUDIO A
LANDSCAPE ARCHITECTURE +
ENGINEERING, DPC

MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866

OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866

(518) 450-4030

IT IS A VIOLATION OF NEW YORK STATE EDUCATION LAW FOR ANY PERSON, UNLESS THEY ARE ACTING UNDER THE DIRECTION OF A LICENSED PROFESSIONAL ENGINEER, ARCHITECT, LANDSCAPE ARCHITECT, OR LAND SURVEYOR, TO ALTER ANY ITEM IN ANY WAY. IF AN ITEM BEARING THE STAMP OF A LICENSED PROFESSIONAL IS ALTERED, THE ALTERING LICENSED PROFESSIONAL SHALL STAMP THE DOCUMENT AND INCLUDE THE NOTATION "ALTERED BY" FOLLOWED BY THEIR SIGNATURE, THE DATE OF SUCH ALTERNATION, AND SPECIFIC DESCRIPTION OF THE ALTERATION.

DRAWINGS
NOT FOR
CONSTRUCTION

REVISIONS	
DATE	DESCRIPTION

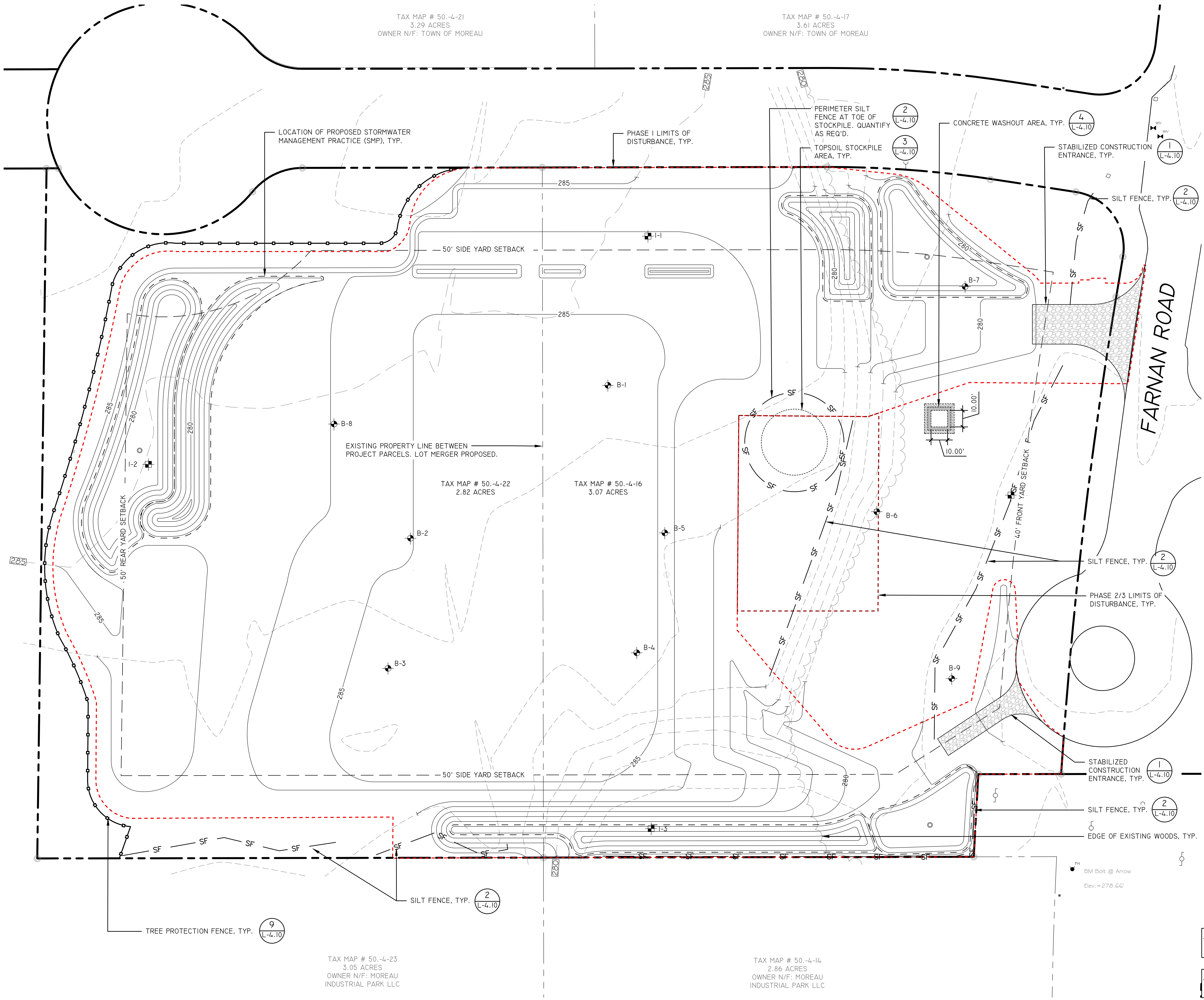
PREPARED FOR
SARATOGA BIOCHAR
SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
COVER SHEET

DATE: 03/25/2022
PROJECT NO.
20019
DRAWING NO.
L-0.00
DWG 0 OF 9

DESIGN BY: ####
DRAWN BY: ####
CHECKED BY: ####



SITE PREPARATION & DEMOLITION NOTES:

1. CONTRACTOR SHALL FIELD VERIFY ALL EXISTING UTILITIES AND SUBSURFACE CONDITIONS PRIOR TO THE START OF WORK. COORDINATE ALL UTILITY REQUIREMENTS AND WORK WITH THE APPROPRIATE UTILITY PROVIDER. NOTIFY OWNER'S REPRESENTATIVE OF ANY AND ALL DISCREPANCIES.
2. ALL REFUSE, DEBRIS AND MISCELLANEOUS ITEMS TO BE REMOVED. MATERIALS THAT ARE NOT TO BE STOCKPILED FOR LATER USE ON THE PROJECT OR DELIVERED TO THE OWNER, SHALL BE LEGALLY DISPOSED OF OFF-SITE BY THE CONTRACTOR IN A TIMELY FASHION SO AS NOT TO DISRUPT PROGRESS AND TO ENSURE SAFE SITE CONDITIONS.
3. CONTRACTOR SHALL NOT REMOVE OR DISTURB ANY ITEMS KNOWN TO CONTAIN HAZARDOUS MATERIALS OR SUBSTANCES. CONTRACTOR SHALL NOTIFY ENGINEER IMMEDIATELY OF HAZARDOUS MATERIALS OR SUBSTANCES DISCOVERED DURING THE COMPLETION OF SPECIFIED WORK.
4. CONTRACTOR SHALL STRIP AND STOCKPILE EXISTING TOPSOIL TO FULL DEPTH WITHIN THE LIMIT OF GRADING BEFORE COMMENCING EXCAVATION AND GRADING OPERATIONS. TOPSOIL SHALL NOT BE REMOVED FROM THE SITE UNLESS APPROVED BY THE OWNER'S REPRESENTATIVE.
5. THE CONTRACTOR IS RESPONSIBLE FOR ANY DAMAGE TO EXISTING CONDITIONS AND WHICH ARE OUTSIDE THE LIMIT OF WORK.
6. CONTRACTOR SHALL IMPLEMENT AND BE RESPONSIBLE FOR ALL NECESSARY MEASURES AND PROCEDURES TO MAINTAIN AND PROTECT EXISTING UTILITIES TO REMAIN, PEDESTRIANS, LOCAL TRAFFIC AND ROADWAYS, ADJACENT PROPERTIES, AND ETC. FOR DURATION OF PROJECT AND UNTIL PROJECT COMPLETION. CONTRACTOR SHALL BE RESPONSIBLE FOR ALL DAMAGES AND/OR RESTORATION REQUIRED AS A RESULT OF DEFICIENT PROTECTION MEASURES.
7. THE CONTRACTOR SHALL COORDINATE ALL ADJUSTMENT OR ABANDONMENT OF UTILITIES WITH THE RESPECTIVE UTILITY COMPANY AND PAY ALL ASSOCIATED COSTS IF APPLICABLE.
8. ALL POINTS OF CONSTRUCTION INGRESS AND EGRESS SHALL BE PROTECTED TO PREVENT MUD ONTO PUBLIC WAYS. ANY MUD ON PUBLIC WAYS ORIGINATING FROM THE JOB SITE SHALL BE CLEANED BY THE CONTRACTOR ONLY.
9. CONTRACTOR SHALL BE REQUIRED TO SECURE ALL PERMITS THAT MAY BE REQUIRED FROM ALL JURISDICTIONS AFFECTED BY THIS WORK.
10. CONTRACTOR SHALL PROTECT ALL EXISTING UTILITIES NOT TO BE REMOVED WHERE APPLICABLE.

EROSION & SEDIMENT CONTROL NOTES:

1. ALL EXPOSED SOIL DISTURBANCE SHALL BE IN ACCORDANCE WITH THE NYS DEC REQUIREMENTS.ANY EXPOSED SOIL SHALL BE PROPERLY STABILIZED WITH EITHER PERMANENT SEED AND MULCH UPON COMPLETION OF CONSTRUCTION, OR TEMPORARILY SEEDED AND MULCHED IF IT WILL BE MORE THAN 14 DAYS BEFORE ADDITIONAL SOIL DISTURBANCE WILL OCCUR. ALL DISTURBED AREAS STRIPPED OF VEGETATION SHALL BE REVEGETATED WITHIN 14 DAYS FROM THE SUBSTANTIAL COMPLETION OF CONSTRUCTION OR CLEARING ACTIVITIES.
2. THE CONTRACTOR SHALL LIMIT THE AREA OF CLEARING AND GRUBBING, EXCAVATION, BORROW, AND EMBANKMENT OPERATIONS IN PROGRESS, COMMENSURATE WITH THEIR CAPABILITY AND PROGRESS IN KEEPING THE FINISH GRADING AND MULCHING, SEEDING AND OTHER TEMPORARY AND/OR PERMANENT CONTROL MEASURES IN ACCORDANCE WITH THESE PLANS.
3. THE CONTRACTOR SHALL DESIGNATE TO THE OWNER'S REPRESENTATIVE A QUALIFIED EROSION AND SEDIMENT CONTROL SUPERVISOR WITH ADEQUATE TRAINING, EXPERIENCE, AND AUTHORITY TO IMPLEMENT AND MAINTAIN ALL EROSION AND SEDIMENT CONTROL MEASURES AS PER THE NYS DEC REQUIREMENTS
4. CONSTRUCTION IS TO PROCEED IN ACCORDANCE WITH THE CONSTRUCTION PHASING SCHEDULE SUPPLIED BY THE CONTRACTOR OR SHOWN ON THE PLANS. GRASSES SHALL BE ESTABLISHED ON ALL DISTURBED AREAS AS SOON AS POSSIBLE. FOR TIME FRAMES OUTSIDE THE GROWING SEASON, OTHER METHODS OF SOIL STABILIZATION (SUCH AS THE USE OF JUTE MESH EXCELSIOR MATTING) WILL BE USED UNTIL SUCH A TIME AS GRASS CAN BE ESTABLISHED.
5. ALL APPLICABLE EROSION AND SEDIMENT CONTROL PRACTICES SHALL BE IN PLACE PRIOR TO ANY SITE DISTURBANCE. THIS INCLUDES GRADING OPERATIONS, UTILITY OR STRUCTURE INSTALL.
6. SOIL EROSION AND SEDIMENT CONTROL PRACTICES ON THIS PLAN SHALL BE CONSTRUCTED IN ACCORDANCE WITH NYS DEC REQUIREMENTS.
7. APPLICABLE EROSION AND SEDIMENT CONTROL PRACTICES SHALL BE LEFT IN PLACE UNTIL THE CONTRIBUTING DRAINAGE AREA SERVED IS STABILIZED.
8. THE CONTRACTOR SHALL PERFORM ALL WORK, FURNISH ALL MATERIALS AND INSTALL ALL MEASURES REQUIRED TO REASONABLY CONTROL SOIL EROSION RESULTING FROM CONSTRUCTION OPERATIONS AND PREVENT EXCESSIVE FLOW OF SEDIMENT FROM THE CONSTRUCTION SITE.
9. THE SITE SHALL AT ALL TIMES BE GRADED AND MAINTAINED SUCH THAT ALL STORMWATER RUNOFF IS DIVERTED TO SOIL EROSION AND SEDIMENT CONTROL FACILITIES.
10. ALL SEDIMENTATION STRUCTURES WILL BE INSPECTED AND MAINTAINED AFTER EVERY STORM EVENT.
11. THE CONTRACTORS ATTENTION IS DIRECTED TO THE FACT THAT THROUGHOUT THE DURATION OF THE PROJECT IT WILL BE THE CONTRACTOR'S RESPONSIBILITY TO PROTECT ALL WATER COURSES FROM WATER BORNE SEDIMENT OR POLLUTANTS ORIGINATING FROM ANY WORK DONE ON, OR IN SUPPORT OF THIS PROJECT.
12. ALL NECESSARY PRECAUTIONS SHALL BE TAKEN TO PREVENT CONTAMINATION OF NEARBY WATERBODIES OR STORM SEWER SYSTEMS BY SILT, SEDIMENT, FUELS, SOLVENTS, LUBRICANTS, EPOXY COATINGS, CONCRETE LEACHATE, OR ANY OTHER POLLUTANT ASSOCIATED WITH CONSTRUCTION AND CONSTRUCTION PROCEDURES.
13. NOTE: DROP INLET PROTECTION TO BE INCLUDED AT ALL NEW CATCH BASINS AND AT ALL CATCH BASINS TO REMAIN IF APPLICABLE.

LEGEND:

▬ ‒ ‒ ▬	PROPERTY LINE
— — — —	PROPERTY LINE SETBACK
—— SF ——	SILT FENCE
— —280— —	EXISTING MAJOR CONTOURS
— — — —	EXISTING MINOR CONTOURS
▨	STABILIZED CONSTRUCTION ENTRANCE
- - - - -	PHASE 1 LIMITS OF DISTURBANCE
- - - - -	PHASE 2/3 LIMITS OF DISTURBANCE
—□—□—□—	TREE PROTECTION FENCE
——280——	PROPOSED CONTOUR
⊞ I-4	APPROX. LOCATION OF INFILTRATION TEST*
⊕ B-6	APPROX. LOCATION OF BORING*

*SEE PROJECT SWPPP FOR TEST RESULTS

NOTE: LIMITS OF DISTURBANCE
PHASE 1: ±192,301 SF
PHASE 2/3: ±10,015 SF

NOTE: ALL SMP AREAS SHALL BE PROTECTED FROM HEAVY CONSTRUCTION EQUIPMENT TRAFFIC.

GRAPHIC SCALE
30 0 15 30 60
1 INCH = 30 FEET
ON 24" X 36" SHEET

N

MAP REFERENCE:
BASE MAP INFORMATION OBTAINED FROM "MAP OF TOPOGRAPHIC SURVEY MADE FOR NORTHEAST BIOCHAR SOLUTIONS, INC., TOWN OF MOREAU, SARATOGA COUNTY, NEW YORK" PREPARED BY VAN DUSEN & STEVES SURVEYORS, DATED JULY 28, 2021.

DIG SAFE NOTE:
THIS PLAN SET WAS DRAFTED WITHOUT THE BENEFIT OF "DIG SAFE" MARKINGS. UTILITIES SHOWN ARE NOT WARRANTED TO BE EXACT OR COMPLETE. THE CONTRACTOR SHALL CONTACT "DIG SAFE" AT 811 BEFORE COMMENCING ANY WORK AND SHALL PRESERVE EXISTING UTILITIES WHICH ARE NOT SPECIFIED TO BE REMOVED IN THIS PLAN SET.

studioA
Landscape Architecture + Engineering, DPC

STUDIO A
LANDSCAPE ARCHITECTURE + ENGINEERING, DPC

MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866

OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866

(518) 450-4030

REVISIONS	
DATE	DESCRIPTION

northeastern
BIOCHAR SOLUTIONS
WASTE NOT

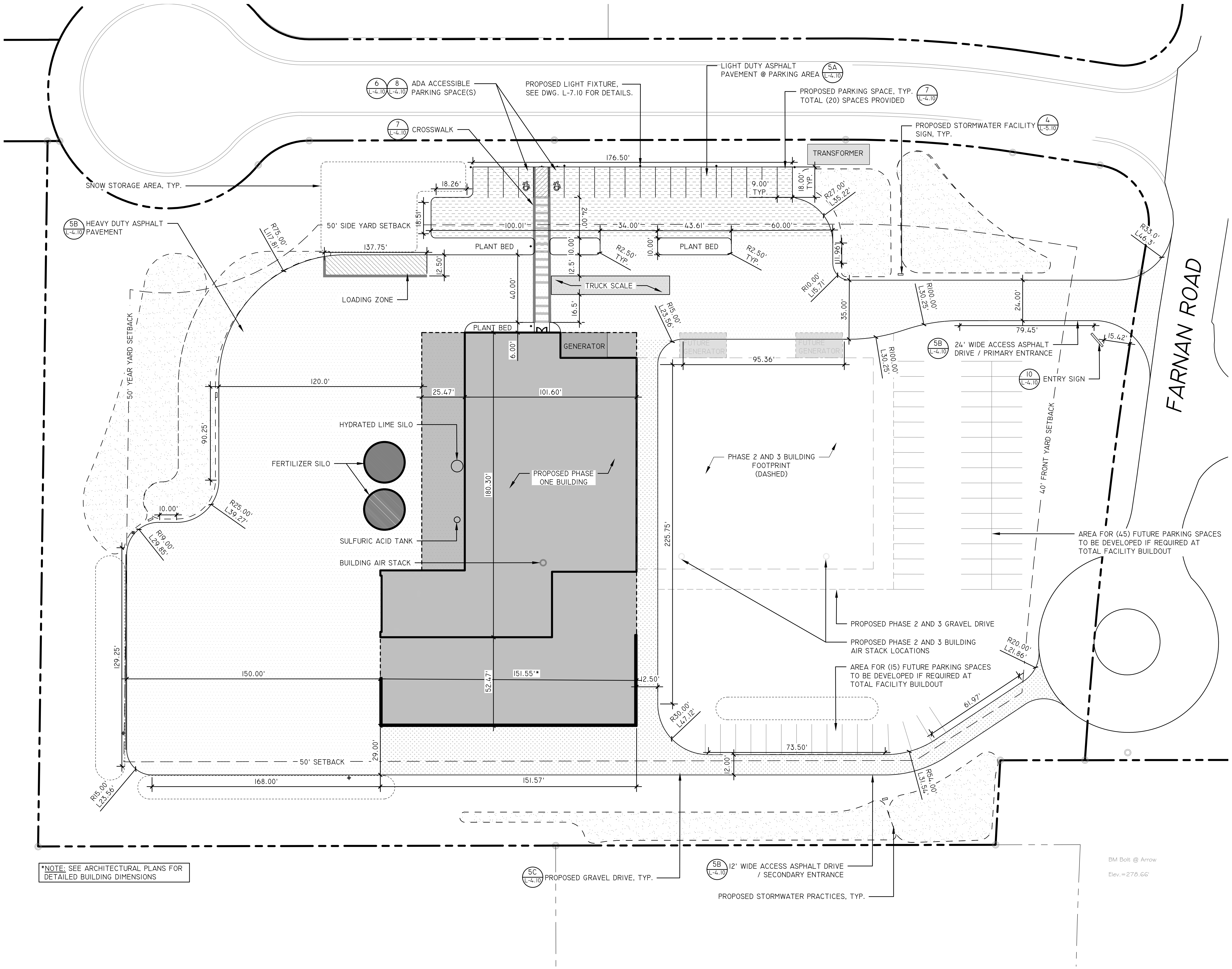
PREPARED FOR
SARATOGA BIOCHAR SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
EROSION & SEDIMENT CONRTOL PLAN

DATE: 03/25/2022
PROJECT NO. 20019
DRAWING NO.
L-0.10
DWG 1 OF 9

PLOTTED BY: QUINN ROESCH
SAVE DATE: 3/25/2022 11:25 AM
FILE NAME: Z:\Projects\2020 Projects\20019 - BioChar Solutions\DWG\03 SHEETS\20019_EXISTING CONDITIONS.DWG



*NOTE: SEE ARCHITECTURAL PLANS FOR DETAILED BUILDING DIMENSIONS

LAYOUT NOTES:

1. VERIFY LOCATION OF ALL BUILDINGS, WALLS, ROADS AND CURBS AFFECTING SCOPE OF WORK.
2. VERIFY LOCATION OF ALL VAULTS, ELECTRICAL DUCT BANKS, MANHOLES, CONDUIT AND PIPING, DRAINAGE STRUCTURES AND OTHER UTILITIES WITH THE APPROPRIATE ENGINEERING DRAWINGS. NOTIFY ENGINEER OF ANY CONFLICTS WITH ENGINEER SCOPE.
3. TAKE ALL DIMENSIONS FROM FACE OF GRAVEL PARKING AREA OR BUILDING TO CENTERLINE OF DRIVE OR TREES UNLESS OTHERWISE NOTED.
4. ALL ANGLES TO BE 90 DEGREES AND ALL LINES OF PAVING AND FENCING TO BE PARALLEL UNLESS NOTED OTHERWISE. MAINTAIN HORIZONTAL ALIGNMENT OF ADJACENT ELEMENTS AS NOTED ON THE DRAWINGS.
5. REFERENCE TO NORTH REFERS TO PLAN NORTH, REFERENCE TO SCALE IS FOR FULL-SIZED DRAWINGS ONLY. DO NOT SCALE FROM REDUCED DRAWINGS.

LEGEND:

━ ━	PROPERTY LINE
— —	PROPERTY LINE SETBACK
- - -	LIMITS OF DISTURBANCE
☐	PROPOSED HEAVY DUTY ASPHALT SURFACE
▨	PROPOSED LIGHT DUTY ASPHALT SURFACE
▨	PROPOSED GRAVEL SURFACE
☐	PROPOSED STORMWATER PRACTICES
• ⊕	PROPOSED LIGHT FIXTURES
☐	PROPOSED SNOW STORAGE AREA

GRAPHIC SCALE
30 0 15 30 60
1 INCH = 30 FEET
ON 24" X 36" SHEET

N

MAP REFERENCE:
BASE MAP INFORMATION OBTAINED FROM "MAP OF TOPOGRAPHIC SURVEY MADE FOR NORTHEAST BIOCHAR SOLUTIONS, INC., TOWN OF MOREAU, SARATOGA COUNTY, NEW YORK" PREPARED BY VAN DUSEN & STEVES SURVEYORS, DATED JULY 28, 2021.

DIG SAFE NOTE:
THIS PLAN SET WAS DRAFTED WITHOUT THE BENEFIT OF "DIG SAFE" MARKINGS. UTILITIES SHOWN ARE NOT WARRANTED TO BE EXACT OR COMPLETE. THE CONTRACTOR SHALL CONTACT "DIG SAFE" AT 811 BEFORE COMMENCING ANY WORK AND SHALL PRESERVE EXISTING UTILITIES WHICH ARE NOT SPECIFIED TO BE REMOVED IN THIS PLAN SET.

studioA
Landscape Architecture + Engineering, DPC

STUDIO A
LANDSCAPE ARCHITECTURE + ENGINEERING, DPC

MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866

OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866

(518) 450-4030

DRAWINGS NOT FOR CONSTRUCTION

REVISIONS	
DATE	DESCRIPTION

northeastern BIOCHAR SOLUTIONS
WASTE NOT

PREPARED FOR
SARATOGA BIOCHAR SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

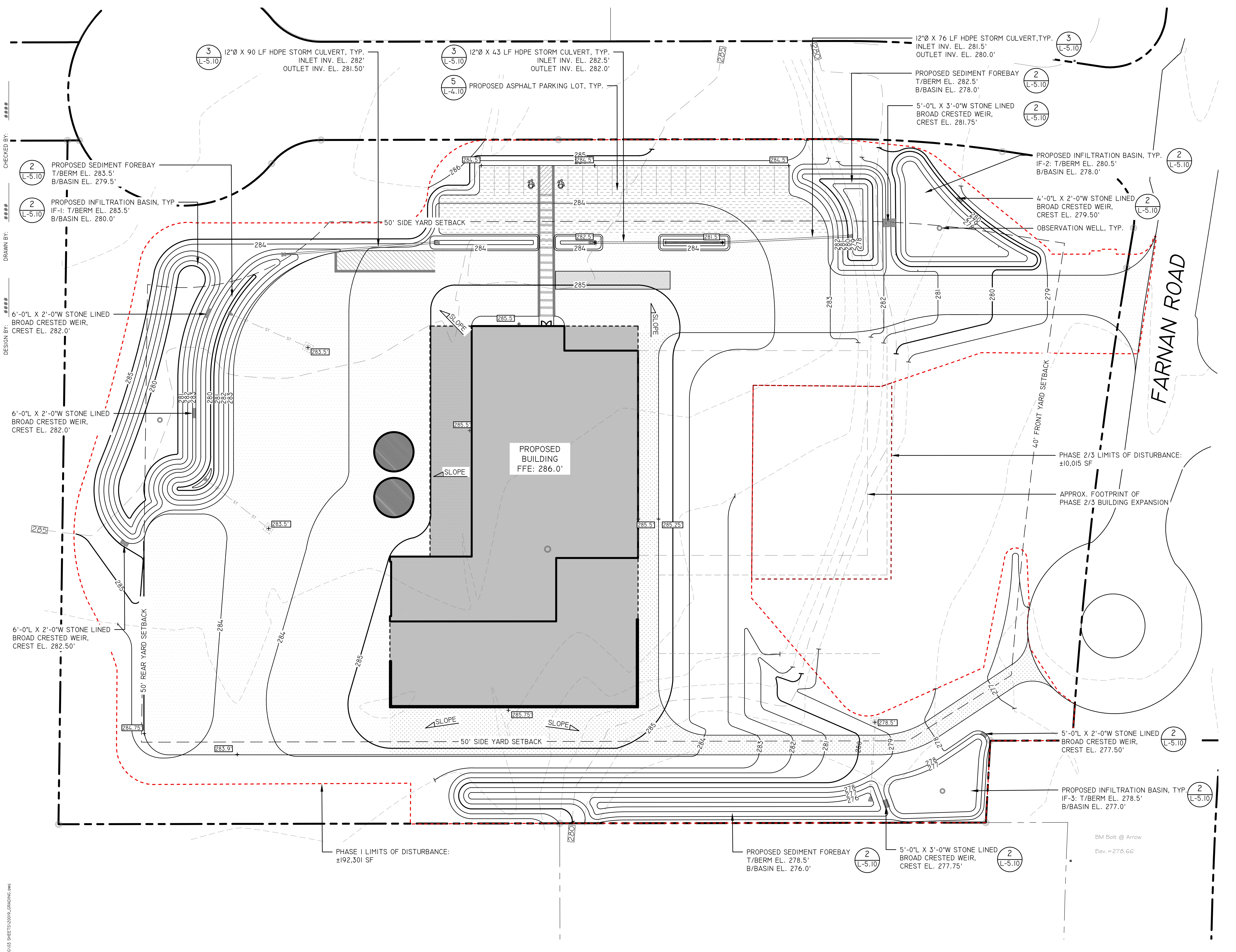
PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
LAYOUT PLAN

DATE: 03/25/2022
PROJECT NO. 20019
DRAWING NO.
L-1.10
DWG 2 OF 9

DESIGN BY: ####
DRAWN BY: ####
CHECKED BY: ####

PLOTTED BY: QUINN ROESCH
SAVE DATE: 4/1/2022 2:34 PM
FILE NAME: Z:\PROJECTS\2020 PROJECTS\20019 - BIOCHAR SOLUTIONS\DWG\03 SHEETS\20019_LAYOUT.DWG



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DRAWN BY: ####

DESIGN BY: ####

PLOTTED BY: QUINN ROESCH
SAVE DATE: 3/25/2022 11:40 AM
FILE NAME: Z:\PROJECTS\2020 PROJECTS\20019 - BIOCHAR SOLUTIONS\DWG\03 SHEETS\20019_GRADING.DWG

EARTHWORK NOTES:

1. BEFORE ANY LAND CLEARING IS COMPLETED, THE CONTRACTOR SHALL ARRANGE A MEETING ON SITE WITH THE OWNER'S REPRESENTATIVE TO IDENTIFY WHICH TREES ARE TO BE PROTECTED OR REMOVED. NO CLEARING SHALL OCCUR WITHOUT A CLEAR UNDERSTANDING OF THE EXISTING CONDITIONS TO BE PRESERVED.
2. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE PROTECTION OF ALL EXISTING TREES AND PLANTS DESIGNATED TO REMAIN FOR THE LENGTH OF THE CONSTRUCTION PERIOD. THE PLACEMENT OF PROTECTION DEVICES ADDITIONAL TO THOSE NOTED SHALL, HOWEVER, BE AT THE CONTRACTORS DISCRETION. VEHICLES SHALL NOT BE PARKED WITHIN THE DRIP LINE OR WHERE DAMAGE MAY RESULT TO TREES TO BE KEPT. CONSTRUCTION MATERIALS SHALL NOT BE STORED BENEATH TREES TO BE KEPT.
3. ALL TEMPORARY EROSION AND SEDIMENT (E&S) CONTROL MEASURES SHALL BE INSTALLED PRIOR TO ANY EARTH DISTURBANCE. E&S CONTROL DEVICES SHALL BE REGULARLY INSPECTED AND MAINTAINED AS NEEDED TO ENSURE SATISFACTORY PERFORMANCE. ANY DAMAGE OCCURRING DURING THE COURSE OF CONSTRUCTION SHALL BE REPAIRED BY THE CONTRACTOR AT NO ADDITIONAL EXPENSE TO THE OWNER. ASSOCIATED FINES RESULTING FROM SUCH DAMAGE SHALL ALSO BE PAID BY THE CONTRACTOR.
4. ALL PROPOSED GRADES SET IN THE FIELD TO BE COMPLETED BY A NEW YORK STATE LICENSED SURVEYOR.
5. ALL AREAS REQUIRING FILL SHALL BE BROUGHT TO REQUIRED GRADE IN A MAXIMUM OF 12" COMPACTED LIFTS.
6. ALL SLOPES 3:1 AND GREATER SHALL BE STABILIZED WITH SLOPE STABILIZATION MATS. LOCATIONS AND METHODS TO BE APPROVED BY THE OWNER'S REPRESENTATIVE.
7. PITCH EVENLY BETWEEN SPOT GRADES. ALL PAVED AREAS MUST PITCH TO DRAIN AT A MINIMUM SLOPE OF ONE-EIGHTH ($\frac{1}{8}$") PER FOOT. ANY DISCREPANCIES NOT ALLOWING THIS TO OCCUR SHALL BE REPORTED TO THE OWNER'S REPRESENTATIVE IMMEDIATELY BEFORE CONTINUING WORK.
8. EXCAVATION REQUIRED WITHIN 3 FEET OF EXISTING UTILITY LINE SHALL BE DONE BY HAND. CONTRACTOR SHALL REPAIR ANY DAMAGE TO EXISTING UTILITY LINES OR STRUCTURES INCURRED DURING CONSTRUCTION OPERATIONS AT NO ADDITIONAL COST TO THE OWNER.
9. CONTRACTOR SHALL BLEND NEW EARTHWORK SMOOTHLY INTO EXISTING GRADE, PROVIDING VERTICAL CURVES OR ROUNDINGS AT THE TOP AND BOTTOM OF ALL SLOPES.
10. DURING GRADING OPERATIONS, DRAINAGE OF THE SITE AND ADJACENT AREAS SHALL BE MAINTAINED CONTINUOUSLY TO PREVENT EROSION OR OTHER DAMAGE. WHEN IT IS NECESSARY TO INTERRUPT DRAINAGE OR OTHER EXISTING UTILITIES, CONTRACTOR IS TO PROVIDE TEMPORARY FACILITIES UNTIL PERMANENT WORK IS COMPLETED AT NO COST TO THE OWNER.
11. GRADE AREAS ADJACENT TO BUILDING LINES TO DRAIN AWAY FROM STRUCTURE TO PREVENT PONDING. FINISHED SURFACES SHALL BE FREE FROM ANY ABRUPT OR IRREGULAR CHANGES.
12. EXCAVATION REQUIRED WITHIN DRIP LINE OF TREES DESIGNATED TO REMAIN SHALL BE DONE BY HAND SO THAT NO DAMAGE OCCURS TO EXISTING ROOT SYSTEM. PLANT MATERIALS DAMAGED BY CONTRACTOR SHALL BE REPLACED IN KIND AT NO ADDITIONAL EXPENSE TO THE OWNER.
13. EXCAVATION SHALL BE TO ELEVATIONS INDICATED WITH A TOLERANCE OF ± 1".
14. SUBBASE COURSE MATERIAL SHALL CONFORM TO NYS DEPARTMENT OF TRANSPORTATION STANDARD SPECIFICATIONS SECTION 304, TYPE 2 AND SHALL CONFORM TO MIN 95% MODIFIED PROCTOR DENSITY. BACKFILL MATERIAL SHALL BE COMPACTED ON SITE SOIL MATERIAL.
15. EMBANKMENT FILL SHALL CONFORM WITH ALL REQUIREMENTS OF NYSDOT SPEC. SECTION 203. MAXIMUM ALLOWABLE LOOSE LIFTS FOR EMBANKMENTS SHALL BE 12 INCH AND SHALL BE COMPACTED TO NOT LESS THAN 95% OF THE MAXIMUM DENSITY AS ESTABLISHED THROUGH THE STANDARD PROCTOR COMPACTION TEST PER ASTM D698.
16. MATERIAL STOCKPILES, IF REQUIRED, SHALL BE LOCATED WHOLLY WITHIN THE WORK AREA. ADDITIONAL SILT FENCES SHALL BE PROVIDED AT THE BASE OF ALL STOCKPILES AS DIRECTED IN THE FIELD BY THE ENGINEER.
17. ALL TRENCHES AND OTHER EXCAVATION SIDE SLOPES INDICATED ON THE DRAWINGS ARE DIAGRAMMATIC ONLY AND ARE NOT INTENDED TO INDICATE A STABLE EXCAVATION SLOPE. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE ADEQUACY AND STABILITY OF ALL EXCAVATION SLOPES, SHEETING, SHORING, TRENCH BOXES, AND ANY OTHER MEANS REQUIRED FOR A SAFE WORK ENVIRONMENT AND FOR PROTECTION OF ADJACENT ROADWAYS AND OTHER STRUCTURES. ALL EXCAVATION WORK SHALL COMPLY WITH THE REQUIREMENTS OF THE FOLLOWING REGULATORY AGENCIES:

-- SUBPART 23-4, "EXCAVATION OPERATIONS", OF NEW YORK DEPARTMENT OF LABOR INDUSTRIAL CODE RULE 23.
-- SUBPART P, "EXCAVATIONS" OF THE UNITED STATES DEPARTMENT OF LABOR OSHA REGULATIONS FOR CONSTRUCTION.
-- ALL OTHER MUNICIPAL, COUNTY, STATE OR FEDERAL AGENCIES, REGULATIONS OR LAWS PERTAINING TO EXCAVATION SAFETY AS MAY APPLY AT THE WORK SITE.
-- THE MORE STRINGENT PROVISION IN EACH OF THE ABOVE CODES SHALL APPLY. THESE PROVISIONS SHALL BE CONSIDERED MINIMUM REQUIREMENTS AND SHALL BE INCREASED IF NECESSARY TO PROVIDE SAFE WORKING CONDITIONS.

18. CRUSHED STONE, WHERE CALLED FOR ON THE DRAWINGS, SHALL CONFORM TO NYS DEPARTMENT OF TRANSPORTATION STANDARD SPECIFICATIONS SECTION 703-02, SIZE DESIGNATION 2.
19. ALL SILT FENCES SHALL BE INSTALLED PRIOR TO DISTURBANCE OF EXISTING SITE FINISHES AND SHALL REMAIN IN PLACE UNTIL A STABLE GROWTH OF TURF IS ESTABLISHED.
20. ALL DISTURBED AREAS NOT COVERED WITH SITE IMPROVEMENTS OR LANDSCAPING SHALL BE COVERED WITH 6" OF TOPSOIL AND SEEDED TO ESTABLISH A DENSE GROWTH OF TURF. PRIOR TO APPLYING TOPSOIL, DISTURBED AREAS SHALL BE RESTORED IN ACCORDANCE WITH THE REQUIREMENTS OF SECTION 5.1.6 "SOIL RESTORATION" OF THE NYSDEC STORMWATER DESIGN MANUAL.

LEGEND:

▬ ▬ ▬	PROPERTY LINE
— — — —	PROPERTY LINE SETBACK
— —860— —	EXISTING MAJOR CONTOURS
- - - - - -	EXISTING MINOR CONTOURS
——860——	PROPOSED MAJOR CONTOURS
——862——	PROPOSED MINOR CONTOURS
396.5 + 394.00	PROPOSED SPOT GRADES
- - - - - - - - -	PHASE 1 LIMITS OF DISTURBANCE
- - - - - - - - -	PHASE 2/3 LIMITS OF DISTURBANCE

GRAPHIC SCALE
30 0 15 30 60
1 INCH = 30 FEET
ON 24" X 36" SHEET

N

MAP REFERENCE:
BASE MAP INFORMATION OBTAINED FROM "MAP OF TOPOGRAPHIC SURVEY MADE FOR NORTHEAST BIOCHAR SOLUTIONS, INC., TOWN OF MOREAU, SARATOGA COUNTY, NEW YORK" PREPARED BY VAN DUSEN & STEVES SURVEYORS, DATED JULY 28, 2021.

DIG SAFE NOTE:
THIS PLAN SET WAS DRAFTED WITHOUT THE BENEFIT OF "DIG SAFE" MARKINGS. UTILITIES SHOWN ARE NOT WARRANTED TO BE EXACT OR COMPLETE. THE CONTRACTOR SHALL CONTACT "DIG SAFE" AT 811 BEFORE COMMENCING ANY WORK AND SHALL PRESERVE EXISTING UTILITIES WHICH ARE NOT SPECIFIED TO BE REMOVED IN THIS PLAN SET.

studioA
Landscape Architecture + Engineering, DPC

STUDIO A
LANDSCAPE ARCHITECTURE +
ENGINEERING, DPC

MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866

OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866

(518) 450-4030

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DRAWINGS
NOT FOR
CONSTRUCTION

REVISIONS	
DATE	DESCRIPTION

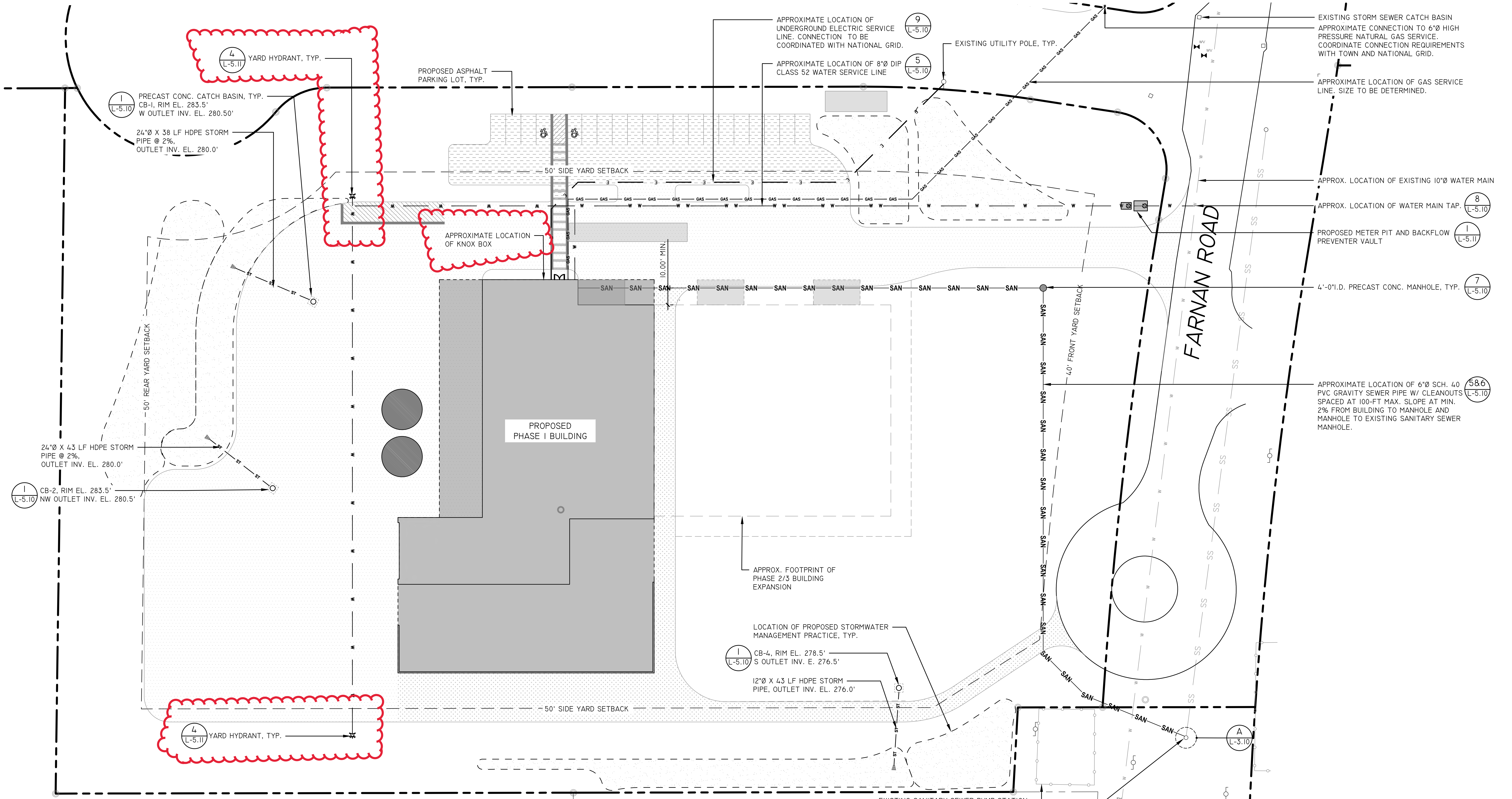
northeastern
BIOCHAR SOLUTIONS
WASTE NOT

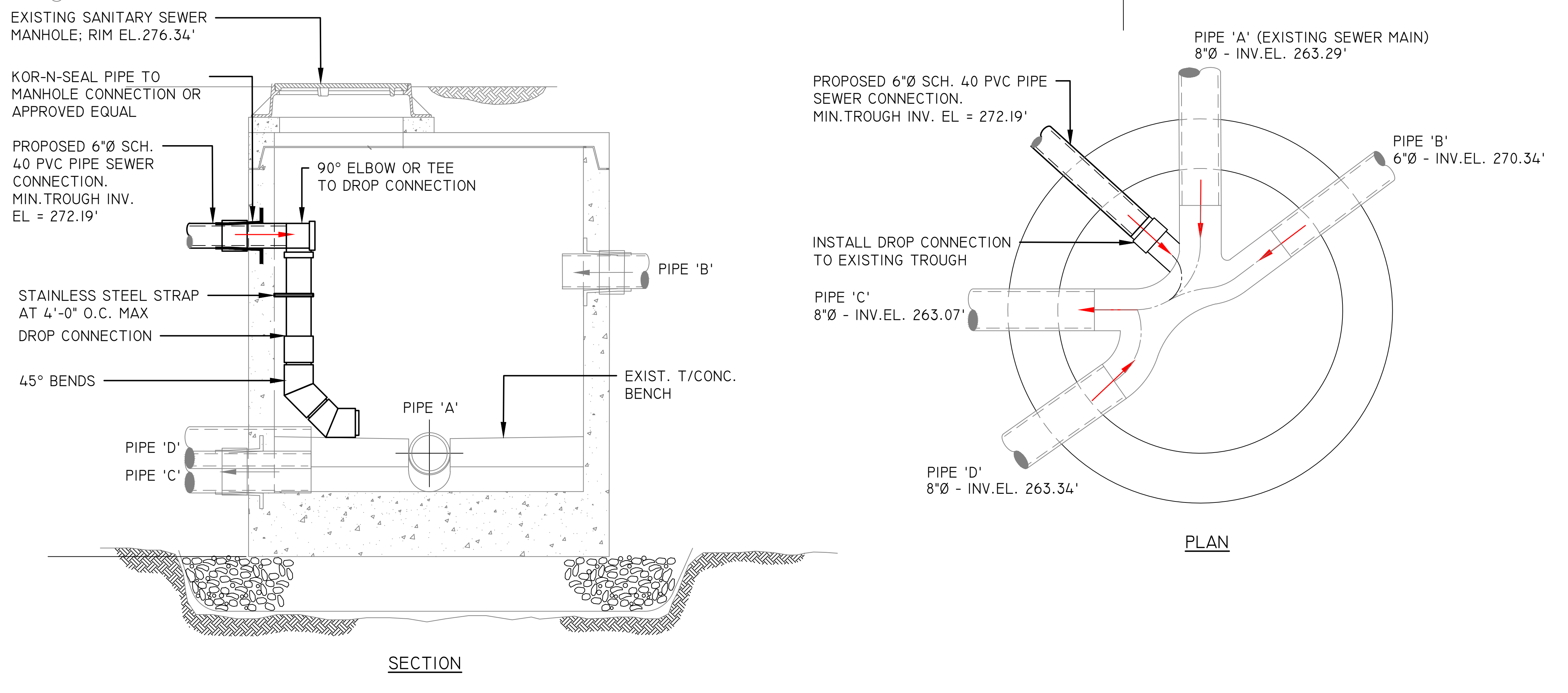
PREPARED FOR
SARATOGA BIOCHAR
SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
GRADING & DRAINAGE PLAN

DATE: 03/25/2022
PROJECT NO.
20019
DRAWING NO.
L-2.10
DWG 3 OF 9





A EXISTING MANHOLE SEWER CONNECTION DETAIL

SCALE: N.T.S.

LEGEND:

━ ━ ━ ━	PROPERTY LINE
— — — —	PROPERTY LINE SETBACK
— ST — ST —	PROPOSED STORM SEWER LINE
——SAN——	PROPOSED SANITARY SEWER LINE
—— SS ——	EXISTING SANITARY SEWER GRAVITY MAIN (ASSUMED)
—— W ——	PROPOSED POTABLE WATER SERVICE LINE
—— E ——	PROPOSED ELECTRIC SERVICE LINE
— GAS — GAS —	PROPOSED GAS SERVICE LINE

GRAPHIC SCALE

30 0 15 30 60

1 INCH = 30 FEET
ON 24" X 36" SHEET

N

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BASE MAP INFORMATION OBTAINED FROM "MAP OF TOPOGRAPHIC SURVEY MADE FOR NORTHEAST BIOCHAR SOLUTIONS, INC., TOWN OF MOREAU, SARATOGA COUNTY, NEW YORK" PREPARED BY VAN DUSEN & STEVES SURVEYORS, DATED JULY 28, 2021.

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CHECKED BY: ####
DRAWN BY: ####
DESIGN BY: ####

PLOTTED BY: QUINN ROESCH
SAVE DATE: 3/30/2022 4:04 PM
FILE NAME: Z:\Projects\2020 Projects\20019 - BioChar Solutions\DWG\03 SHEETS\20019_UTILITIES.DWG

studioA
Landscape Architecture + Engineering, DPC
STUDIO A
LANDSCAPE ARCHITECTURE +
ENGINEERING, DPC
MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866
OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866
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DATE	REVISIONS DESCRIPTION

northeastern
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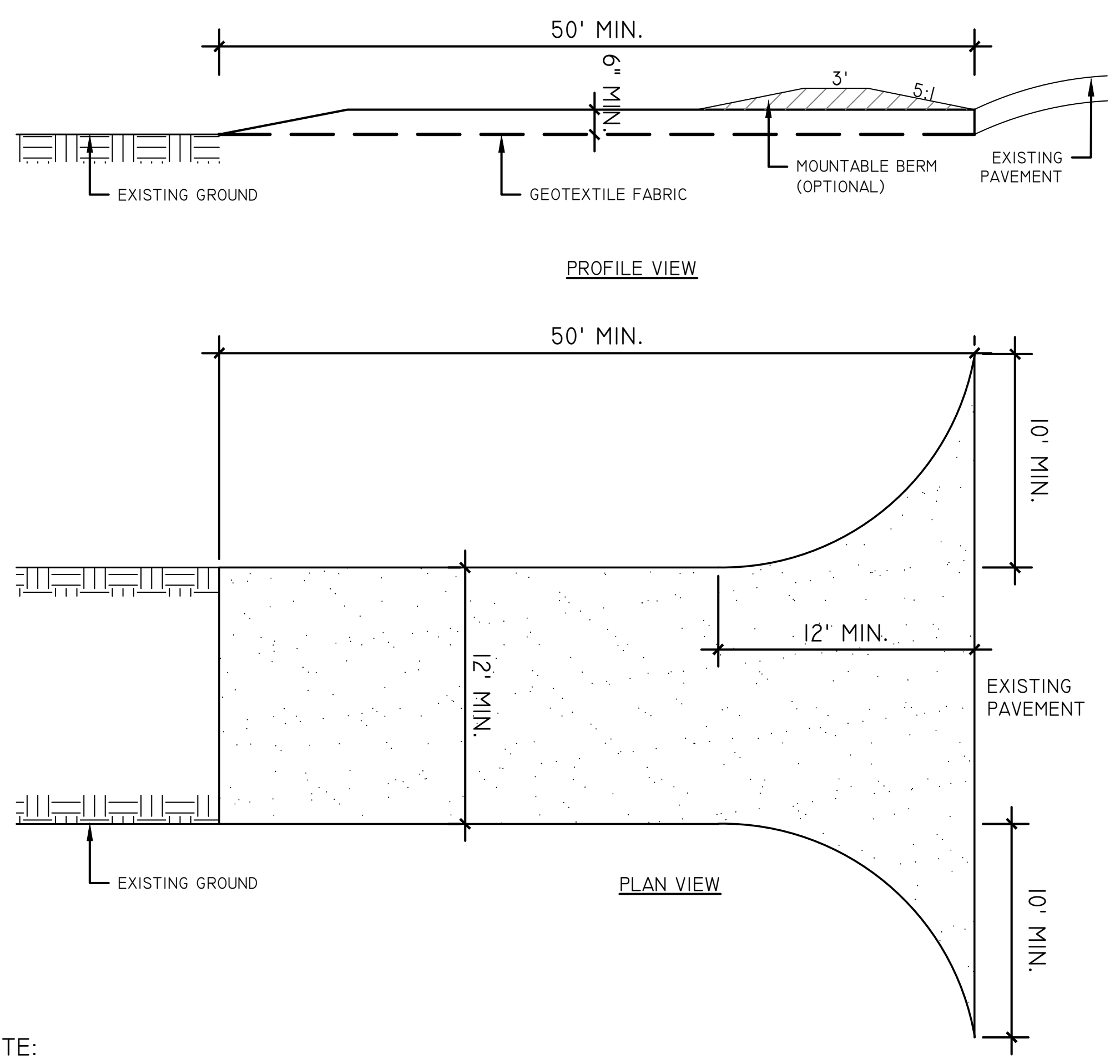
SARATOGA BIOCHAR
SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
UTILITIES PLAN

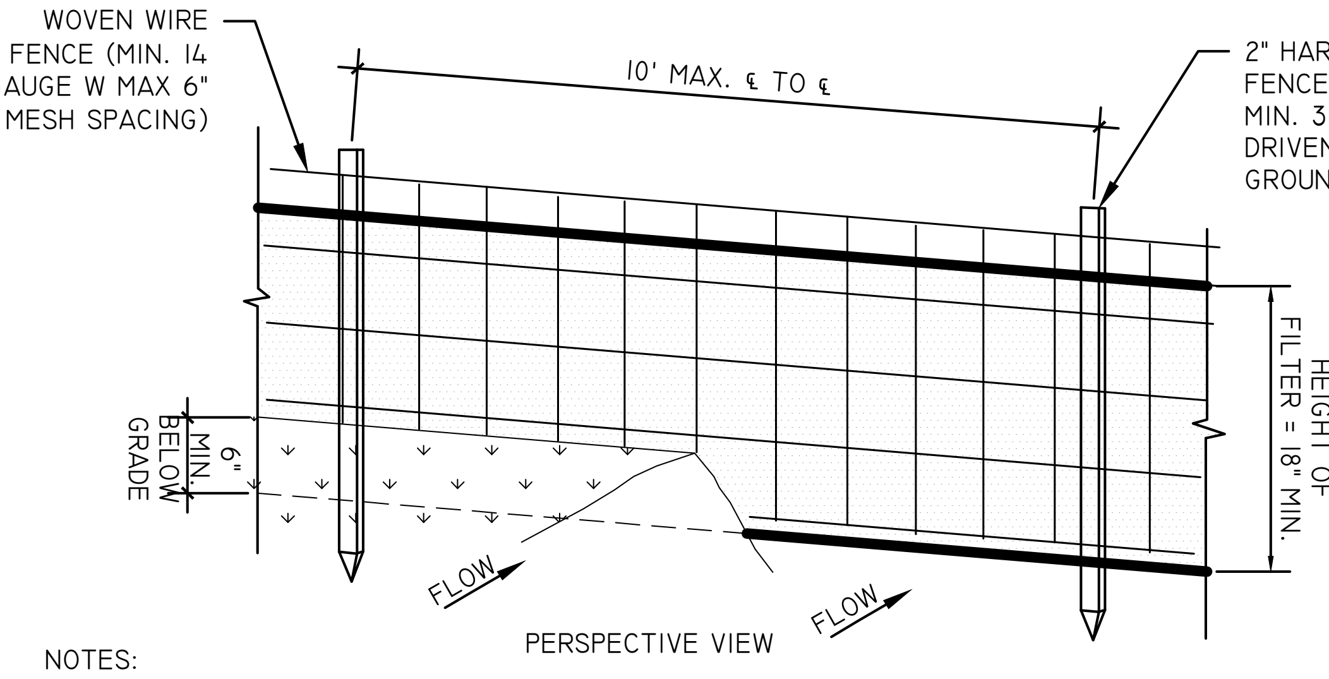
DATE: 03/25/2022
PROJECT NO.
20019
DRAWING NO.
L-3.10
DWG 4 OF 9

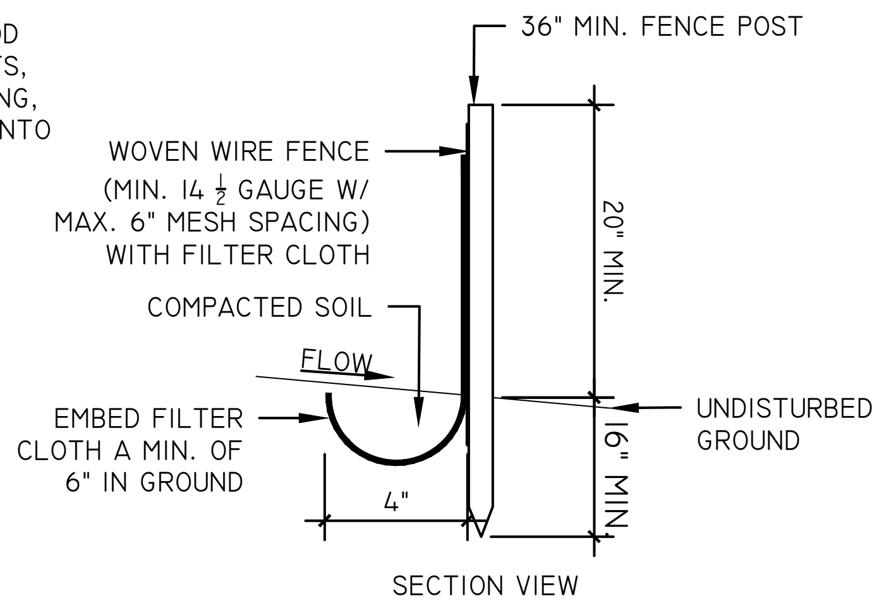


NOTE:
1. STONE SIZE - USE 1" -4" TYPE 3 STONE.
2. LENGTH - NOT LESS THAN 50 FEET (EXCEPT ON A SINGLE RESIDENCE LOT WHERE A 30' MINIMUM LENGTH WOULD APPLY).
3. THICKNESS - NOT LESS THAN 6".
4. WIDTH - 12 FEET MINIMUM, BUT NOT LESS THAN THE FULL WIDTH WHERE INGRESS AND EGRESS OCCUR. 24 FEET IF SINGLE ENTRANCE TO THE SITE.
5. GEOTEXTILE - WILL BE PLACED OVER THE ENTIRE AREA PRIOR TO PLACING THE STONE.
6. SURFACE WATER - ALL SURFACE WATER FLOWING OR DIVERTED TOWARD CONSTRUCTION ENTRANCES SHALL BE PIPED ACROSS THE ENTRANCE. IF PIPING IS IMPRACTICAL, A MOUNTABLE BERM WITH A 5:1 SLOPE WILL BE PERMITTED.
7. MAINTENANCE- THE ENTRANCE SHALL BE MAINTAINED IN A CONDITION WHICH WILL PREVENT TRACKING OR FLOWING OF SEDIMENT ONTO PUBLIC RIGHTS-OF WAY MUST BE REMOVED IMMEDIATELY.
8. WHEN WASHING IS REQUIRED, IT SHALL BE DONE ON A AREA STABILIZED WITH STONE AND WHICH DRAINS INTO AN APPROVED SEDIMENT TRAPPING DEVICE.
9. PERIODIC INSPECTION AND NEEDED MAINTENANCE SHALL BE PROVIDED AFTER EACH RAIN.

1 STABILIZED CONSTRUCTION ENTRANCE DETAIL

SCALE: N.T.S.



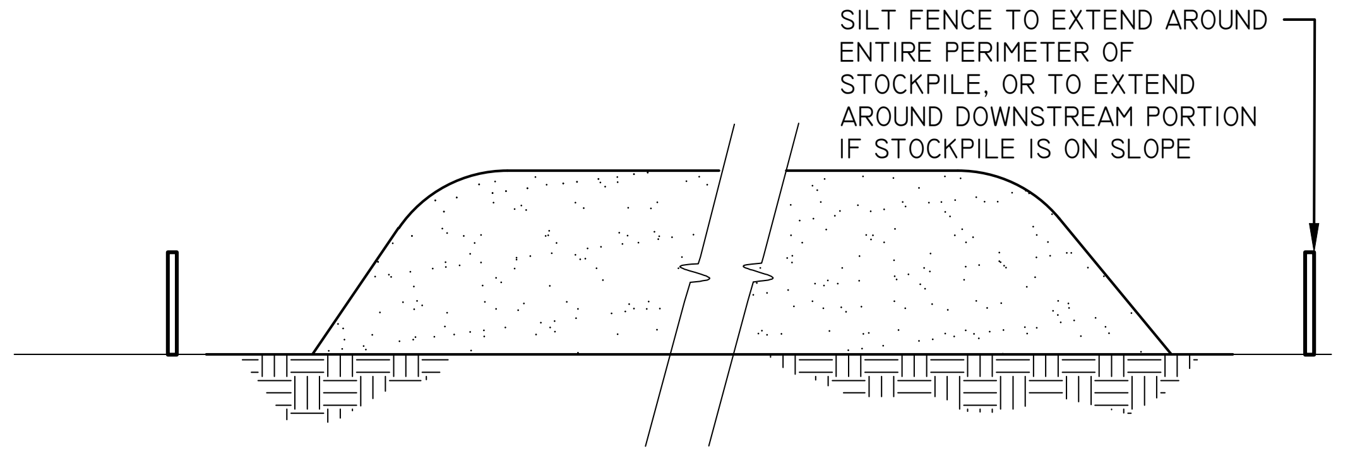


NOTES:
1. WOVEN WIRE FENCE TO BE FASTENED SECURELY TO FENCE POSTS WITH WIRE TIES OR STAPLES. POSTS SHALL BE STEEL EITHER "T" OR "U" TYPE HARDWOOD.
2. FILTER CLOTH TO BE FASTENED SECURELY TO WOVEN WIRE FENCE WITH TIES SPACED EVERY 34" AT TOP AND MID SECTION. FENCE SHALL BE WOVEN WIRE, 6" MAX MESH OPENING.
3. WHEN TWO SECTIONS OF FILTER CLOTH ADJOIN EACH OTHER THEY SHALL BE OVERLAPPED BY SIX INCHES AND FOLDED. FILTER CLOTH SHALL BE EITHER FIXTER X, MARAFI 100X, STABILINKA T140N OR APPROVE EQUIVALENT IF USING THE WOVEN WIRE FENCE. IF THE WOVEN WIRE FENCE IS NOT USED, FILTER FABRIC MUST BE NYSDOT APPROVED MATERIAL LIST FOR SILT FENCE, UNSUPPORTED 1.2M POST SPACING

SILT FENCE SLOPE LENGTH/FENCE LENGTH (FT.)			
SLOPE	STANDARD FENCE	REINFORCED FENCE	SUPER
<2%	300 / 1500	NA	NA
2%-10%	125 / 1000	250 / 2000	300 / 2500
10-20%	100 / 750	150 / 1000	200 / 1000
20%-33%	60 / 500	80 / 750	100 / 1000

2 SILT FENCE DETAIL

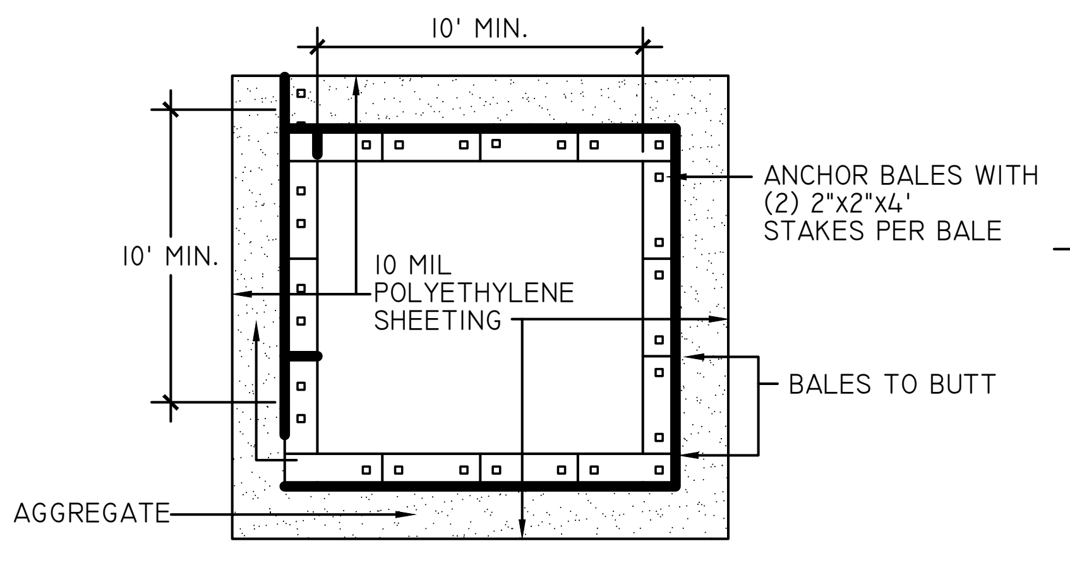
SCALE: N.T.S.

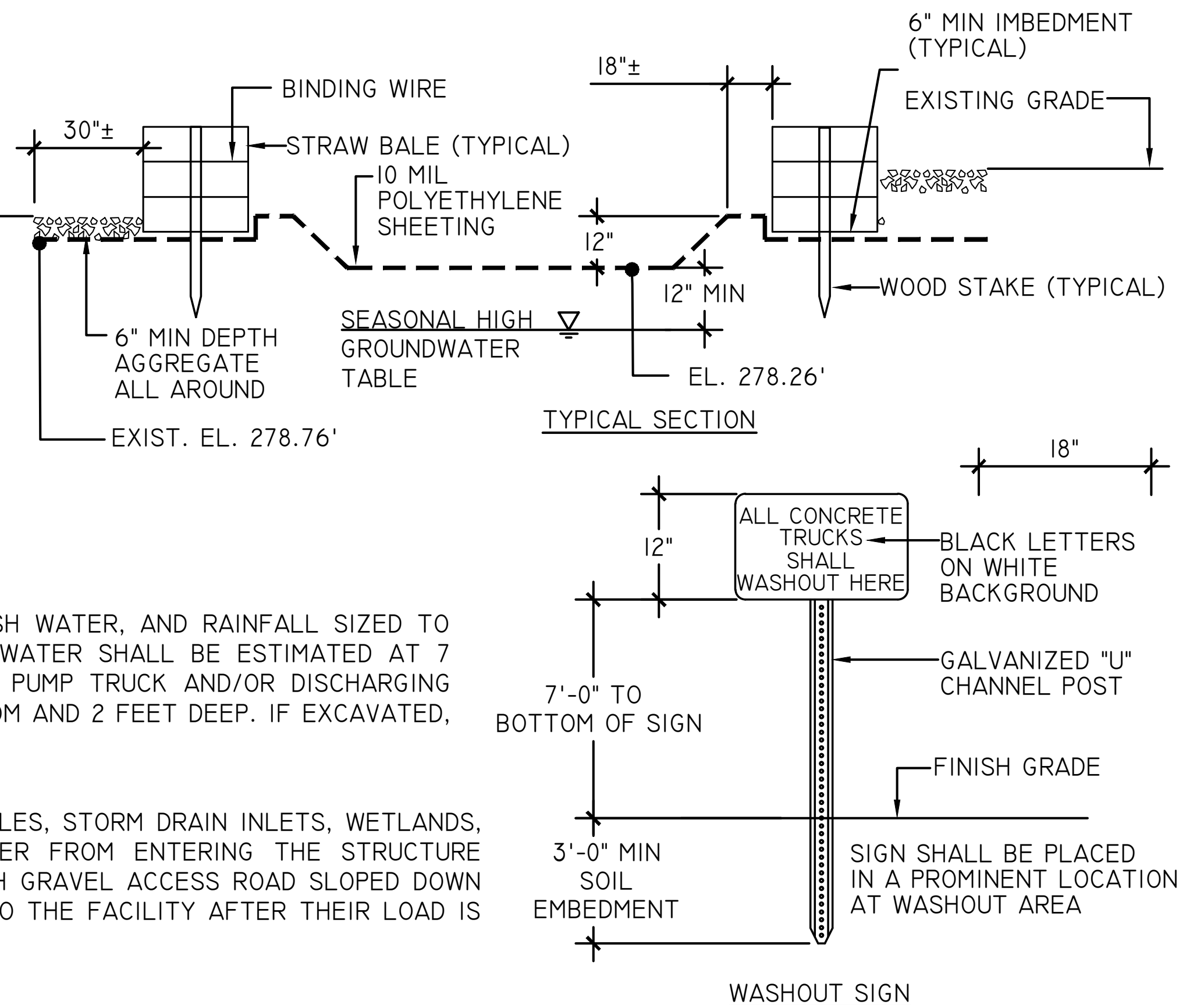


NOTES:
1. REFERENCE IS MADE TO THE SILT FENCE DETAIL FOR MATERIALS AND INSTALLATION METHODS.
2. IF THE STOCKPILE IS TO REMAIN FOR MORE THAN 10 DAYS, IT SHALL BE STABILIZED WITH BURLAP MATTING OR SEEDED WITHIN 7 DAYS OF COMPLETION TO MINIMIZE EROSION.
3. INSPECTION OF SILT FENCES SHALL BE AT LEAST ONCE PER WEEK OR AFTER SUBSTANTIAL RAINFALL. REPAIR OR REPLACE DEFICIENCIES IMMEDIATELY.
4. SILT FENCES SHALL BE MAINTAINED IN PLACE UNTIL TOPSOIL STOCKPILE HAS BEEN ELIMINATED AND SHALL BE REMOVED ONLY WHEN DIRECTED BY TOWN OR ENGINEER.

3 TOPSOIL STOCKPILE DETAIL

SCALE: N.T.S.





CAPACITY:

THE WASHOUT FACILITY SHALL BE SIZED TO CONTAIN SOLIDS, WASH WATER, AND RAINFALL SIZED TO ALLOW FOR EVAPORATION OF WASH WATER AND RAINFALL. WASH WATER SHALL BE ESTIMATED AT 7 GALLONS PER CHUTE AND 50 GALLONS PER HOPPER OF CONCRETE PUMP TRUCK AND/OR DISCHARGING DRUM. THE MINIMUM SIZE SHALL BE 8 FEET BY 8 FEET AT THE BOTTOM AND 2 FEET DEEP. IF EXCAVATED, THE SIDE SLOPES SHALL BE 2 HORIZONTAL TO 1 VERTICAL.

LOCATION:

LOCATE THE FACILITY A MINIMUM OF 100 FEET FROM DRAINAGE SWALES, STORM DRAIN INLETS, WETLANDS, STREAMS AND OTHER SURFACE WATERS. PREVENT SURFACE WATER FROM ENTERING THE STRUCTURE EXCEPT FOR THE ACCESS ROAD. PROVIDE APPROPRIATE ACCESS WITH GRAVEL ACCESS ROAD SLOPED DOWN TO THE STRUCTURE. SIGNS SHALL BE PLACED TO DIRECT DRIVERS TO THE FACILITY AFTER THEIR LOAD IS DISCHARGED.

LINER:

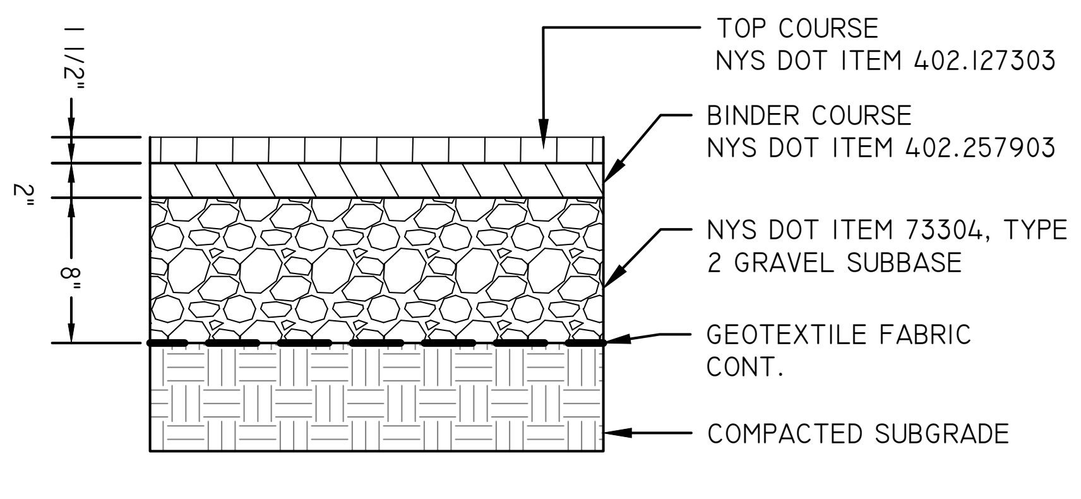
ALL WASHOUT FACILITIES SHALL BE LINED TO PREVENT LEACHING OF LIQUIDS IN THE GROUND. THE LINER SHALL BE PLASTIC SHEETING WITH A MINIMUM THICKNESS OF 10 MILS WITH NO HOLES OR TEAR, AND ANCHORED BEYOND THE TOP OF THE PIT WITH AN APPURTENANCE EXCEPT AT THE ACCESS POINT

IF PRE-FABRICATED WASHOUTS ARE USED THEY MUST ENSURE THE CAPTURE AND CONTAINMENT OF THE CONCRETE WASH AND BE SIZED BASED ON THE EXPECTED FREQUENCY OF CONCRETE POURS. THEY SHALL BE SITED AS NOTED IN THE LOCATION CRITERIA.

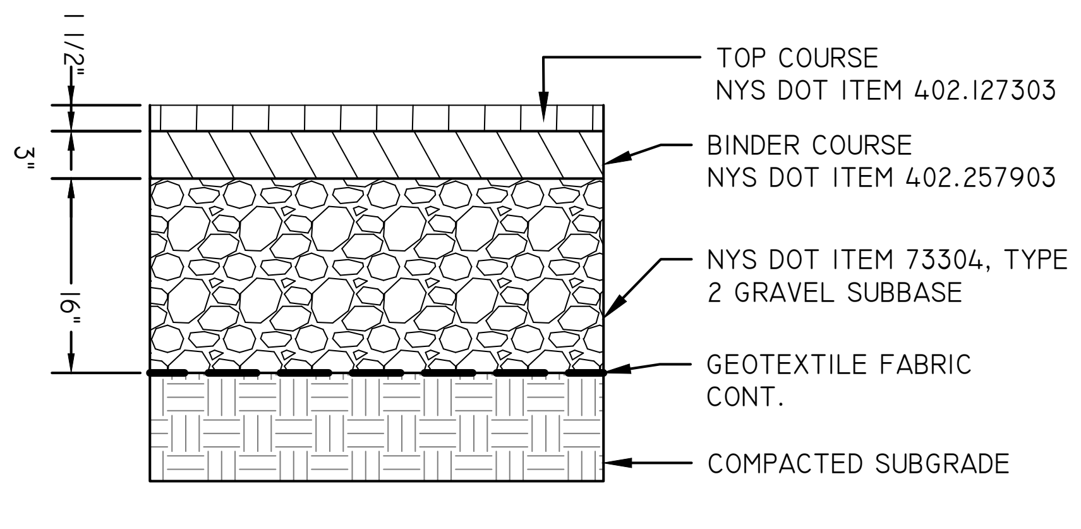
MAINTENANCE:
- ALL CONCRETE WASHOUT FACILITIES SHALL BE INSPECTED DAILY. DAMAGED OR LEAKING FACILITIES SHALL BE DEACTIVATED AND REPAIRED IMMEDIATELY. EXCESS RAINWATER THAT HAS ACCUMULATED OVER HARDENED CONCRETE SHALL BE PUMPED TO A STABILIZED AREA SUCH AS GRASS FILTER STRIP.
- ACCUMULATED HARDENED MATERIAL SHALL BE REMOVED WHEN 75% OF STORAGE CAPACITY OF THE STRUCTURE IS FILLED. ANY EXCESS WASH WATER SHALL BE PUMPED INTO A CONTAINMENT VESSEL AND PROPERLY DISPOSED OF OFF SITE.
- DISPOSE OF THE HARDENED MATERIAL OFF-SITE IN A CONSTRUCTION/DEMOLITION LANDFILL. ON-SITE DISPOSAL MAY BE ALLOWED IF THIS HAS BEEN APPROVED AND ACCEPTED AS PART OF THE PROJECTS SWPPP. IN THAT CASE, THE MATERIAL SHOULD BE RECYCLED AS SPECIFIED, OR BURIED AND COVERED WITH A MINIMUM OF 2 FEET OF CLEAN COMPACTED EARTH FILL THAT IS PERMANENTLY STABILIZED TO PREVENT EROSION.
- THE PLASTIC LINER SHALL BE REPLACED WITH EACH CLEANING OF THE WASHOUT FACILITY.
- INSPECT THE PROJECT SITE FREQUENTLY TO ENSURE THAT NO CONCRETE DISCHARGES ARE TAKING PLACE IN NON-DESIGNATED AREAS.

4 CONCRETE WASHOUT AREA DETAIL

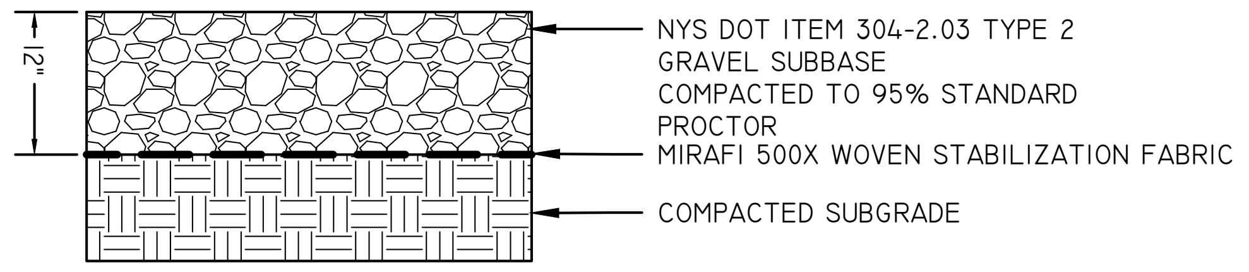
SCALE: N.T.S.



Ⓐ LIGHT DUTY ASPHALT APPLICATION



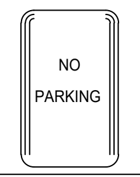
Ⓑ HEAVY DUTY ASPHALT APPLICATION



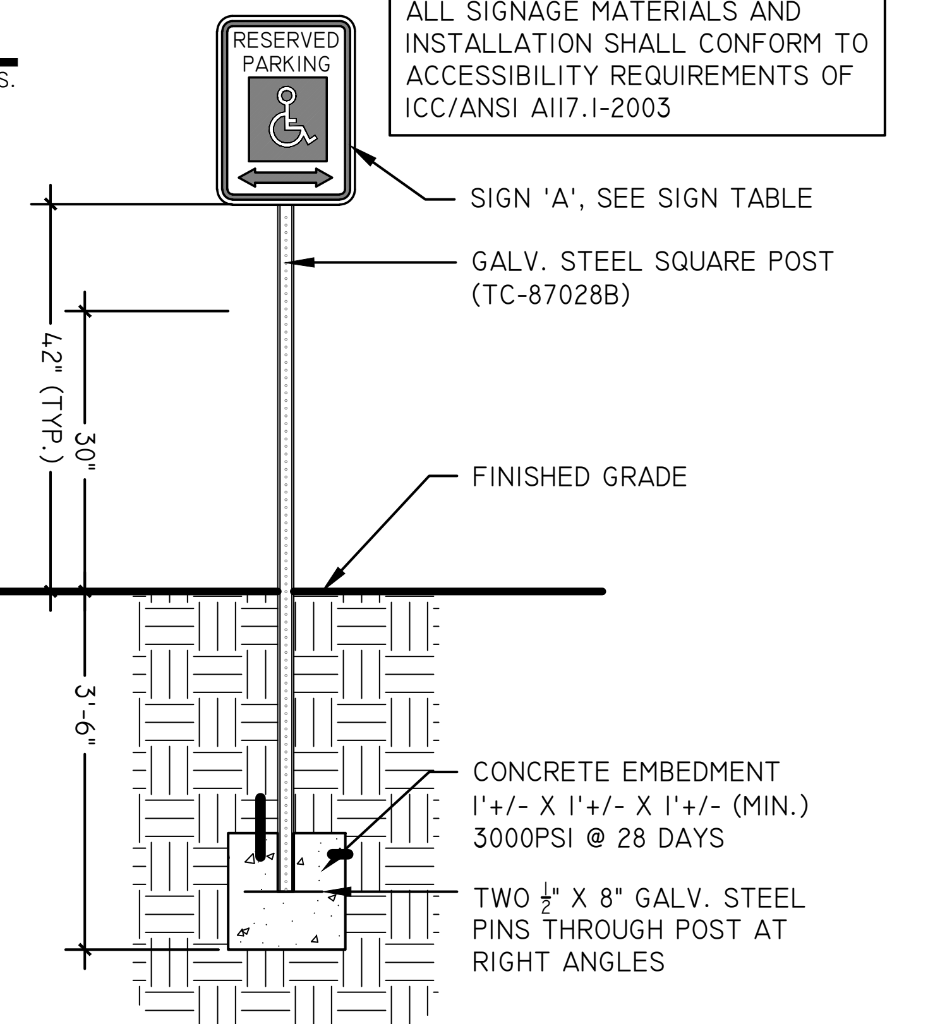
Ⓒ GRAVEL SURFACE APPLICATION

5 SURFACE SCHEDULE

SCALE: N.T.S.

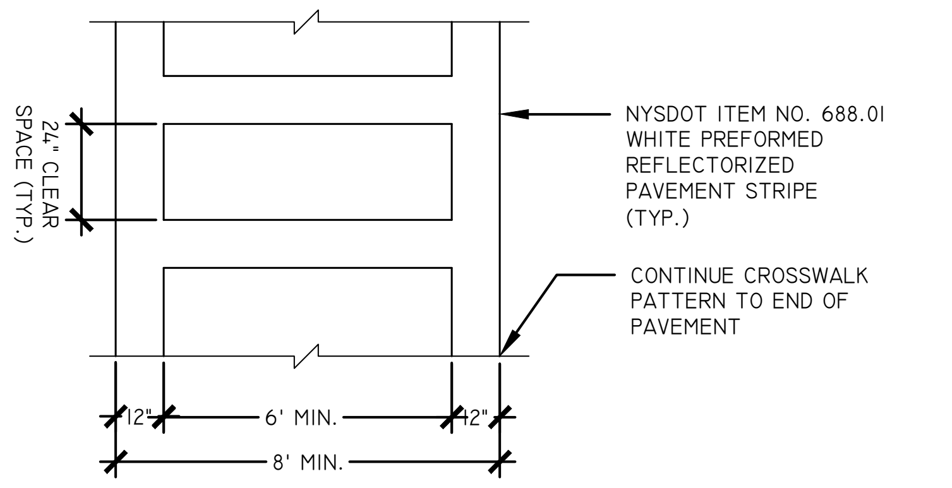
SITE SIGN TABLE				
SIGN NO.	DESCRIPTION	M.U.T.C.D. NO./SIZE	QTY	COLORS
A		R7-1 12"x18"	2	GREEN LEGEND/BORDER, WHITE BKGD
B		M1982 12"x18"	1	GREEN LEGEND/BORDER, WHITE BKGD

NOTE:
ALL SIGNAGE MATERIALS AND INSTALLATION SHALL CONFORM TO ACCESSIBILITY REQUIREMENTS OF ICC/ANSI A117.1-2003



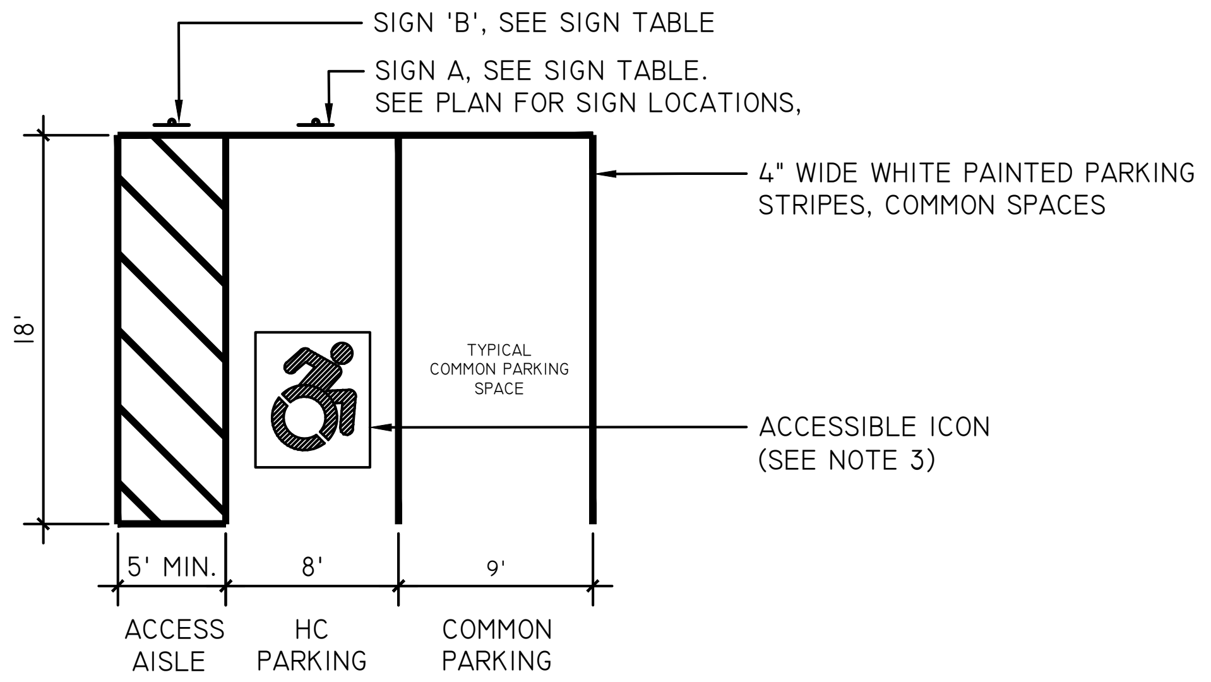
6 ACCESSIBLE SIGN DETAIL

SCALE: N.T.S.



7 CROSSWALK STRIPING DETAIL

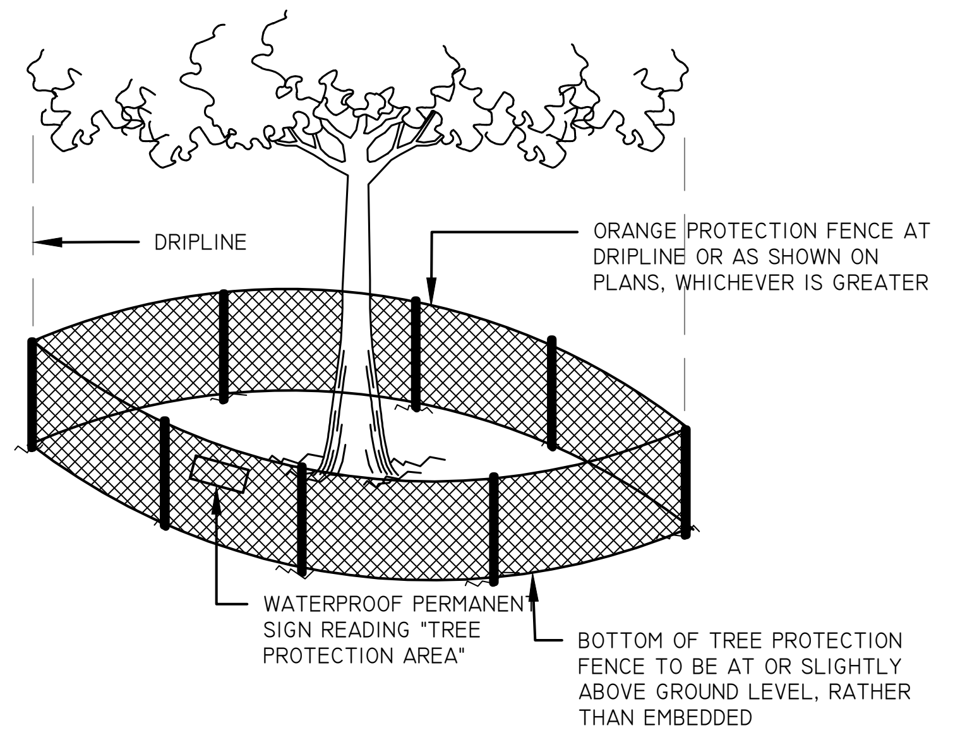
SCALE: N.T.S.

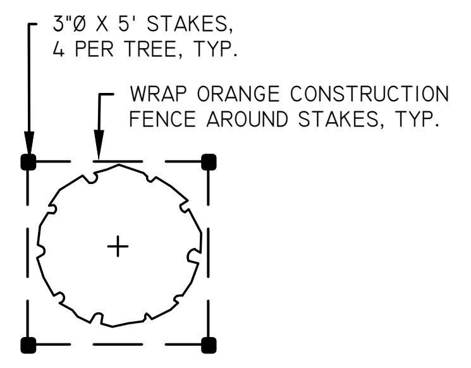


NOTES:
1. ALL DIMENSIONS SHALL BE IN ACCORDANCE WITH ADA STANDARD AND CURRENT ZONING AND SITE REGULATIONS.
2. PAINTED ACCESSIBLE LOGO TO BE IN ACCORDANCE WITH NEW YORK STATE LAW.
3. SLOPE OF PAVEMENT SURFACE IN HANDICAP PARKING AREA SHALL NOT EXCEED 2% IN ANY DIRECTION.

8 PARKING LOT STRIPING DETAIL

SCALE: N.T.S.

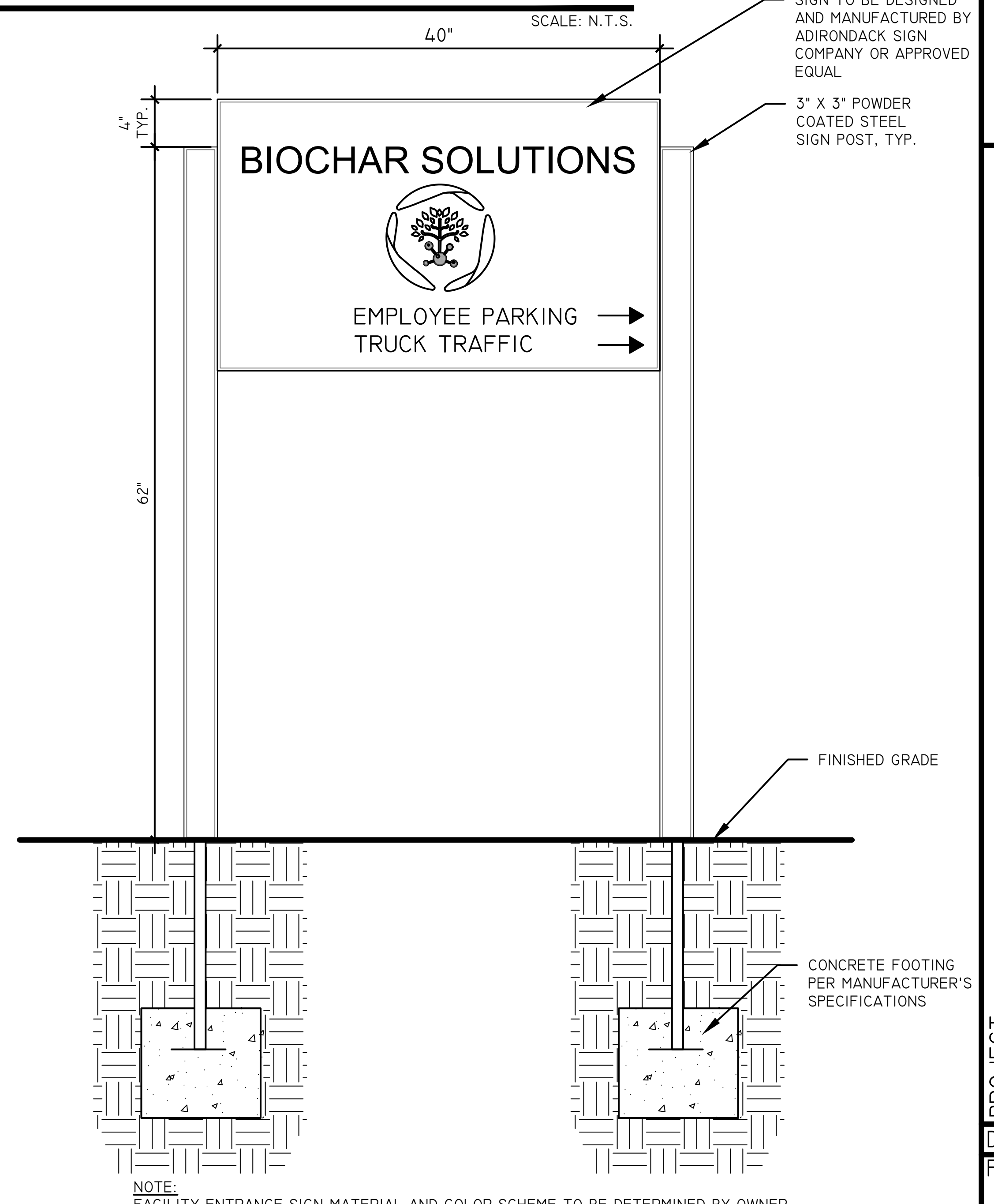




NOTES:
1. NO SOIL PLACEMENT OVER EXISTING TREE AND SHRUB ROOTS. NO SOIL SHOULD BE ADDED WITHIN PROTECTED AREAS UNLESS ADDED TO ACHIEVE PROPOSED GRADES.
2. NO TRENCHING IN PROTECTED AREAS. TRENCHING ACROSS THE ROOT SYSTEMS SHOULD START NO CLOSER THAN THE DRIPLINE OF THE TREE. TUNNEL UNDER ROOT SYSTEMS FOR UNDERGROUND UTILITIES SHOULD START 18 INCHES OR DEEPER BELOW THE NORMAL GROUND SURFACE. TREE ROOTS WHICH MUST BE SEVERED SHOULD BE CUT CLEAN. BACKFILL MATERIAL THAT WILL BE IN CONTACT WITH THE ROOTS SHOULD BE TOPSOIL OR A PREPARED PLANTING SOIL MIXTURE.
3. CONSTRUCT STURDY FENCES, OR BARRIERS, OF WOOD, STEEL, OR OTHER PROTECTIVE MATERIAL AROUND VALUABLE VEGETATION FOR PROTECTION FROM CONSTRUCTION EQUIPMENT.
4. PREVENT TALL EQUIPMENT, SUCH AS BACKHOES AND DUMP TRUCKS, FROM CONTACTING TREE BRANCHES.
5. SEE L-0.10 FOR TREE PROTECTION LOCATIONS.

9 TREE PROTECTION DETAIL

SCALE: N.T.S.



NOTE:
FACILITY ENTRANCE SIGN MATERIAL AND COLOR SCHEME TO BE DETERMINED BY OWNER. NO ILLUMINATION FEATURES ARE TO BE USED.

10 ENTRANCE SIGN DETAIL

SCALE: N.T.S.

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MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866

OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866

(518) 450-4030

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REVISIONS						
DESCRIPTION						
DATE						

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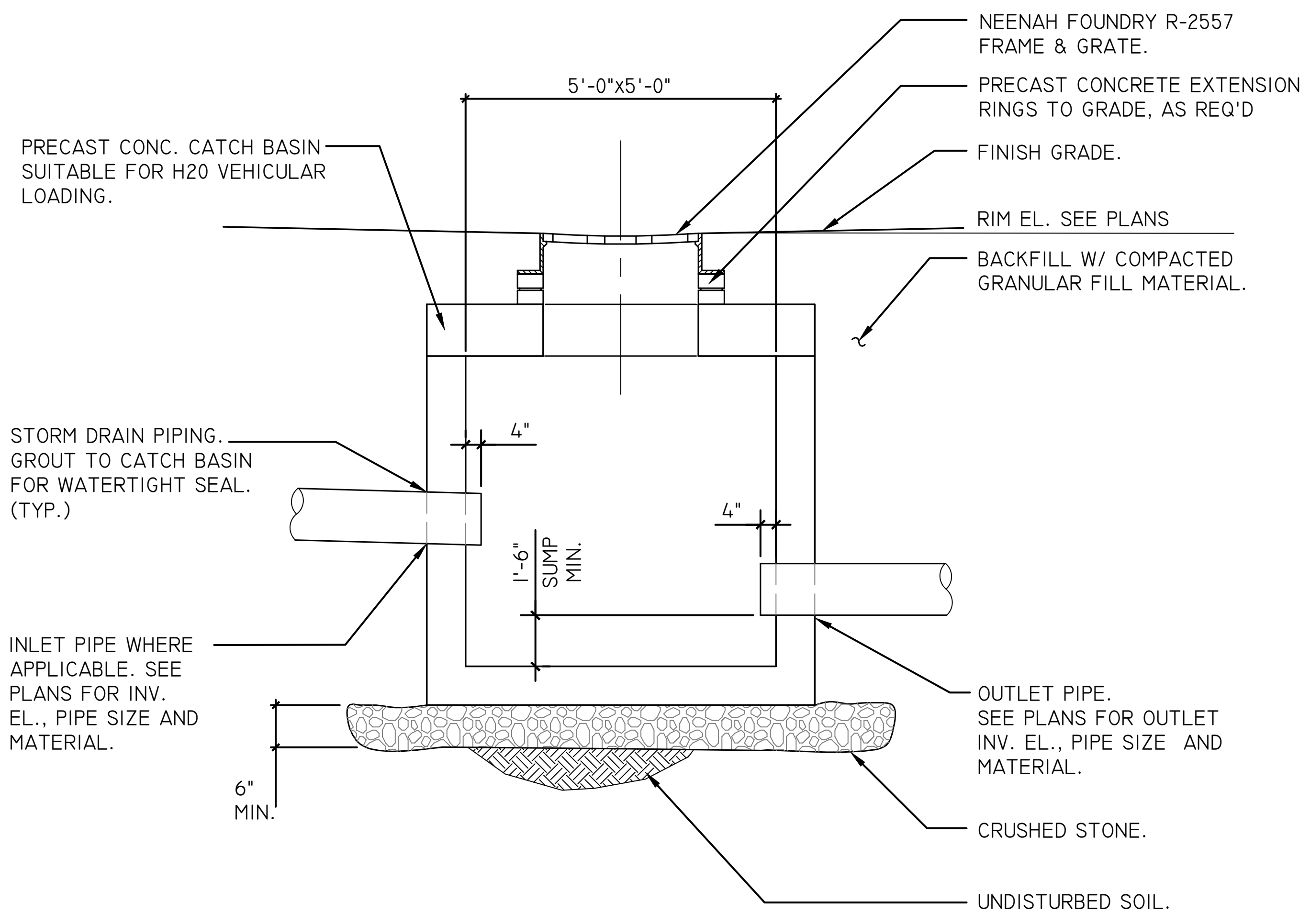
SARATOGA BIOCHAR SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

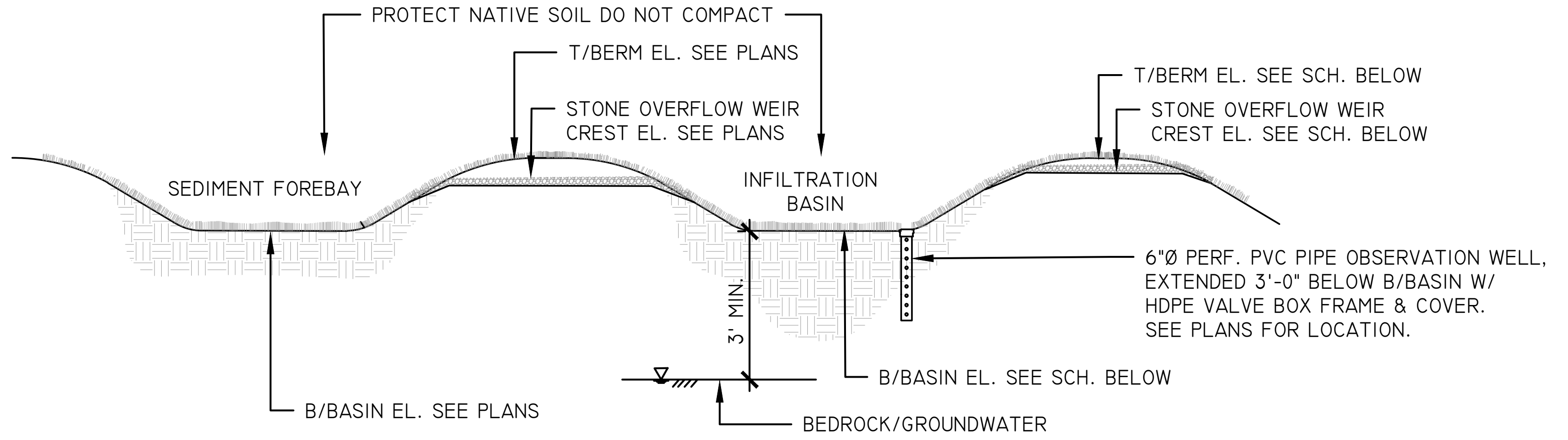
DRAWING TITLE
CONSTRUCTION DETAILS

DATE: 03/25/2022
PROJECT NO. 20019
DRAWING NO.
L-4.10
DWG 5 OF 9



① PRECAST CONCRETE CATCH BASIN DETAIL

SCALE: N.T.S.

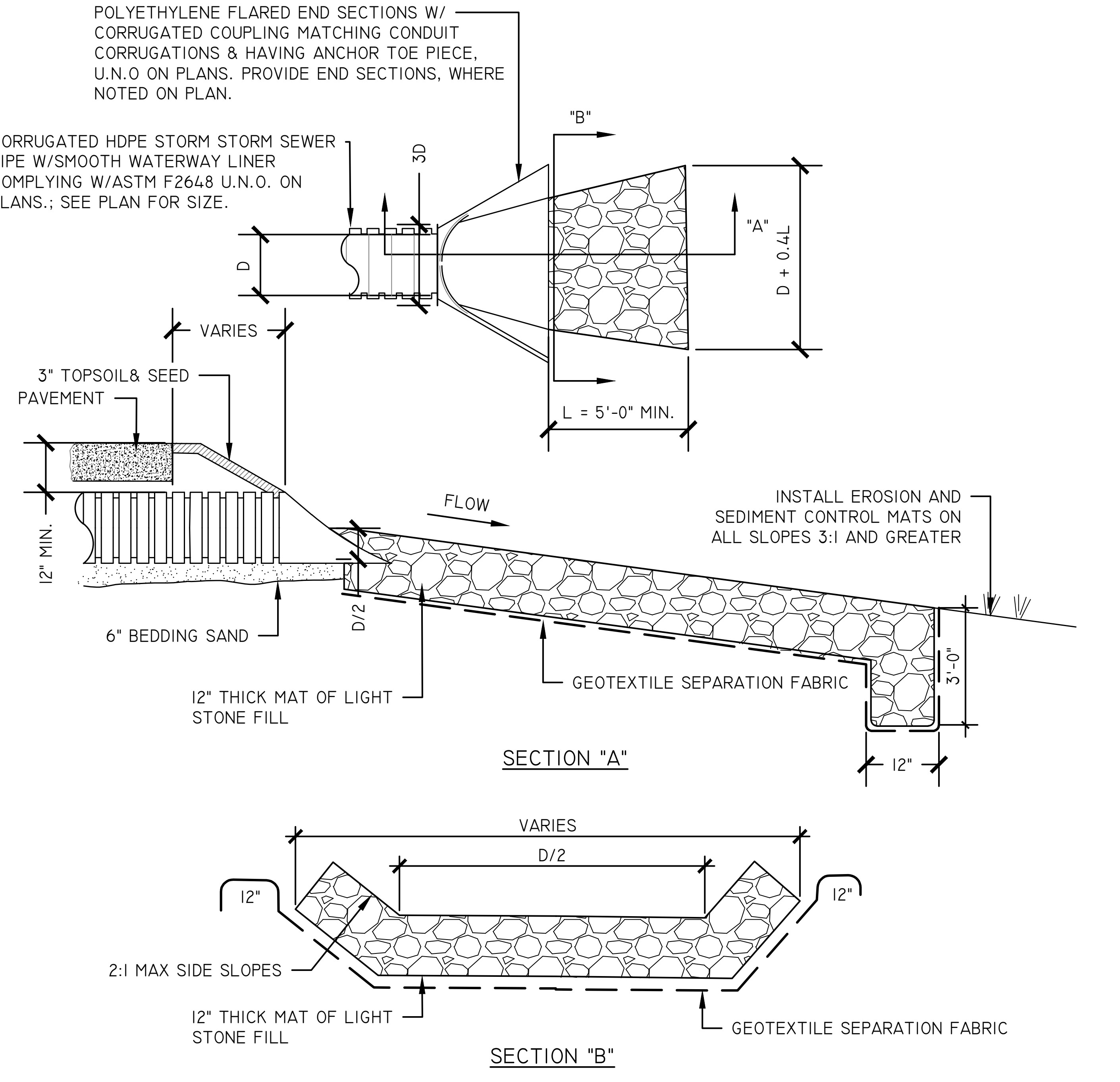


INFILTRATION BASIN SCHEDULE				
BASIN ID	PRETREATMENT VOL. PROV'D	T/BERM	B/BASIN	OUTLET CREST EL.
IF-1	7240 CF	283.5'	280.0'	282.75'
IF-2	5103 CF	280.5'	278.0'	279.25'
IF-3	4977 CF	278.5'	277.0'	277.75'

WATER SURFACE ELEVATIONS			
BASIN ID	DESIGN STORM		
	1-YR	10-YR	100-YR
IF-1	280.0'	280.01'	281.19'
IF-2	278.0'	278.04'	279.43'
IF-3	277.0'	277.0'	277.01'

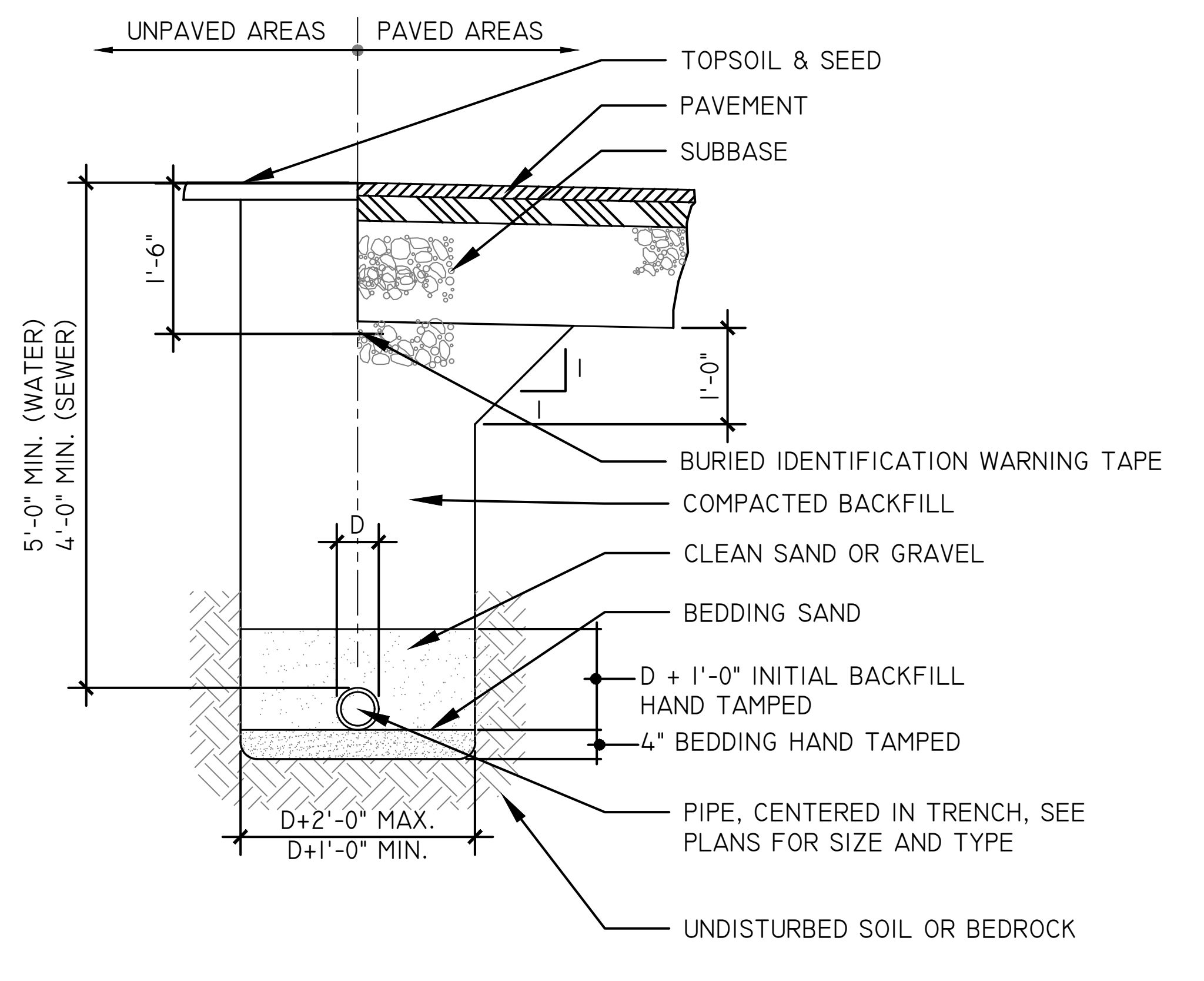
② TYPCIAL INFILTRATION BASIN DETAIL

SCALE: N.T.S.



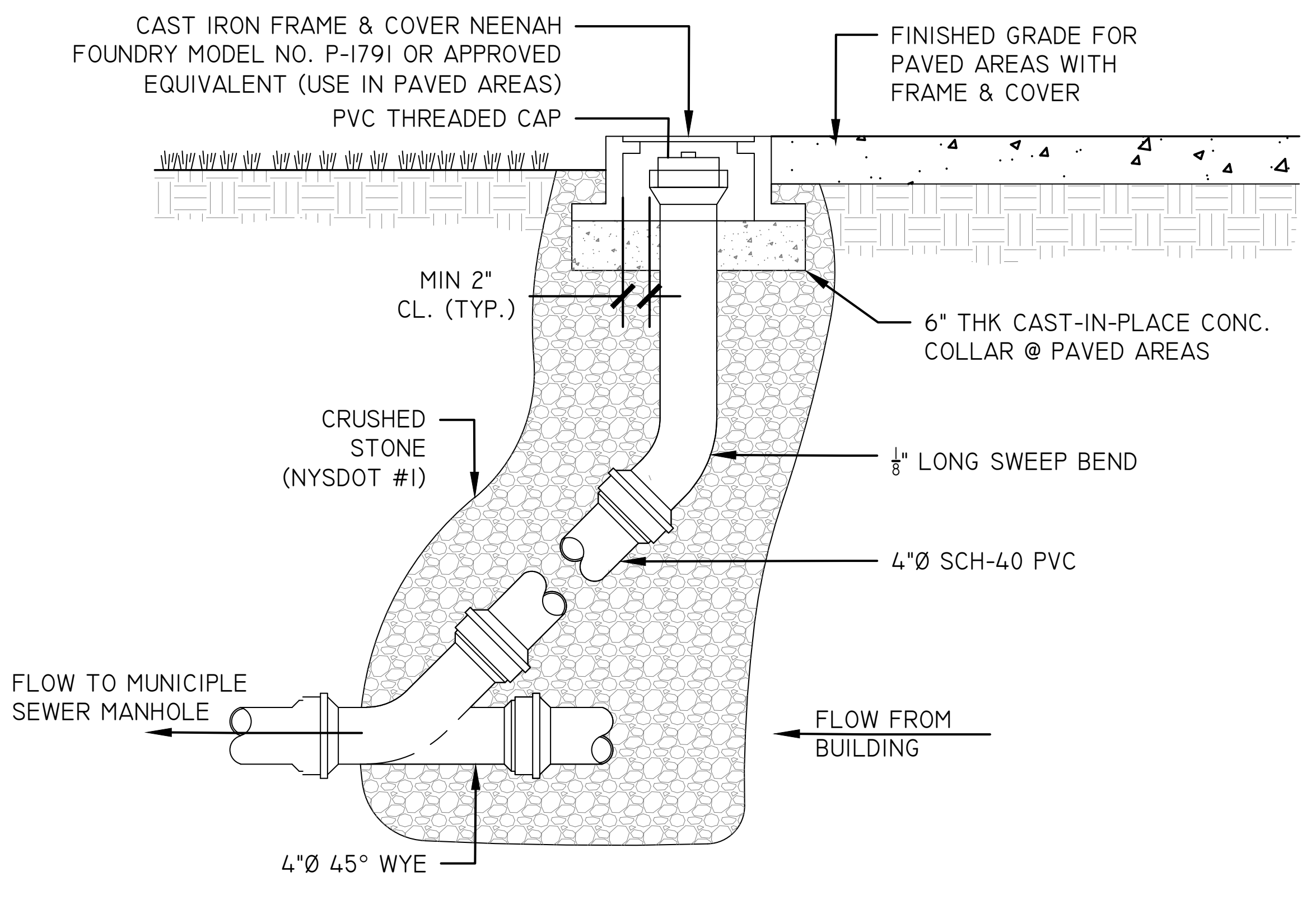
③ STONE OUTLET PROTECTION DETAIL

SCALE: N.T.S.



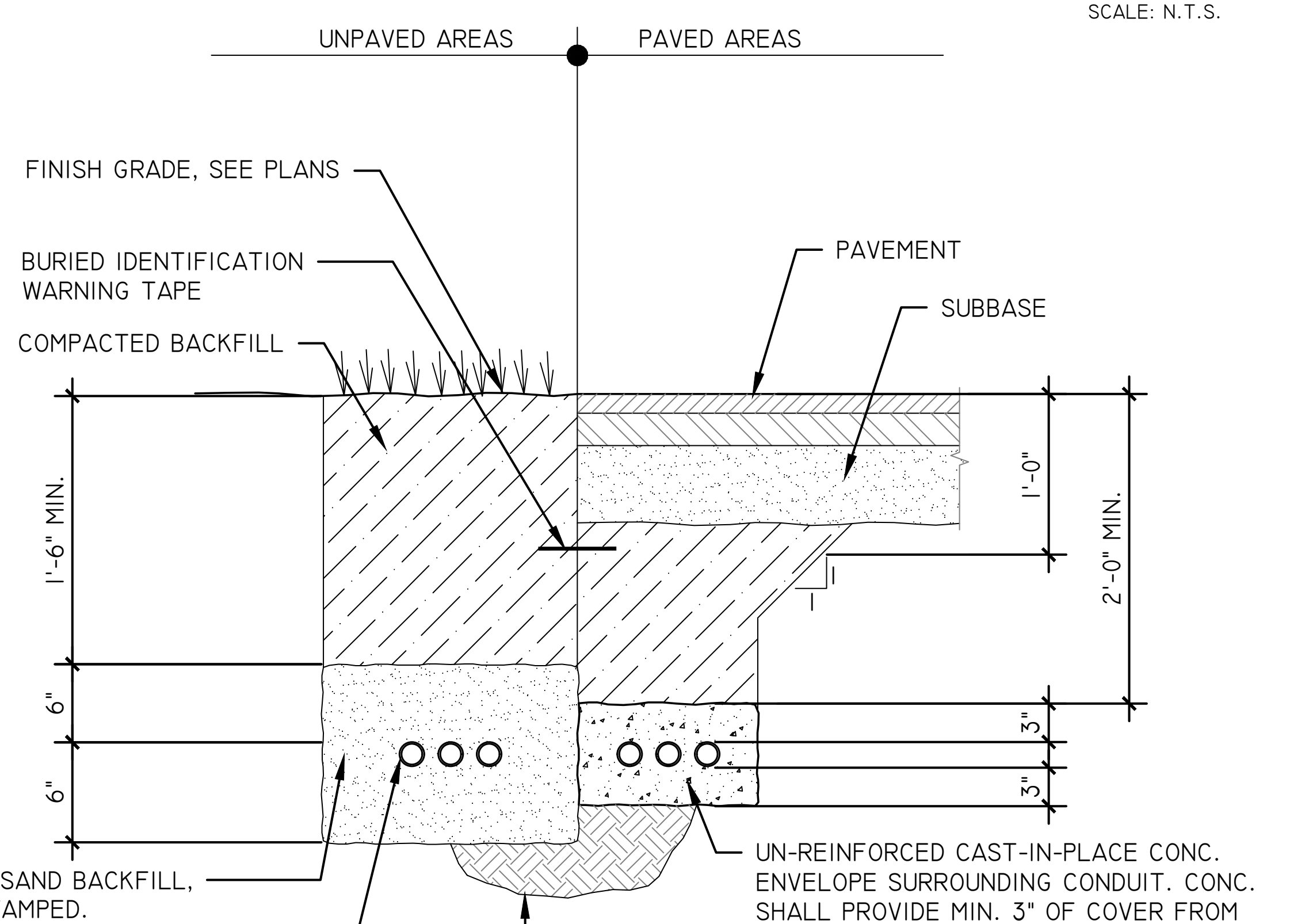
⑤ PIPE TRENCH DETAIL

SCALE: N.T.S.



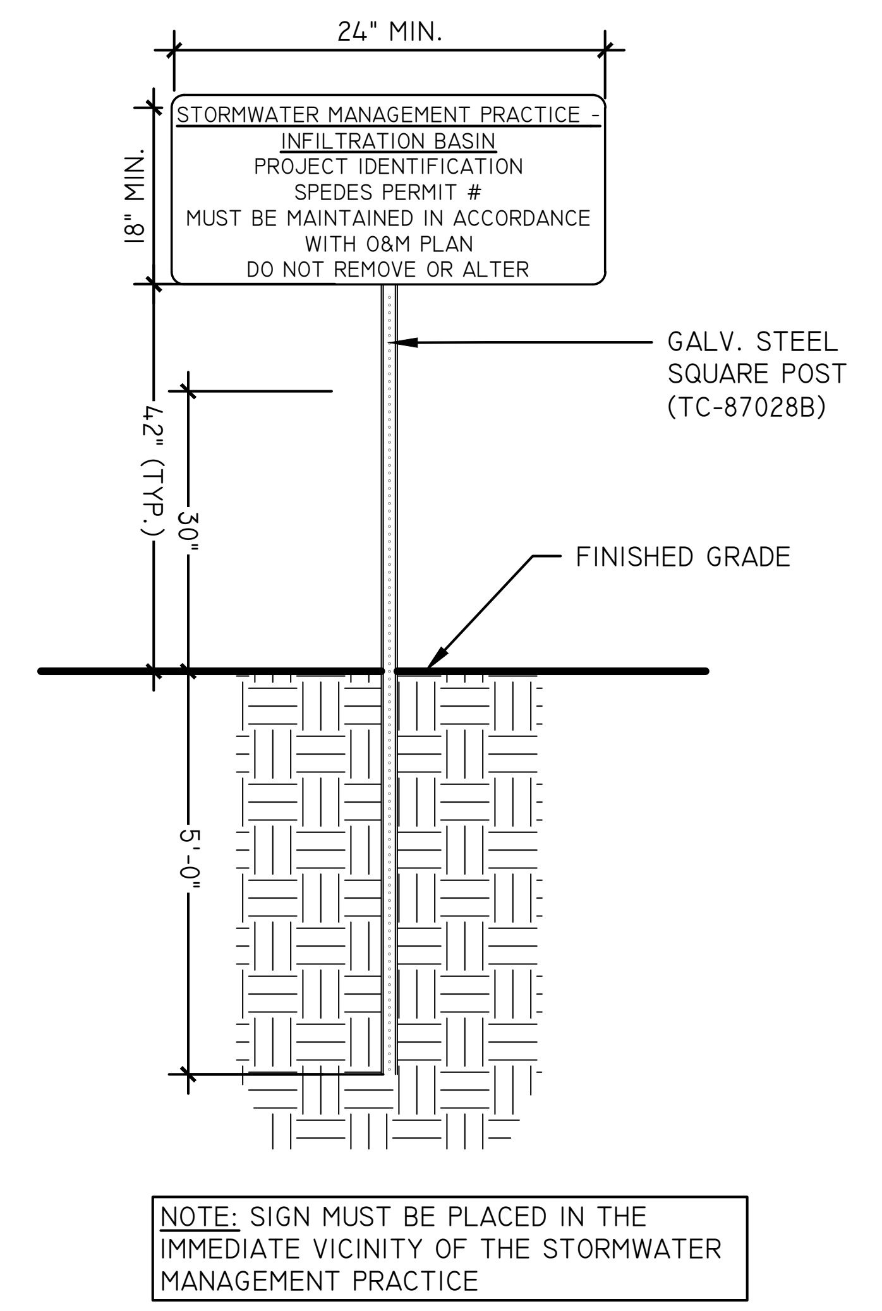
⑥ SEWER CLEANOUT DETAIL

SCALE: N.T.S.



⑨ TYPICAL CONDUIT TRENCH DETAIL

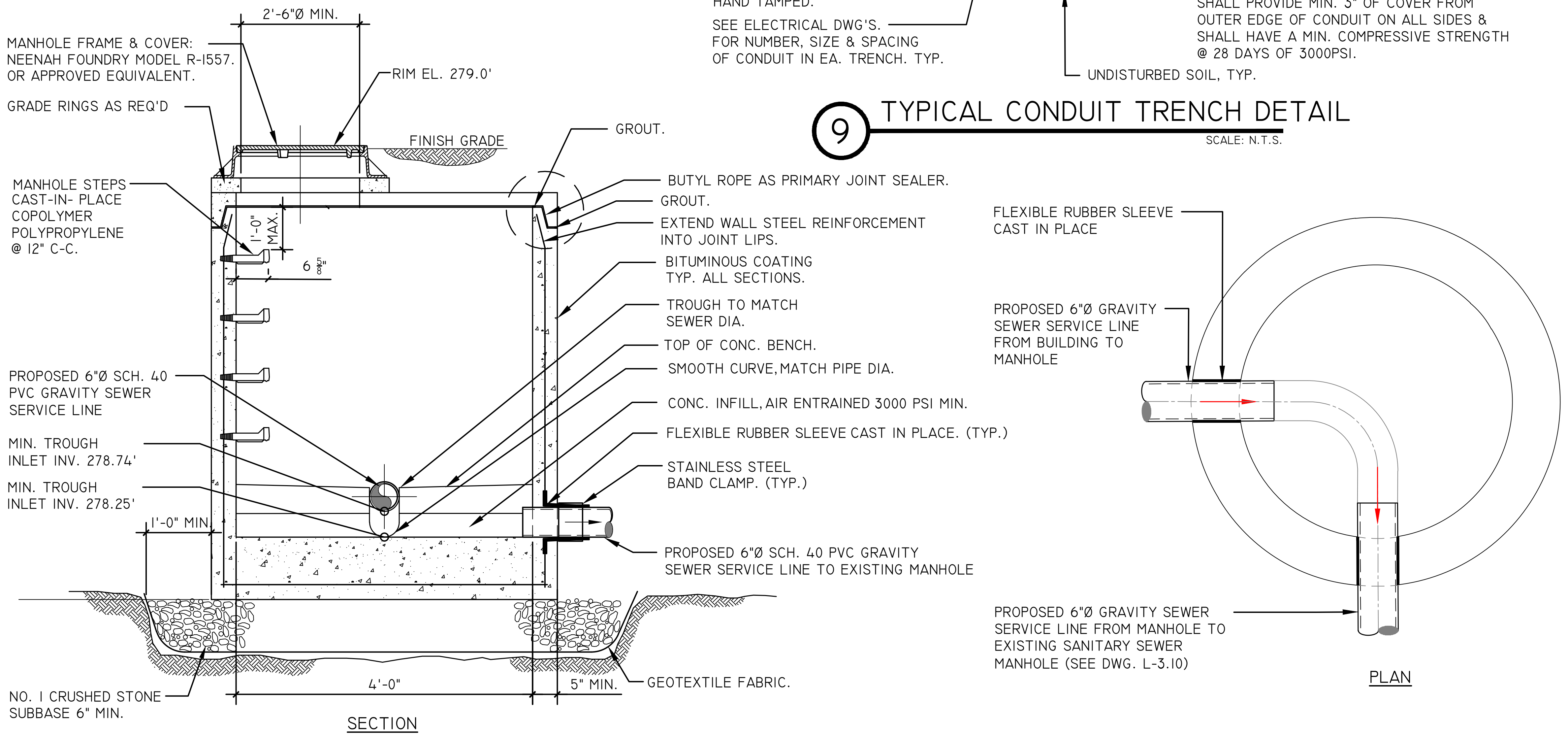
SCALE: N.T.S.



NOTE: SIGN MUST BE PLACED IN THE IMMEDIATE VICINITY OF THE STORMWATER MANAGEMENT PRACTICE

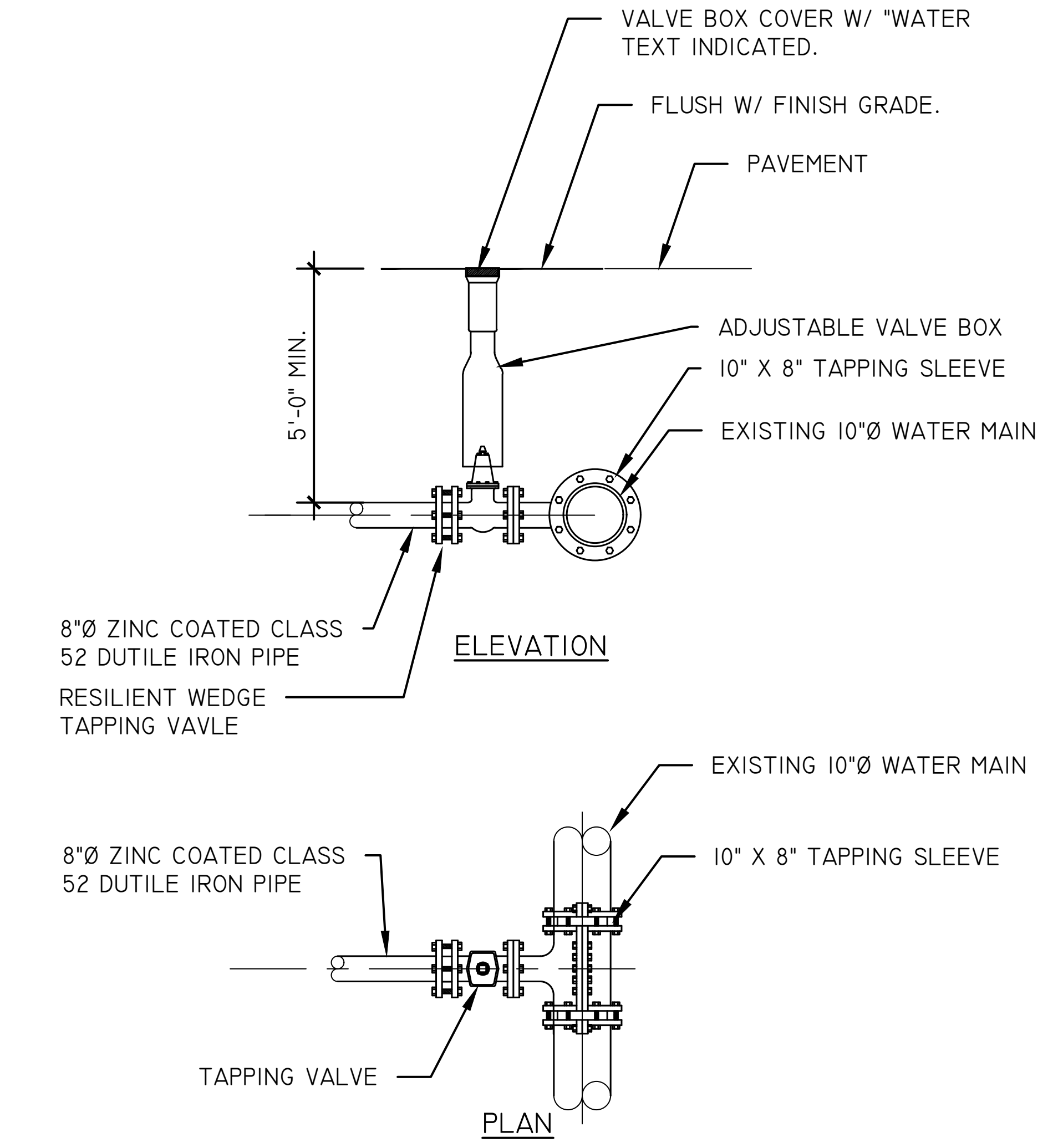
④ SWM FACILITY SIGN DETAIL

SCALE: N.T.S.



⑦ TYPCIAL PRECAST CONCRETE SEWER MANHOLE DETAIL

SCALE: N.T.S.



⑧ WATER MAIN TAPPING SLEEVE

SCALE: N.T.S.

DESIGN BY: ####
DRAWN BY: ####
CHECKED BY: ####

PLOTTED BY: QUINN ROESCH
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FILE NAME: Z:\Projects\2020 Projects\20019 - BioChar Solutions\DWG\03 SHEETS\20019_UTILITY DETAILS.dwg

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LANDSCAPE ARCHITECTURE + ENGINEERING, DPC
MAILING:
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OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866

(518) 450-4030

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SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
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DATE: 03/25/2022
PROJECT NO. 20019
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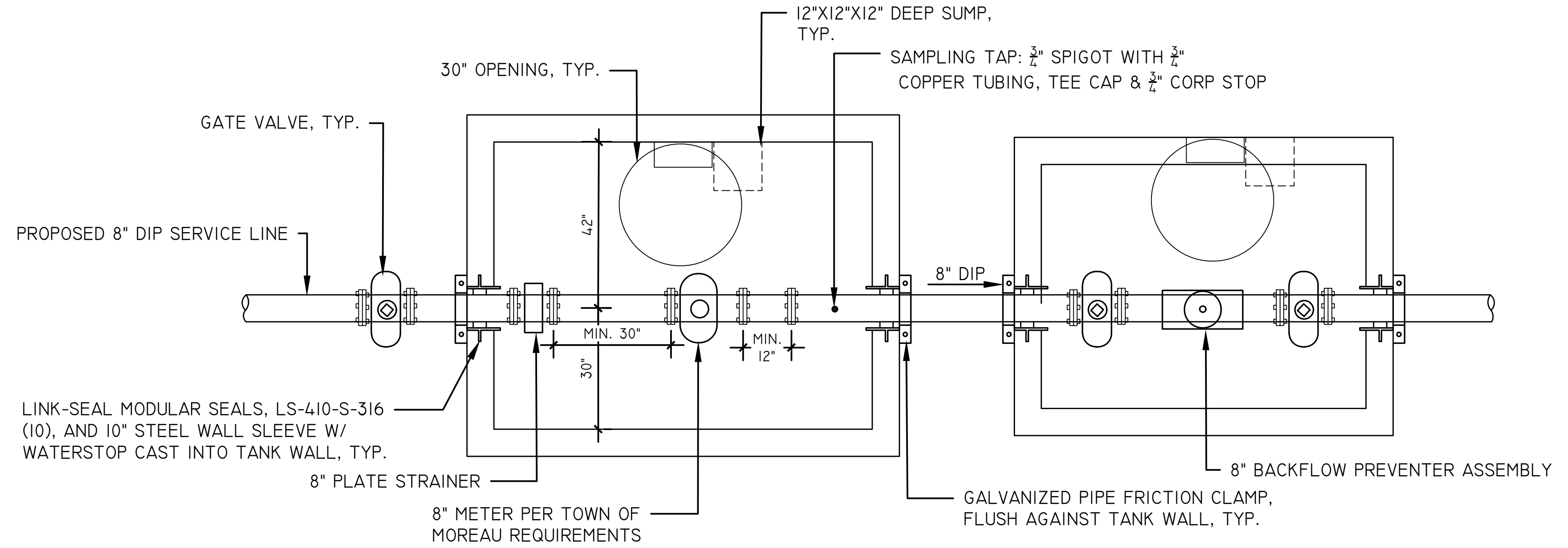
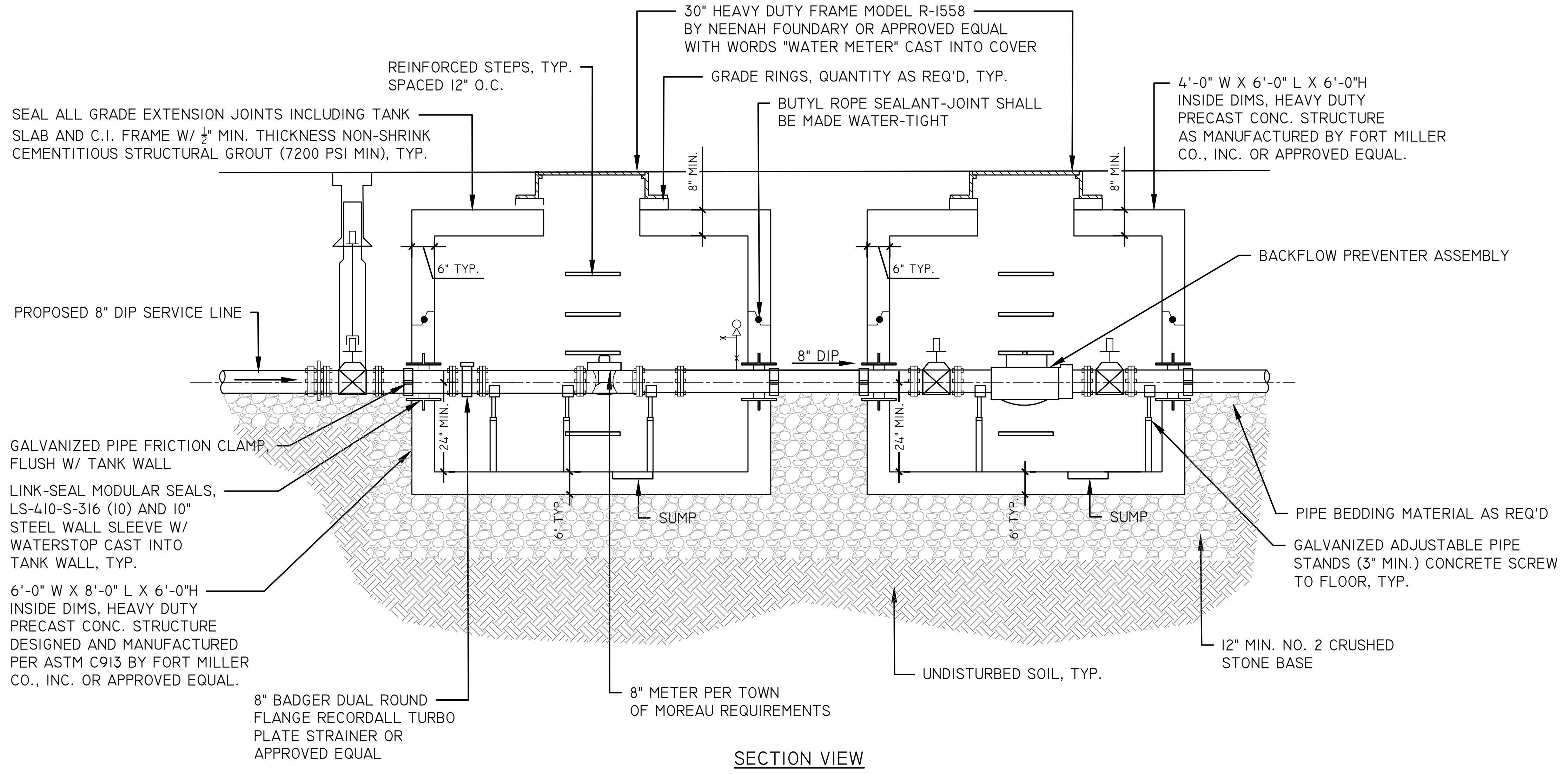
L-5.10
DWG 6 OF 9



PLAN VIEW

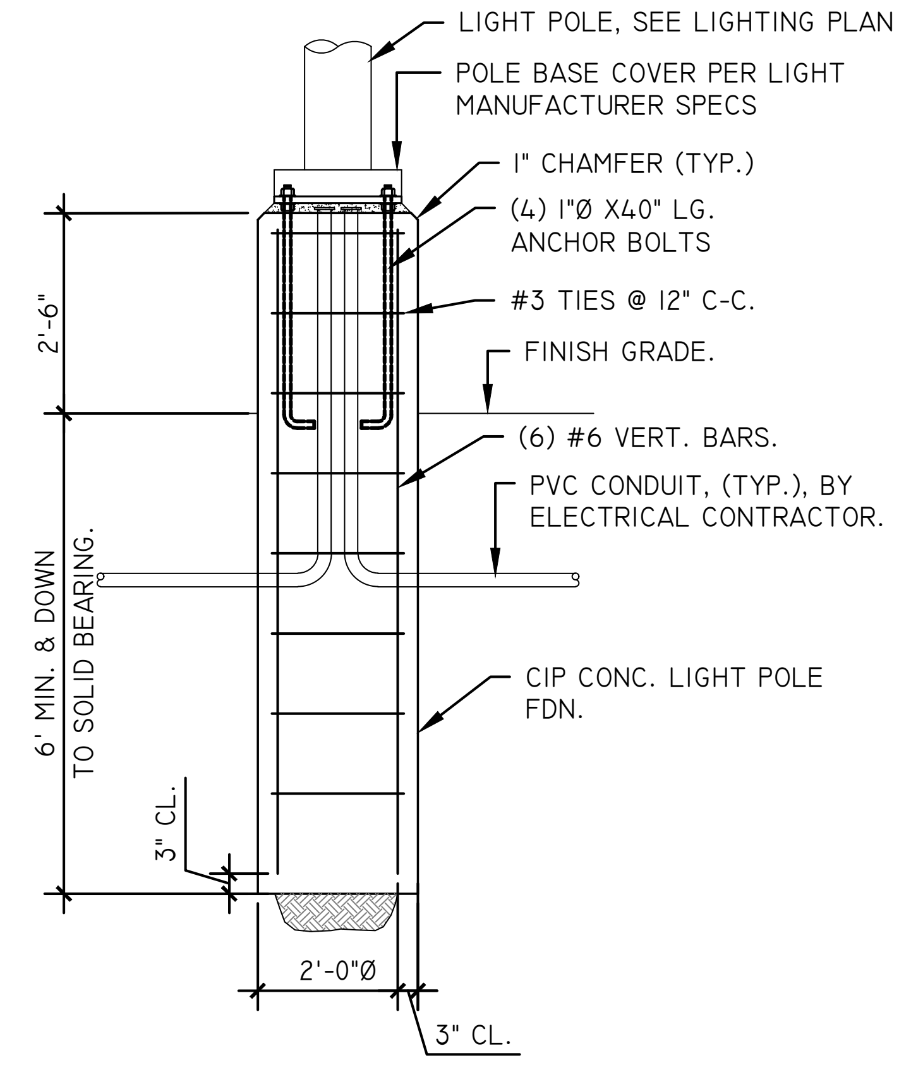


SECTION VIEW

NOTE: ALL INTERIOR PIPE JOINTS SHALL BE FLANGED-TYPE, USE FLANGE-END PIPE AND MAX. (2) FLANGE ADAPTERS. ALL FLANGE NUTS AND BOLTS SHALL BE EITHER STAINLESS STEEL OR FLUOROPOLYMER COATED ALLOY STEEL 'BLUE BOLTS'

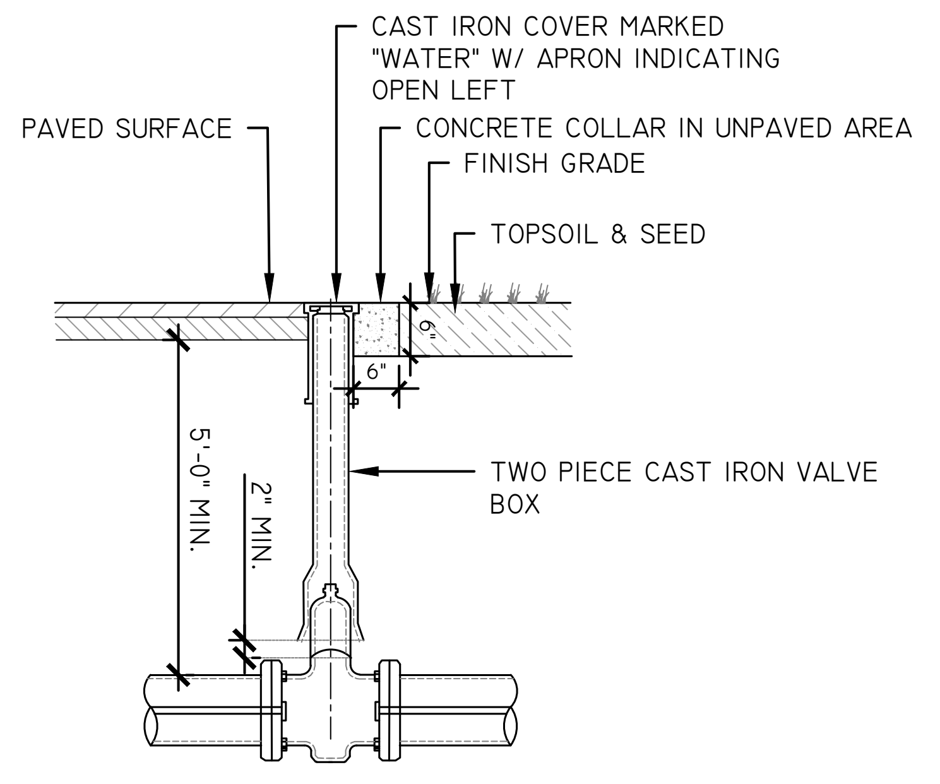
① WATER METER PIT AND BACKFLOW PREVENTER VAULT DETAIL

SCALE: N.T.S.



② TYPICAL LIGHT POLE FDN DETAIL

SCALE: N.T.S.



NOTES:
1. NON-RISING STEM GATE VALVE, OPERATING DIRECTION SHALL BE COUNTERCLOCKWISE TO OPEN.
2. MINIMUM DISTANCE TO JOINTS, FITTINGS OR OTHER WET TAPS OR STOPS SHALL BE 3-FEET.
3. IF VALVE IS TO BE RODDED, PROVIDE VALVE WITH RODDING FLANGES OR EYEBOLTS. TWO (2) $\frac{3}{4}$"Ø GALVANIZED STEEL RODS WITH MALLEABLE IRON NUTS AT 180° SPACING SHALL BEE USED FOR RODDING VALVES.
4. GATE VALVE SHALL BE IN ACCORDANCE WITH MUNICIPAL STANDARDS & AS MANUFACTURED BY CLOW OR APPROVED EQUAL.
5. VALVE BOX SHALL BE SIGMA MODEL VB466 W/ VB2600 COVER OR APPROVED EQUAL.

③ TYPICAL GATE VALVE DETAIL

SCALE: N.T.S.

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PLOTTED BY: QUINN ROESCH
SAVE DATE: 3/30/2022 12:03 PM
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DATE	DESCRIPTION

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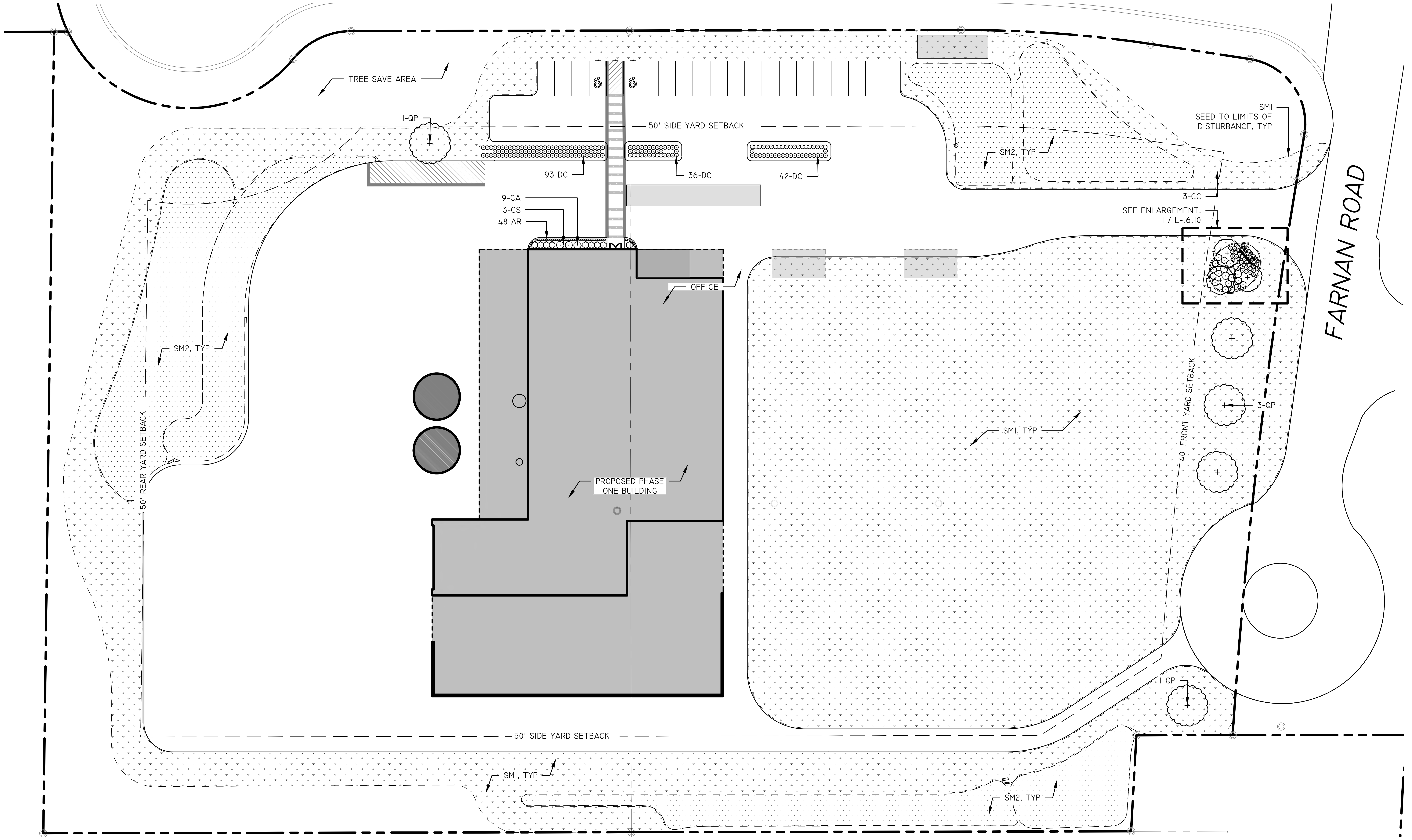
BIOCHAR SOLUTIONS
WASTE NOT

PREPARED FOR
SARATOGA BIOCHAR
SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

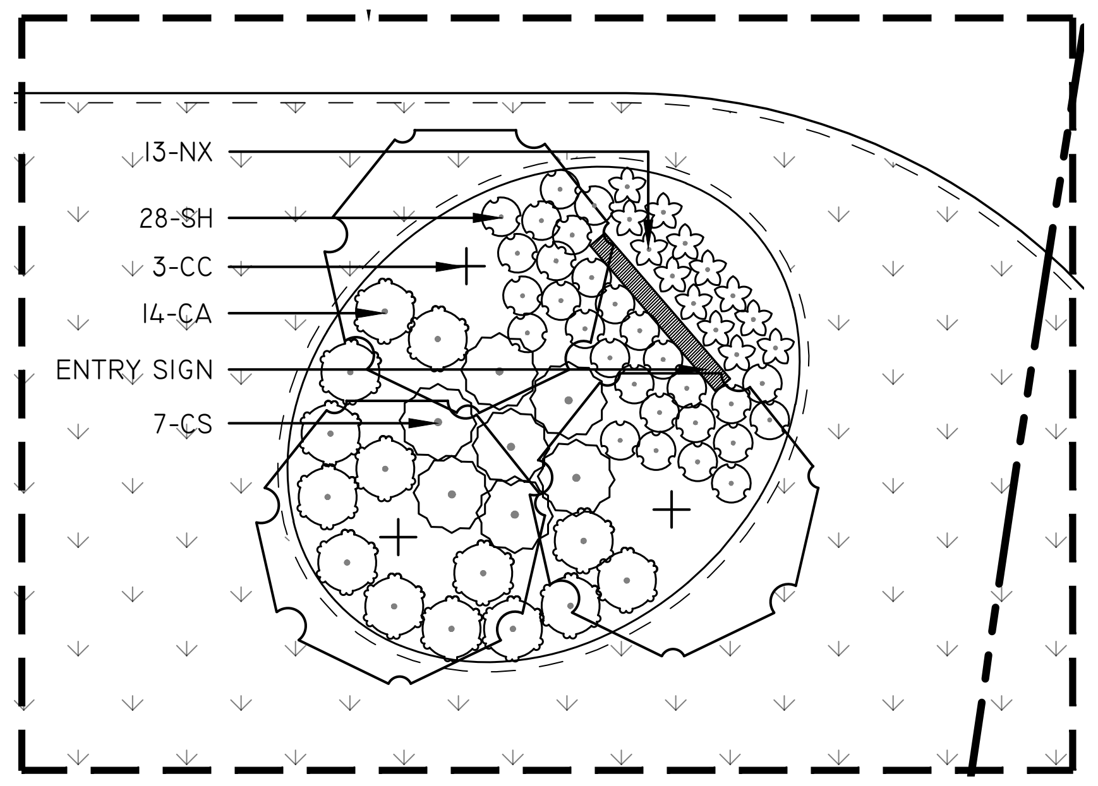
DRAWING TITLE
CONSTRUCTION DETAILS

DATE: 03/25/2022
PROJECT NO.
20019
DRAWING NO.
L-5.11
DWG 7 OF 9



PLANTING NOTES:

1. ALL PLANT BEDS TO BE MULCHED WITH 4" DEEP BROWN HARDWOOD MULCH, UNLESS OTHERWISE NOTED ON THE PLANS.
2. PRIOR TO PLANTING, CONTRACTOR SHALL LOCATE, VERIFY, AND REPORT ANY CONFLICTS OF EXISTING UTILITY LINES TO THE LANDSCAPE ARCHITECT.
3. ALL NEW PLANT MATERIAL SHALL CONFORM TO THE MINIMAL GUIDELINES ESTABLISHED BY THE AMERICAN STANDARD FOR NURSERY STOCK PUBLISHED BY THE AMERICAN ASSOCIATION OF NURSERYMEN, INC. AND SHALL BE OF SPECIMEN QUALITY UNLESS APPROVED OTHERWISE BY DIRECTOR'S REPRESENTATIVE.
4. WRITTEN APPROVAL IS REQUIRED FROM LANDSCAPE ARCHITECT OF ANY PROPOSED SUBSTITUTIONS OF PLANT MATERIAL. CHANGED PLANTS SHALL BE EQUIVALENT FORM, HEIGHT, FLOWER, COLOR, LEAF, SIZE, BRANCHING, CULTURE AND FRUIT.
5. A MINIMUM OF 6" OF SUITABLE TOPSOIL IS REQUIRED IN AREAS WITH PROPOSED LAWN SEEDING PRIOR TO SEEDING.
6. PRIOR TO COMMENCEMENT OF PLANTING, STAKE LOCATION OF ALL PLANTINGS FOR APPROVAL BY LANDSCAPE ARCHITECT.
7. SCHEDULE DELIVERY OF PLANTS ONLY IN REASONABLE TIME AS TO WHEN THEY CAN BE INSTALLED. PLANTS TO BE INSPECTED BY LANDSCAPE ARCHITECT AT DELIVERY.
8. MAINTENANCE TO BEGIN IMMEDIATELY FOLLOWING INSTALLATION OF PLANT MATERIALS AND LAWN UNTIL FINAL ACCEPTANCE.
9. TREES SHALL NOT BE PLANTED BEFORE ACCEPTANCE OF ROUGH GRADING. TREES SHALL BE PLANTED 3" HIGHER THAN PREVIOUS GRADE. SHRUBS AND GROUND COVER SHALL BE PLANTED AS THE SAME RELATIONSHIP TO GRADE AS PREVIOUS GRADE.
10. PLANT MATERIAL QUANTITIES TO BE PROVIDED BY CONTRACTOR AS SHOWN ON DRAWINGS.
11. UNLESS NOTED ON PLANT LIST, PLANTS TO BE BALLED AND BURLAPPED OR CONTAINER GROWN.
12. FOR SEEDING OF DISTURBED AREAS USE SPECIFIED MIX FOR DESIGNATED AREA OR APPROVED EQUAL APPROVED BY LANDSCAPE ARCHITECT.

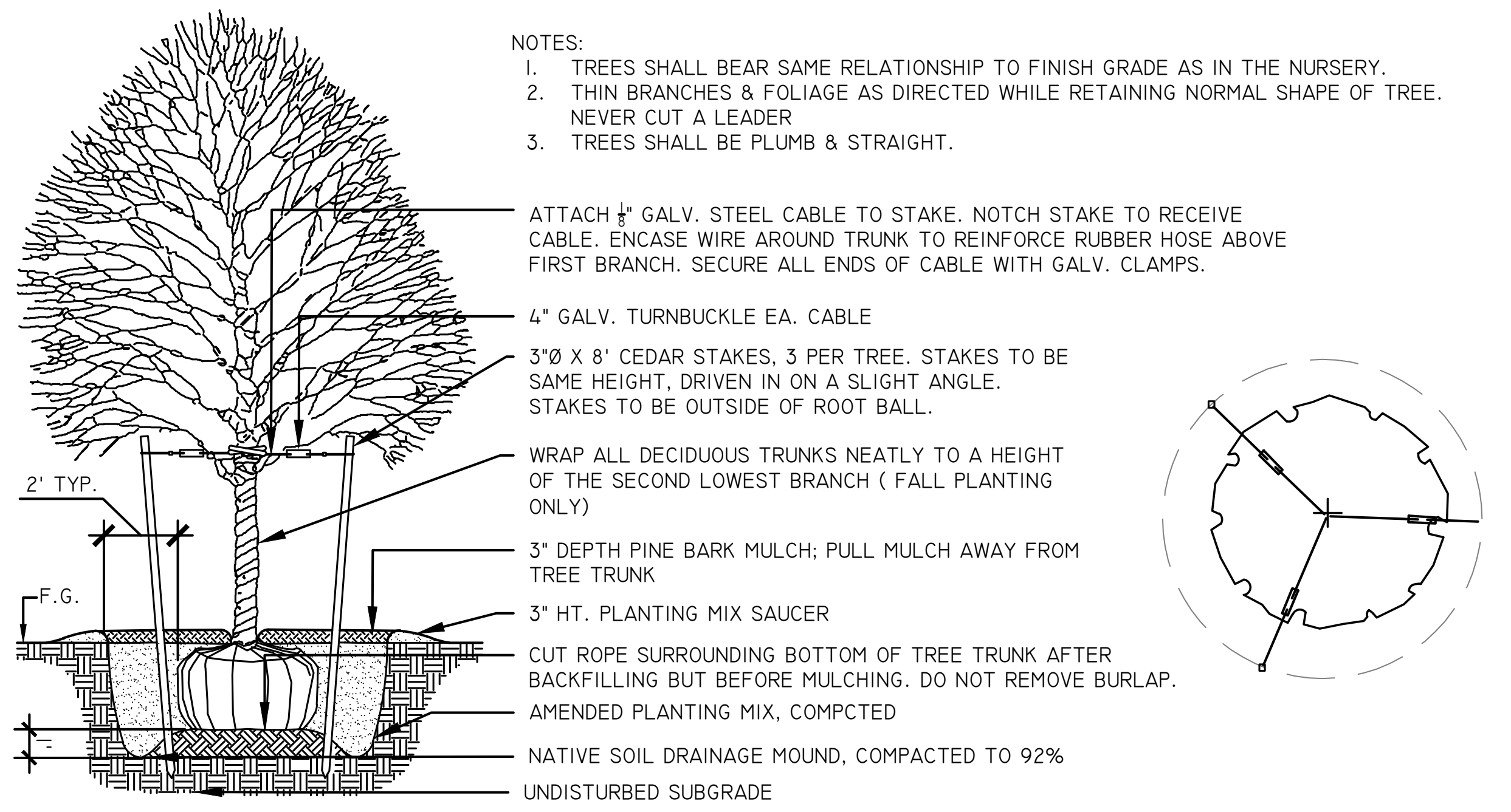


① ENTRY SIGN PLANTING ENGLARGEMENT

1"=10'-0"

PLANTING SCHEDULE

KEY	QTY	SYMBOL	SCIENTIFIC NAME	COMMON NAME	SIZE	COMMENTS
TREES						
CC	3	⊕	CRATAEGUS CRUS-GALLI	THORNLESS COCKSPURE HAWTHORN	10-12' HEIGHT	SINGLE STEMMED
QP	5	⊕	QUERCUS PALUSTRIS	PIN OAK	3" CAL. 14-16' HT.	SINGLE STEMMED. 5' CLEAR TRUNK
SHRUBS						
CA	24	⊙	CLETHRA ALNIFOLIA 'HUMMINGBIRD'	HUMMINGBIRD SUMEMRWEET	3 GAL. CONT.	36" O.C.
CS	10	⊙	CORNUS SERICEA 'FARROW'	ARCTIC FIRE DOGWOOD	3 GAL.	42" O.C.
PERENNIALS / GRASSES / SEDGES						
AR	48	⬡	AJUGA REPTANS 'CATLIN'S GIANT'	CATLIN'S GIANT AJUGA	4" POT	12" O.C.
DC	171	⊙	DESCHAMPSIA CAESPITOSA	TUFTED HAIR GRASS	4" PLUGS	24" O.C.
NX	13	✿	NEPETA X FAASSENII 'WALKER'S LOW'	WALKERS LOW CATMINT	1 GAL.	24" O.C.
SH	28	⊙	SPOROBOLUS HETEROLEPIS	PRAIRIE DROPSEED	1 GAL.	24" O.C.
SM1	87,500 S.F.	▨	CONSERVATION SEED MIX	ERNST ERNMX-114	SEED	OR APPROVED EQUAL. INSTALL PER MAN. SPECIFICATIONS
SM2	24,500 S.F.	▨	NATIVE DETENTION SEED MIX	ERNST ERNMX-183	SEED	OR APPROVED EQUAL. INSTALL PER MAN. SPECIFICATIONS



NOTES:
1. TREES SHALL BEAR SAME RELATIONSHIP TO FINISH GRADE AS IN THE NURSERY.
2. THIN BRANCHES & FOLIAGE AS DIRECTED WHILE RETAINING NORMAL SHAPE OF TREE. NEVER CUT A LEADER
3. TREES SHALL BE PLUMB & STRAIGHT.

ATTACH 1/8" GALV. STEEL CABLE TO STAKE. NOTCH STAKE TO RECEIVE CABLE. ENCASE WIRE AROUND TRUNK TO REINFORCE RUBBER HOSE ABOVE FIRST BRANCH. SECURE ALL ENDS OF CABLE WITH GALV. CLAMPS.

4" GALV. TURNBUCKLE EA. CABLE

3"Ø X 8' CEDAR STAKES, 3 PER TREE. STAKES TO BE SAME HEIGHT, DRIVEN IN ON A SLIGHT ANGLE. STAKES TO BE OUTSIDE OF ROOT BALL.

WRAP ALL DECIDUOUS TRUNKS NEATLY TO A HEIGHT OF THE SECOND LOWEST BRANCH (FALL PLANTING ONLY)

3" DEPTH PINE BARK MULCH; PULL MULCH AWAY FROM TREE TRUNK

3" HT. PLANTING MIX SAUCER

CUT ROPE SURROUNDING BOTTOM OF TREE TRUNK AFTER BACKFILLING BUT BEFORE MULCHING. DO NOT REMOVE BURLAP.

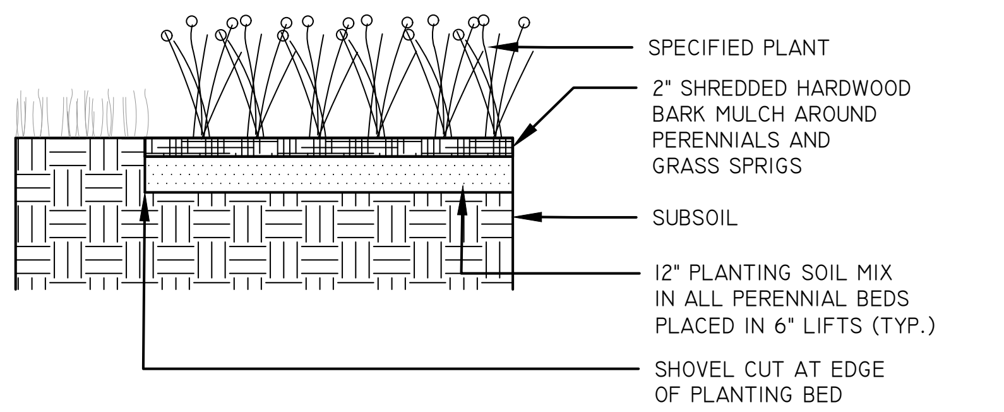
AMENDED PLANTING MIX, COMPCTED

NATIVE SOIL DRAINAGE MOUND, COMPACTED TO 92%

UNDISTURBED SUBGRADE

① DECIDUOUS TREE PLANTING DETAIL

SCALE: N.T.S.



SPECIFIED PLANT

2" SHREDDED HARDWOOD BARK MULCH AROUND PERENNIALS AND GRASS SPRIGS

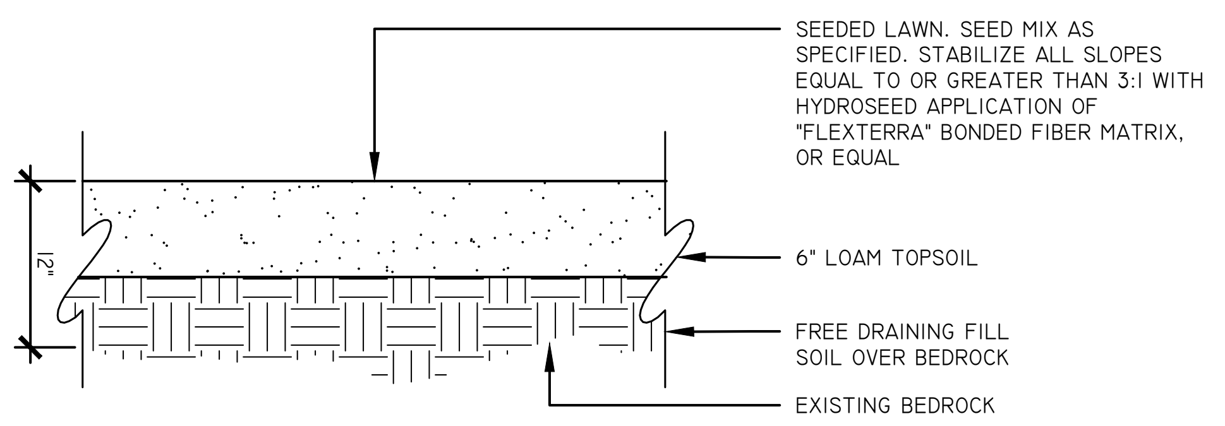
SUBSOIL

12" PLANTING SOIL MIX IN ALL PERENNIAL BEDS PLACED IN 6" LIFTS (TYP.)

SHOVEL CUT AT EDGE OF PLANTING BED

② PERENNIAL & GRASS PLANTING DETAIL

SCALE: N.T.S.



SEEDED LAWN. SEED MIX AS SPECIFIED. STABILIZE ALL SLOPES EQUAL TO OR GREATER THAN 3:1 WITH HYDROSEED APPLICATION OF "FLEXTERRA" BONDED FIBER MATRIX, OR EQUAL

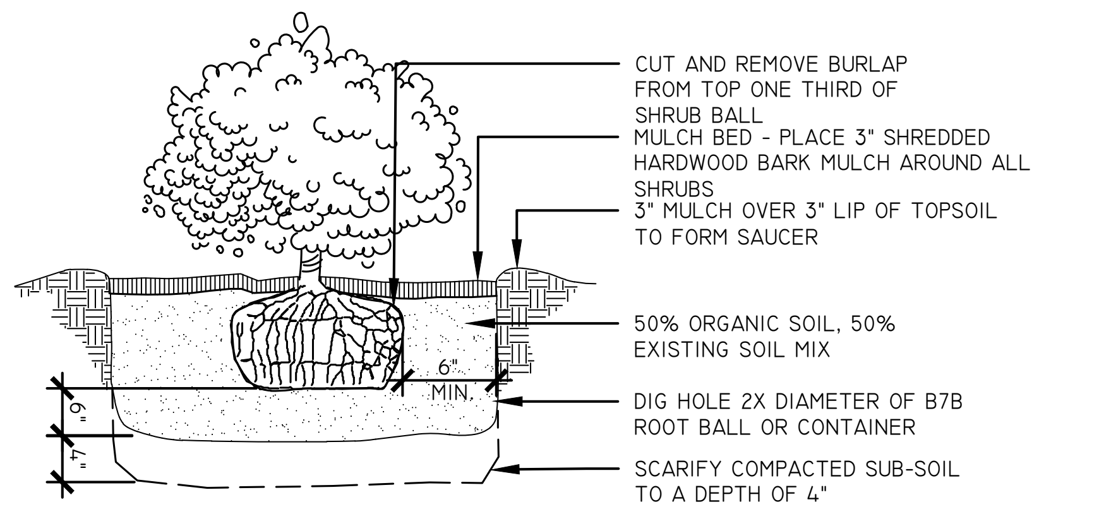
6" LOAM TOPSOIL

FREE DRAINING FILL SOIL OVER BEDROCK

EXISTING BEDROCK

③ SEEDED AREA DETAIL

SCALE: N.T.S.



CUT AND REMOVE BURLAP FROM TOP ONE THIRD OF SHRUB BALL

MULCH BED - PLACE 3" SHREDDED HARDWOOD BARK MULCH AROUND ALL SHRUBS

3" MULCH OVER 3" LIP OF TOPSOIL TO FORM SAUCER

50% ORGANIC SOIL, 50% EXISTING SOIL MIX

DIG HOLE 2X DIAMETER OF B7B ROOT BALL OR CONTAINER

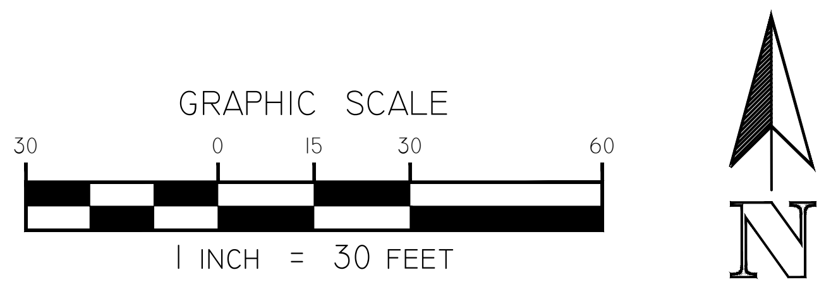
SCARIFY COMPACTED SUB-SOIL TO A DEPTH OF 4"

④ BALLED & BURLAPPED (B&B) DETAIL

SCALE: N.T.S.

LEGEND:

▬ ▬ ▬	PROPERTY LINE
— — —	PROPERTY LINE SETBACK
—···—	MEAN HIGH WATER LINE
- - - -	LIMITS OF DISTURBANCE
✿	EXISTING TREE TO REMAIN
⌒⌒⌒	EXISTING TREE LINE
✿ ⊙	PROPOSED SHRUBS/ GROUNDCOVER
⊕ ○	PROPOSED TREES
(— —)	PROPOSED RAIN GARDEN
▨	PROPOSED TURF GRASS AREA



MAP REFERENCE:
BASE MAP INFORMATION OBTAINED FROM "MAP OF TOPOGRAPHIC SURVEY MADE FOR NORTHEAST BIOCHAR SOLUTIONS, INC., TOWN OF MOREAU, SARATOGA COUNTY, NEW YORK" PREPARED BY VAN DUSEN & STEVES SURVEYORS, DATED JULY 28, 2021.

DIG SAFE NOTE:
THIS PLAN SET WAS DRAFTED WITHOUT THE BENEFIT OF "DIG SAFE" MARKINGS. UTILITIES SHOWN ARE NOT WARRANTED TO BE EXACT OR COMPLETE. THE CONTRACTOR SHALL CONTACT "DIG SAFE" AT 811 BEFORE COMMENCING ANY WORK AND SHALL PRESERVE EXISTING UTILITIES WHICH ARE NOT SPECIFIED TO BE REMOVED IN THIS PLAN SET.

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Landscape Architecture + Engineering, DPC
STUDIO A
LANDSCAPE ARCHITECTURE + ENGINEERING, DPC
MAILING:
PO BOX 272
SARATOGA SPRINGS, NY 12866
OFFICE LOCATION:
38 HIGH ROCK AVE, SUITE 3
SARATOGA SPRINGS, NY 12866
(518) 450-4030

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REVISIONS	
DATE	DESCRIPTION

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26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

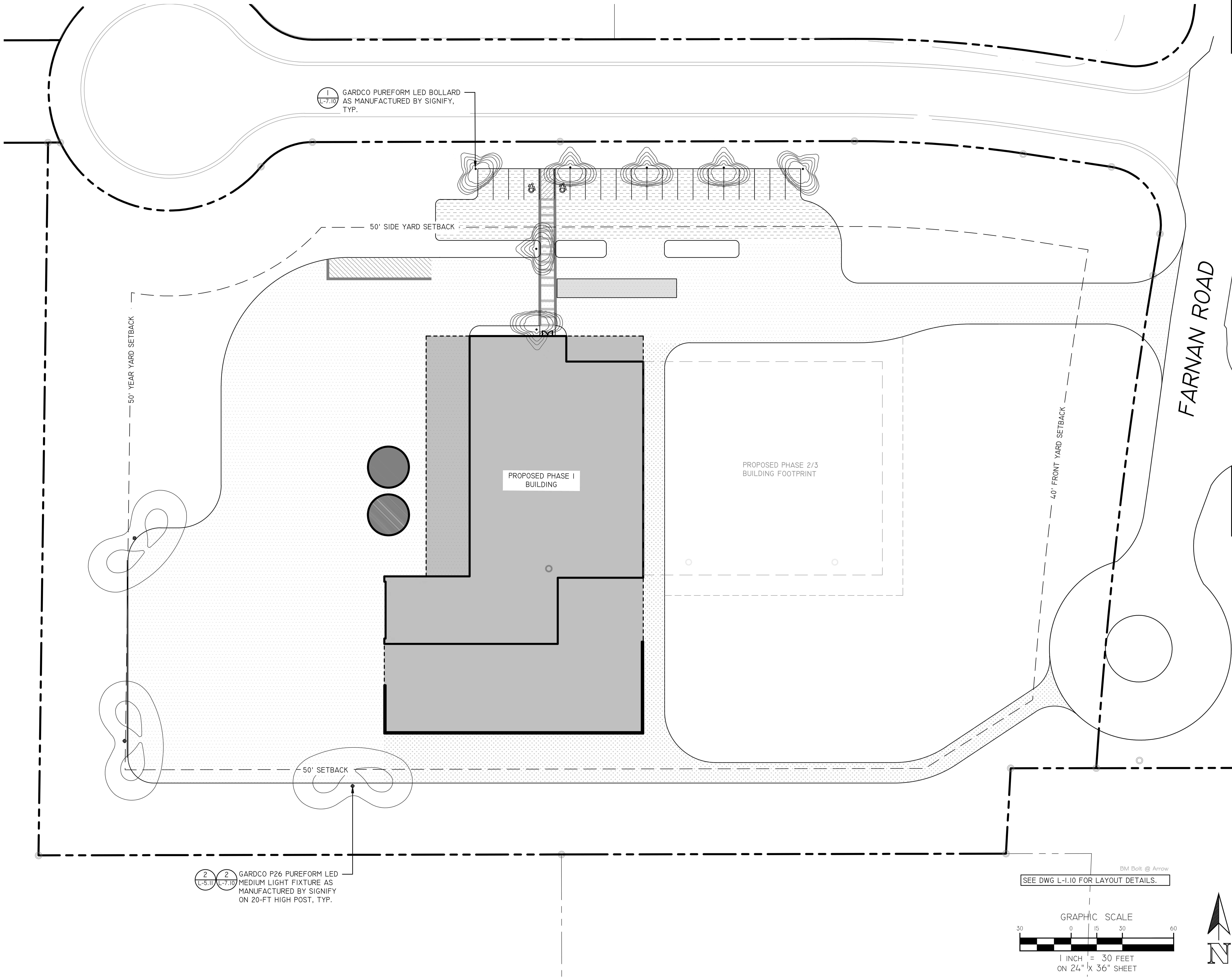
PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

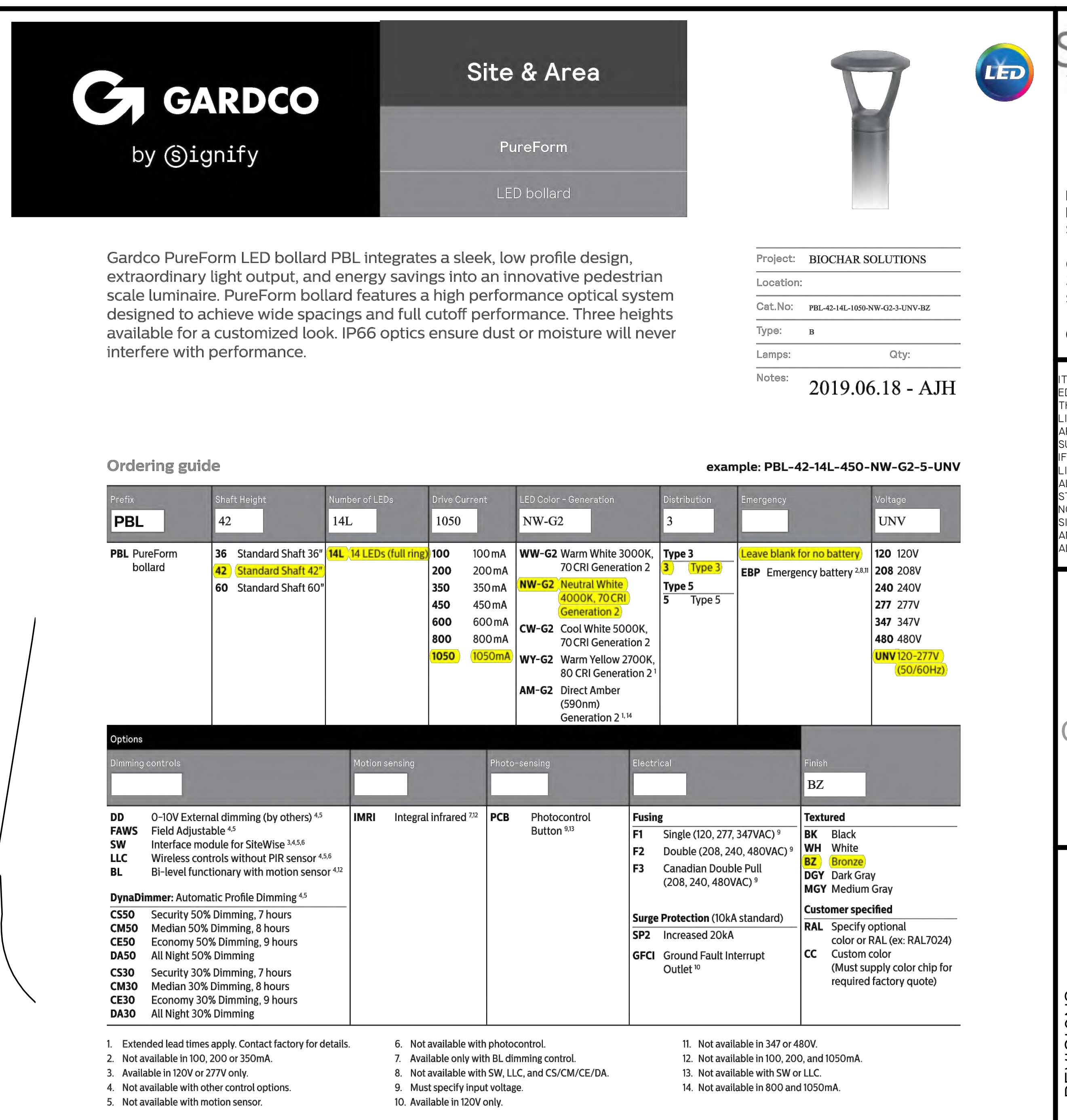
DRAWING TITLE
PLANTING PLAN

DATE: 03/25/2022
PROJECT NO. 20019
DRAWING NO.
L-6.10
DWG 8 OF 9

CHECKED BY: ####
DRAWN BY: ####
DESIGN BY: ####

PLOTTED BY: QUINN ROESCH
SAVE DATE: 3/17/2022 5:59 PM
FILE NAME: Z:\PROJECTS\2020 PROJECTS\20019 - BIOCHAR SOLUTIONS\DWG\03 SHEETS\20019_PLANTING.DWG





Gardco PureForm LED bollard PBL integrates a sleek, low profile design, extraordinary light output, and energy savings into an innovative pedestrian scale luminaire. PureForm bollard features a high performance optical system designed to achieve wide spacings and full cutoff performance. Three heights available for a customized look. IP66 optics ensure dust or moisture will never interfere with performance.

Project: BIOCHAR SOLUTIONS
Location:
Cat.No: PBL-42-14L-1050-NW-G2-3-UNV-BZ
Type: B
Lamps: Qty:
Notes: 2019.06.18 - AJH

Ordering guide

example: PBL-42-14L-450-NW-G2-5-UNV

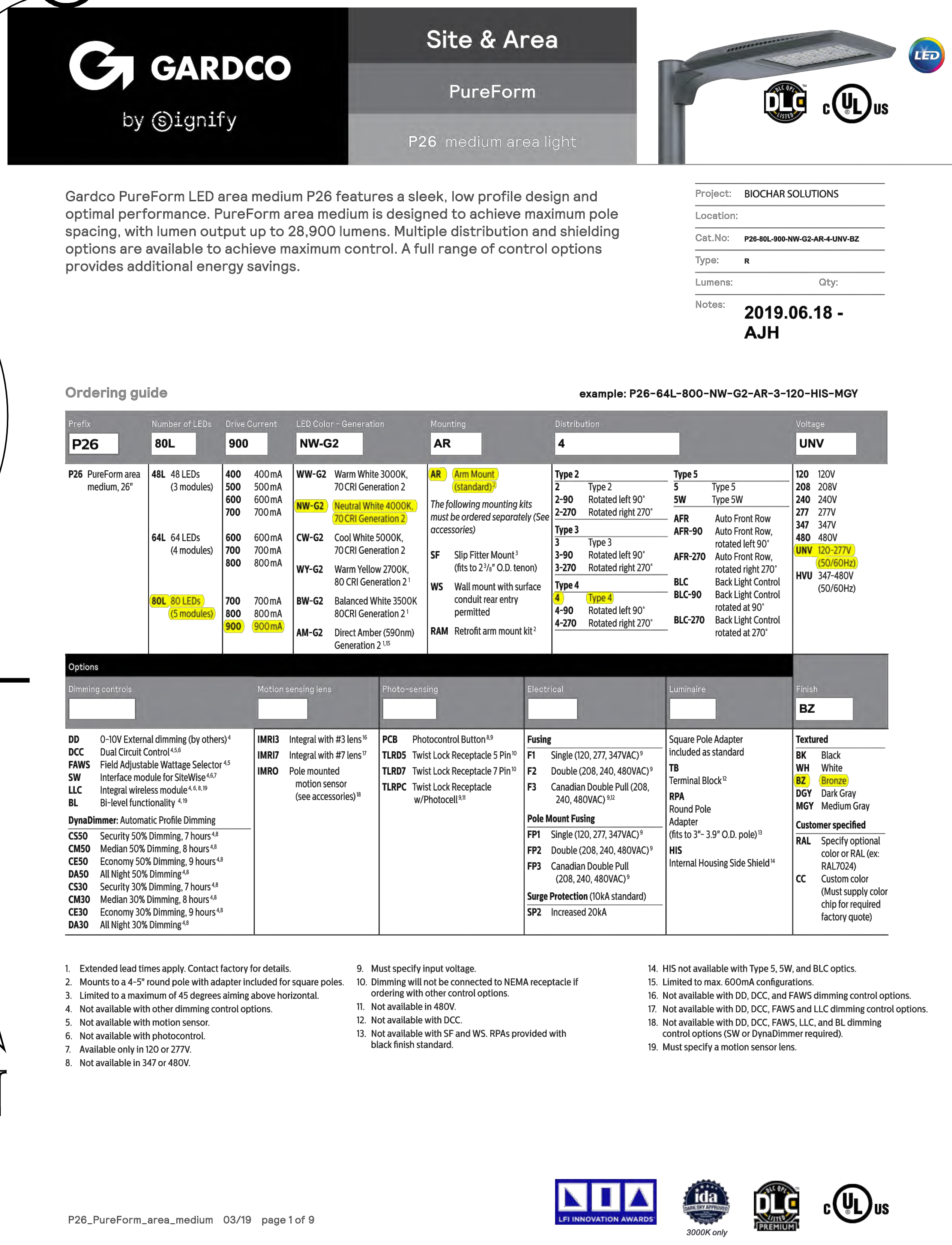
Prefix	Shaft Height	Number of LEDs	Drive Current	LED Color - Generation	Distribution	Emergency	Voltage
PBL	42	14L	1050	NW-G2	3		UNV
PBL PureForm bollard	**36** Standard Shaft 36" **42** Standard Shaft 42" **60** Standard Shaft 60"	**14L** 14 LEDs (full ring)	**100** 100mA **200** 200mA **350** 350mA **450** 450mA **600** 600mA **800** 800mA **1050** 1050mA	**WW-G2** Warm White 3000K, 70CRI Generation 2 **NW-G2** Neutral White 4000K, 70CRI Generation 2 **CW-G2** Cool White 5000K, 70CRI Generation 2 **WY-G2** Warm Yellow 2700K, 80 CRI Generation 2 ^{1} **AM-G2** Direct Amber (590nm) Generation 2 ^{1,14}	**Type 3** **3** Type 3 **Type 5** **5** Type 5	Leave blank for no battery **EBP** Emergency battery ^{2,8,11}	**120** 120V **208** 208V **240** 240V **277** 277V **347** 347V **480** 480V **UNV** 120-277V (50/60Hz)

Options

Dimming controls	Motion sensing	Photo-sensing	Electrical	Finish
				BZ
DD 0-10V External dimming (by others) ^{4,5} **FAWS** Field Adjustable ^{4,5} **SW** Interface module for SiteWise ^{3,4,5,6} **LLC** Wireless controls without PIR sensor ^{4,5,6} **BL** Bi-level functionary with motion sensor ^{4,12} **DynaDimmer:** Automatic Profile Dimming ^{4,5} **CS50** Security 50% Dimming, 7 hours **CM50** Median 50% Dimming, 8 hours **CE50** Economy 50% Dimming, 9 hours **DA50** All Night 50% Dimming **CS30** Security 30% Dimming, 7 hours **CM30** Median 30% Dimming, 8 hours **CE30** Economy 30% Dimming, 9 hours **DA30** All Night 30% Dimming	**IMRI** Integral infrared ^{7,12}	**PCB** Photocontrol Button ^{9,13}	**Fusing** **F1** Single (120, 277, 347VAC) ^{9} **F2** Double (208, 240, 480VAC) ^{9} **F3** Canadian Double Pull (208, 240, 480VAC) ^{9} **Surge Protection** (10kA standard) **SP2** Increased 20kA **GFCI** Ground Fault Interrupt Outlet ^{10}	**Textured** **BK** Black **WH** White **BZ** Bronze **DGY** Dark Gray **MGY** Medium Gray **Customer specified** **RAL** Specify optional color or RAL (ex: RAL7024) **CC** Custom color (Must supply color chip for required factory quote)

1. Extended lead times apply. Contact factory for details.
2. Not available in 100, 200 or 350mA.
3. Available in 120V or 277V only.
4. Not available with other control options.
5. Not available with motion sensor.
6. Not available with photocontrol.
7. Available only with BL dimming control.
8. Not available with SW, LLC, and CS/CM/CE/DA.
9. Must specify input voltage.
10. Available in 120V only.
11. Not available in 347 or 480V.
12. Not available in 100, 200, and 1050mA.
13. Not available with SW or LLC.
14. Not available in 800 and 1050mA.

① GARDCO PBL PUREFORM LED BOLLARD



Gardco PureForm LED area medium P26 features a sleek, low profile design and optimal performance. PureForm area medium is designed to achieve maximum pole spacing, with lumen output up to 28,900 lumens. Multiple distribution and shielding options are available to achieve maximum control. A full range of control options provides additional energy savings.

Project: BIOCHAR SOLUTIONS
Location:
Cat.No: P26-80L-900-NW-G2-AR-4-UNV-BZ
Type: R
Lumens: Qty:
Notes: 2019.06.18 - AJH

Ordering guide

example: P26-64L-800-NW-G2-AR-3-120-HIS-MGY

Prefix	Number of LEDs	Drive Current	LED Color - Generation	Mounting	Distribution		Voltage
P26	80L	900	NW-G2	AR	4		UNV
P26 PureForm area medium, 26"	**48L** 48 LEDs (3 modules) **64L** 64 LEDs (4 modules) **80L** 80 LEDs (5 modules)	**400** 400mA **500** 500mA **600** 600mA **700** 700mA **600** 600mA **700** 700mA **800** 800mA **700** 700mA **800** 800mA **900** 900mA	**WW-G2** Warm White 3000K, 70CRI Generation 2 **NW-G2** Neutral White 4000K, 70CRI Generation 2 **CW-G2** Cool White 5000K, 70CRI Generation 2 **WY-G2** Warm Yellow 2700K, 80 CRI Generation 2 ^{1} **BW-G2** Balanced White 3500K 80CRI Generation 2 ^{1} **AM-G2** Direct Amber (590nm) Generation 2 ^{1,15}	**AR** Arm Mount (standard) ^{2} *The following mounting kits must be ordered separately (See accessories)* **SF** Slip Fitter Mount ^{3} (fits to 2 3/8" O.D. tenon) **WS** Wall mount with surface conduit rear entry permitted **RAM** Retrofit arm mount kit ^{2}	**Type 2** **2** Type 2 **2-90** Rotated left 90° **2-270** Rotated right 270° **Type 3** **3** Type 3 **3-90** Rotated left 90° **3-270** Rotated right 270° **Type 4** **4** Type 4 **4-90** Rotated left 90° **4-270** Rotated right 270°	**Type 5** **5** Type 5 **5W** Type 5W **AFR** Auto Front Row **AFR-90** Auto Front Row, rotated left 90° **AFR-270** Auto Front Row, rotated right 270° **BLC** Back Light Control **BLC-90** Back Light Control rotated at 90° **BLC-270** Back Light Control rotated at 270°	**120** 120V **208** 208V **240** 240V **277** 277V **347** 347V **480** 480V **UNV** 120-277V (50/60Hz) **HVU** 347-480V (50/60Hz)

Options

Dimming controls	Motion sensing lens	Photo-sensing	Electrical	Luminaire	Finish
					BZ
DD 0-10V External dimming (by others) ^{4} **DCC** Dual Circuit Control ^{4,5,6} **FAWS** Field Adjustable Wattage Selector ^{4,5} **SW** Interface module for SiteWise ^{4,6,7} **LLC** Integral wireless module ^{4,6,8,19} **BL** Bi-level functionality ^{4,19} **DynaDimmer:** Automatic Profile Dimming **CS50** Security 50% Dimming, 7 hours ^{4,8} **CM50** Median 50% Dimming, 8 hours ^{4,8} **CE50** Economy 50% Dimming, 9 hours ^{4,8} **DA50** All Night 50% Dimming ^{4,8} **CS30** Security 30% Dimming, 7 hours ^{4,8} **CM30** Median 30% Dimming, 8 hours ^{4,8} **CE30** Economy 30% Dimming, 9 hours ^{4,8} **DA30** All Night 30% Dimming ^{4,8}	**IMRI3** Integral with #3 lens ^{16} **IMRI7** Integral with #7 lens ^{17} **IMRO** Pole mounted motion sensor (see accessories) ^{18}	**PCB** Photocontrol Button ^{8,9} **TLRD5** Twist Lock Receptacle 5 Pin ^{10} **TLRD7** Twist Lock Receptacle 7 Pin ^{10} **TLRPC** Twist Lock Receptacle w/Photocell ^{9,11}	**Fusing** **F1** Single (120, 277, 347VAC) ^{9} **F2** Double (208, 240, 480VAC) ^{9} **F3** Canadian Double Pull (208, 240, 480VAC) ^{9,12} **Pole Mount Fusing** **FP1** Single (120, 277, 347VAC) ^{9} **FP2** Double (208, 240, 480VAC) ^{9} **FP3** Canadian Double Pull (208, 240, 480VAC) ^{9} **Surge Protection** (10kA standard) **SP2** Increased 20kA	Square Pole Adapter included as standard **TB** Terminal Block ^{12} **RPA** Round Pole Adapter (fits to 3"- 3.9" O.D. pole) ^{13} **HIS** Internal Housing Side Shield ^{14}	**Textured** **BK** Black **WH** White **BZ** Bronze **DGY** Dark Gray **MGY** Medium Gray **Customer specified** **RAL** Specify optional color or RAL (ex: RAL7024) **CC** Custom color (Must supply color chip for required factory quote)

1. Extended lead times apply. Contact factory for details.
2. Mounts to a 4-5" round pole with adapter included for square poles.
3. Limited to a maximum of 45 degrees aiming above horizontal.
4. Not available with other dimming control options.
5. Not available with motion sensor.
6. Not available with photocontrol.
7. Available only in 120 or 277V.
8. Not available in 347 or 480V.
9. Must specify input voltage.
10. Dimming will not be connected to NEMA receptacle if ordering with other control options.
11. Not available in 480V.
12. Not available with DCC.
13. Not available with SF and WS. RPAs provided with black finish standard.
14. HIS not available with Type 5, 5W, and BLC optics.
15. Limited to max. 600mA configurations.
16. Not available with DD, DCC, and FAWS dimming control options.
17. Not available with DD, DCC, FAWS and LLC dimming control options.
18. Not available with DD, DCC, FAWS, LLC, and BL dimming control options (SW or DynaDimmer required).
19. Must specify a motion sensor lens.

P26_PureForm_area_medium 03/19 page 1 of 9

② GARDCO P26 PUREFORM LED MEDIUM AREA LIGHT

MAP REFERENCE:
BASE MAP INFORMATION OBTAINED FROM "MAP OF TOPOGRAPHIC SURVEY MADE FOR NORTHEAST BIOCHAR SOLUTIONS, INC., TOWN OF MOREAU, SARATOGA COUNTY, NEW YORK" PREPARED BY VAN DUSEN & STEVES SURVEYORS, DATED JULY 28, 2021.

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PREPARED FOR
SARATOGA BIOCHAR SOLUTIONS, LLC
26 F CONGRESS ST. #346
SARATOGA SPRINGS, NY 12866

PROJECT
SARATOGA BIOCHAR SOLUTIONS, LLC

DRAWING TITLE
LIGHTING PLAN

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PROJECT NO. 20019
DRAWING NO.
L-7.10
DWG 9 OF 9

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DRAWN BY: ####
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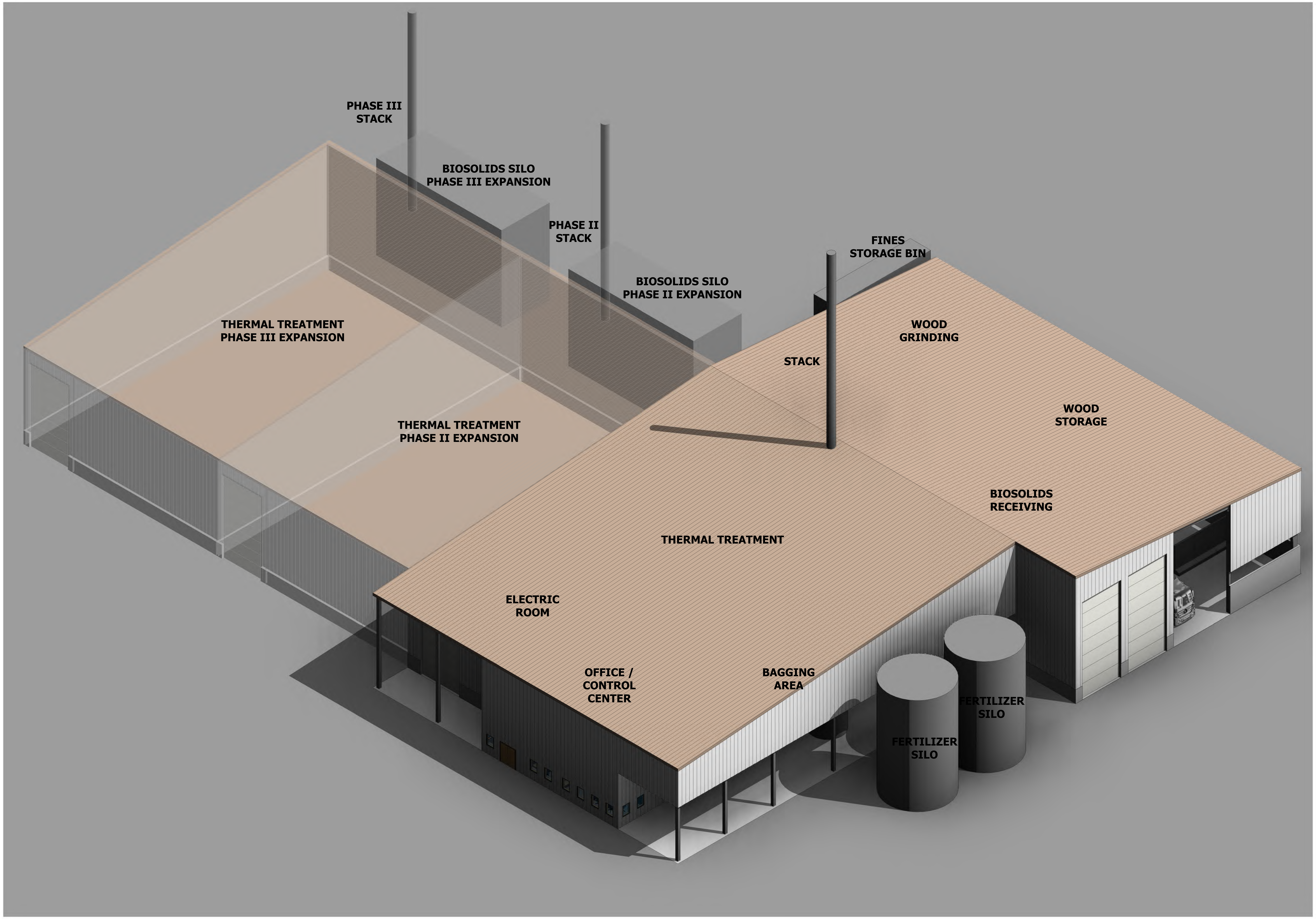

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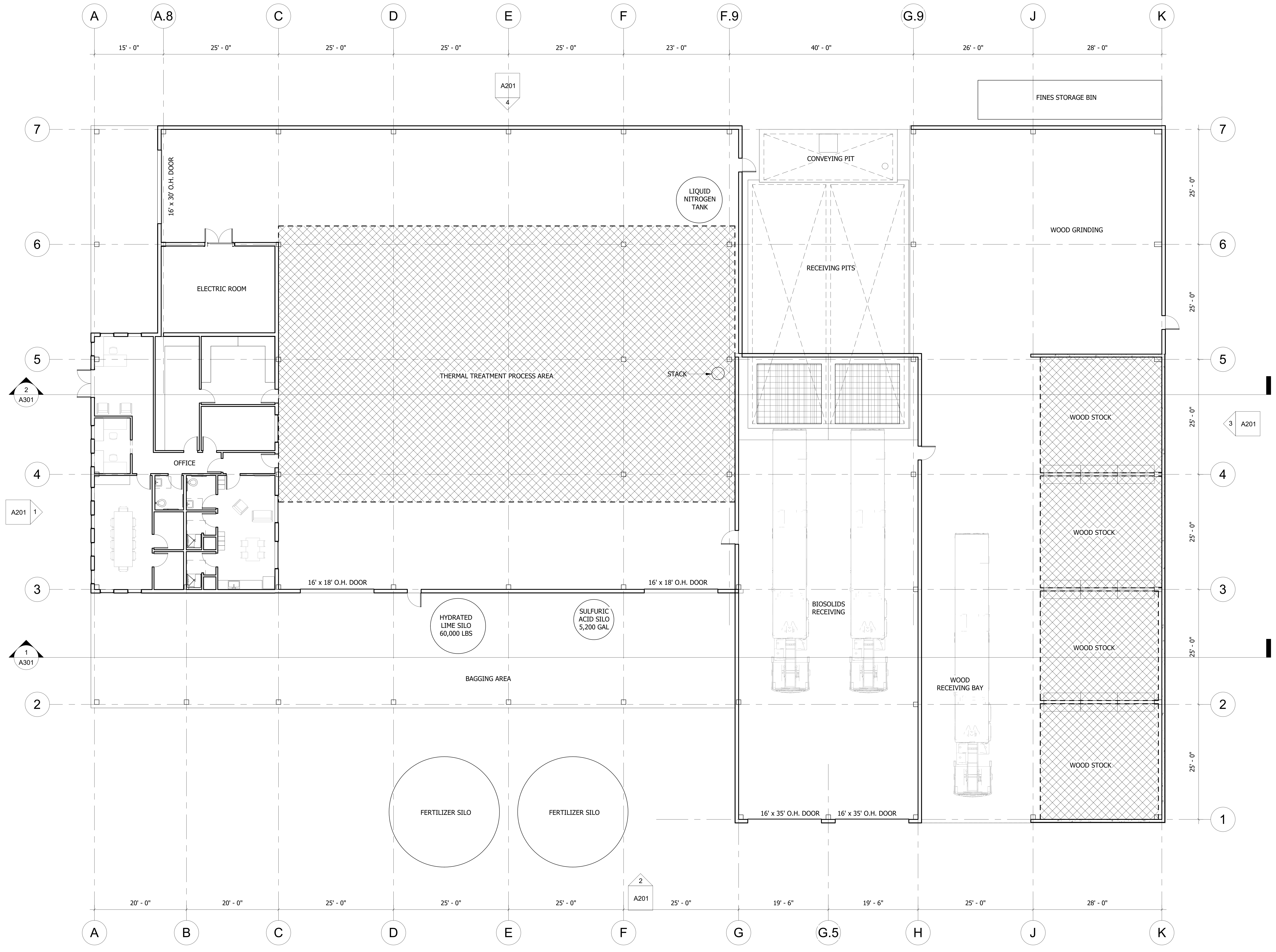

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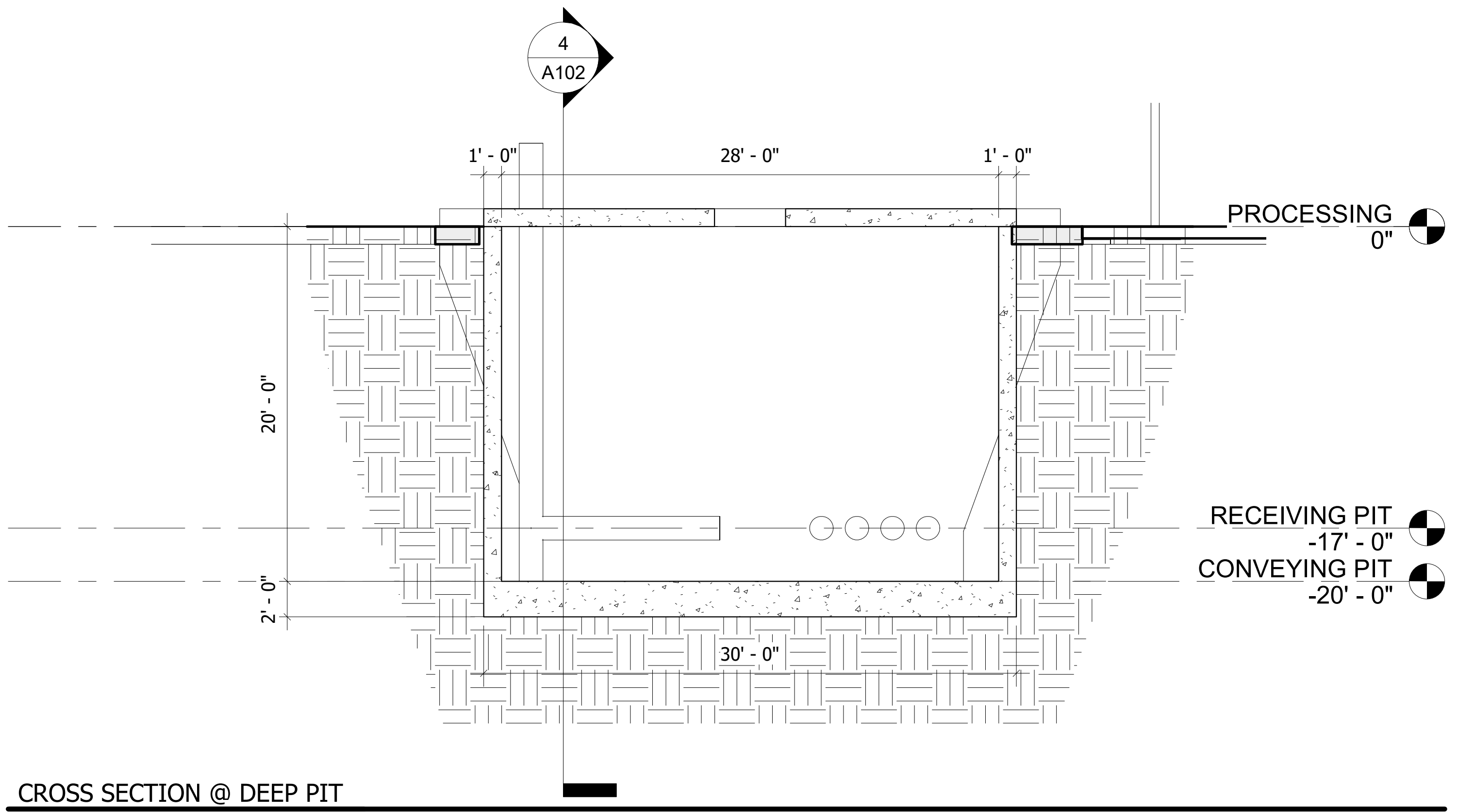
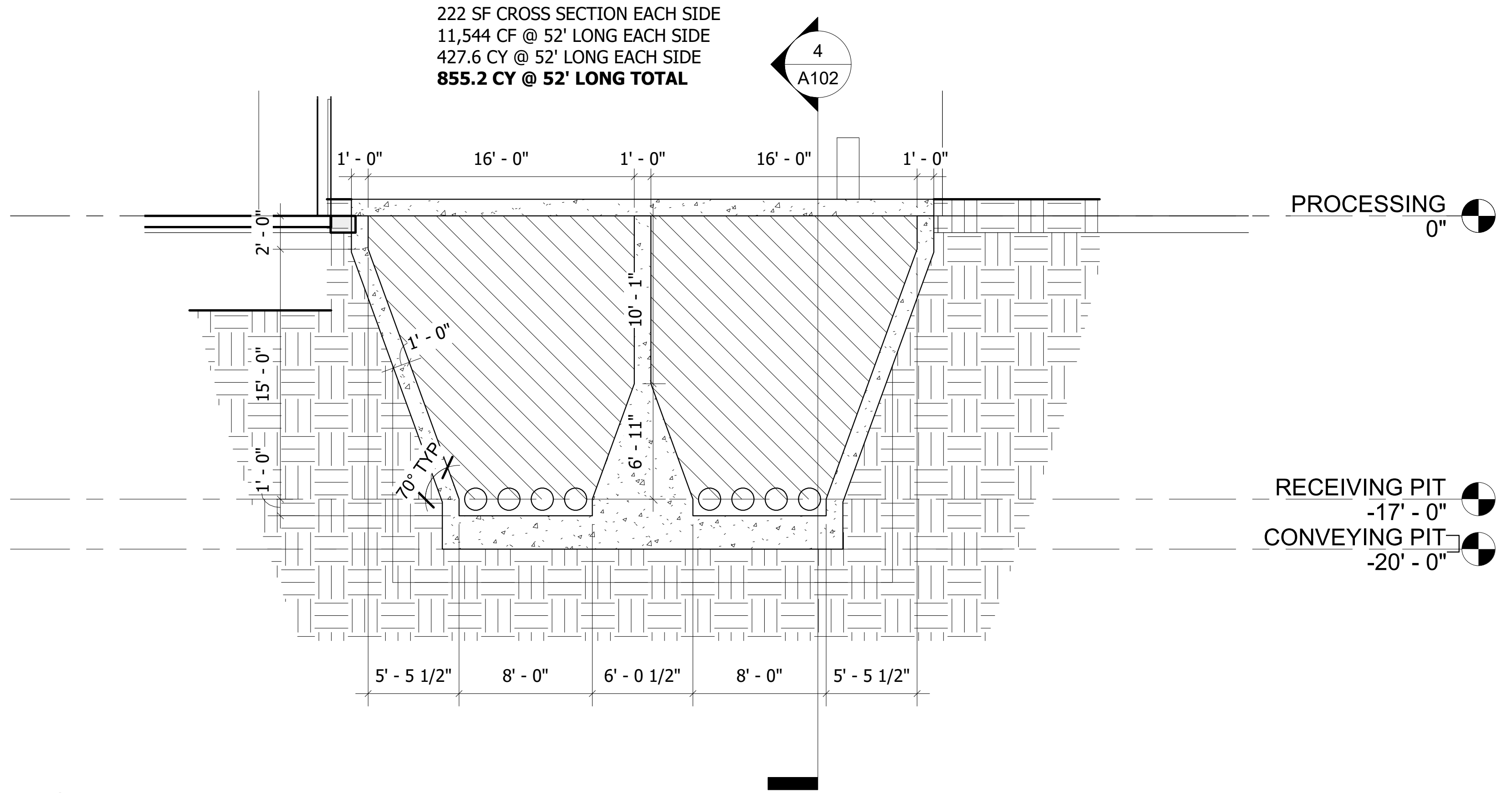
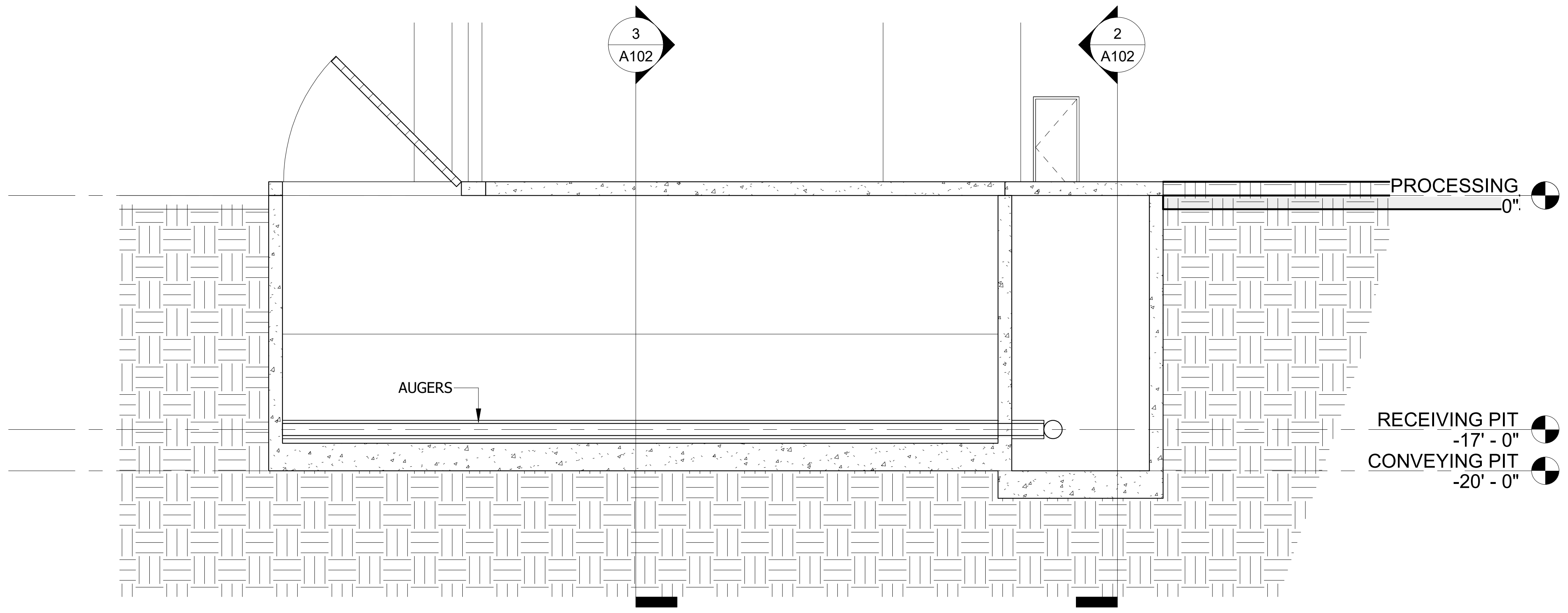


2 CROSS SECTION @ DEEP PIT
1/8" = 1'-0"

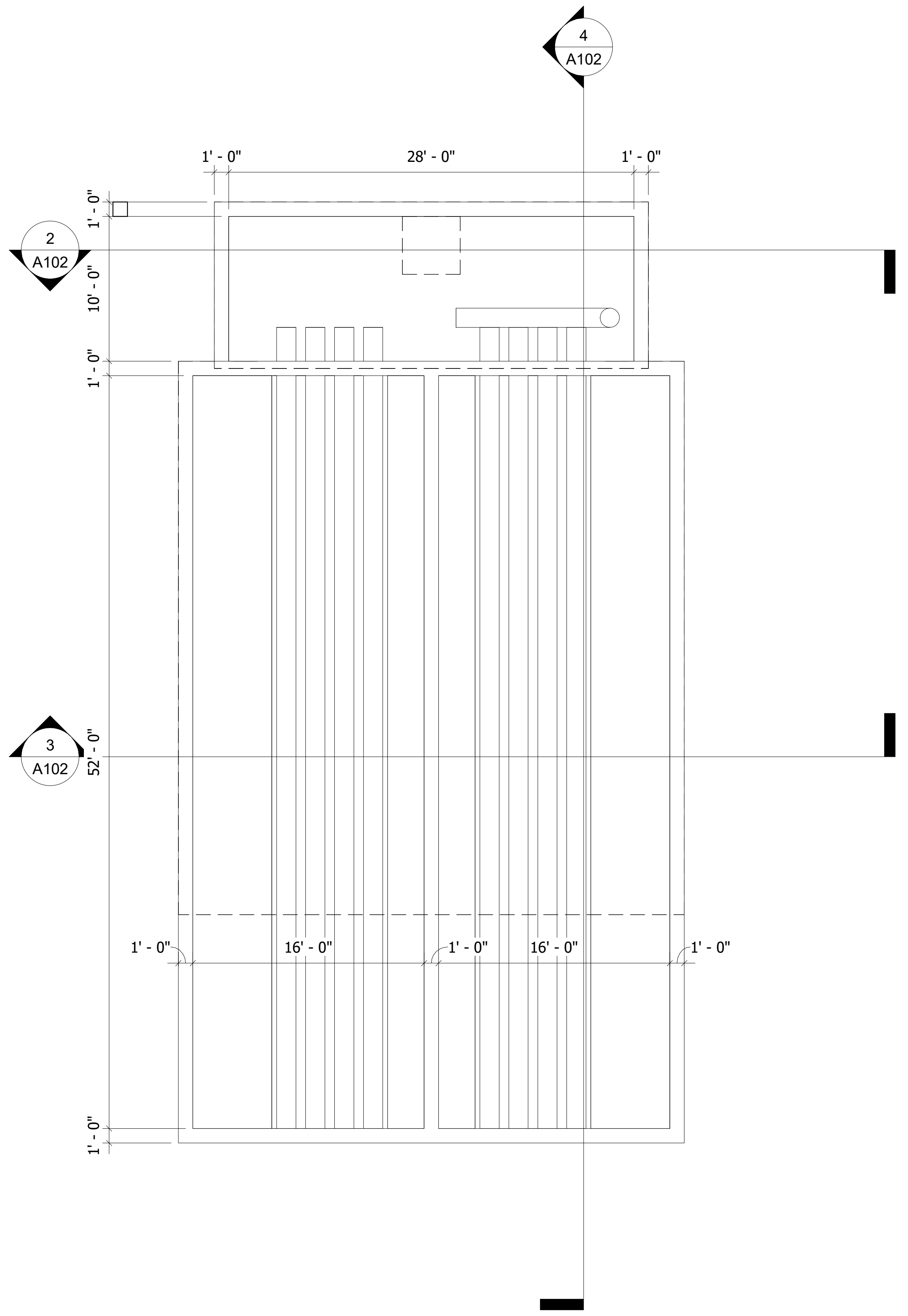
222 SF CROSS SECTION EACH SIDE
11,544 CF @ 52' LONG EACH SIDE
427.6 CY @ 52' LONG EACH SIDE
855.2 CY @ 52' LONG TOTAL



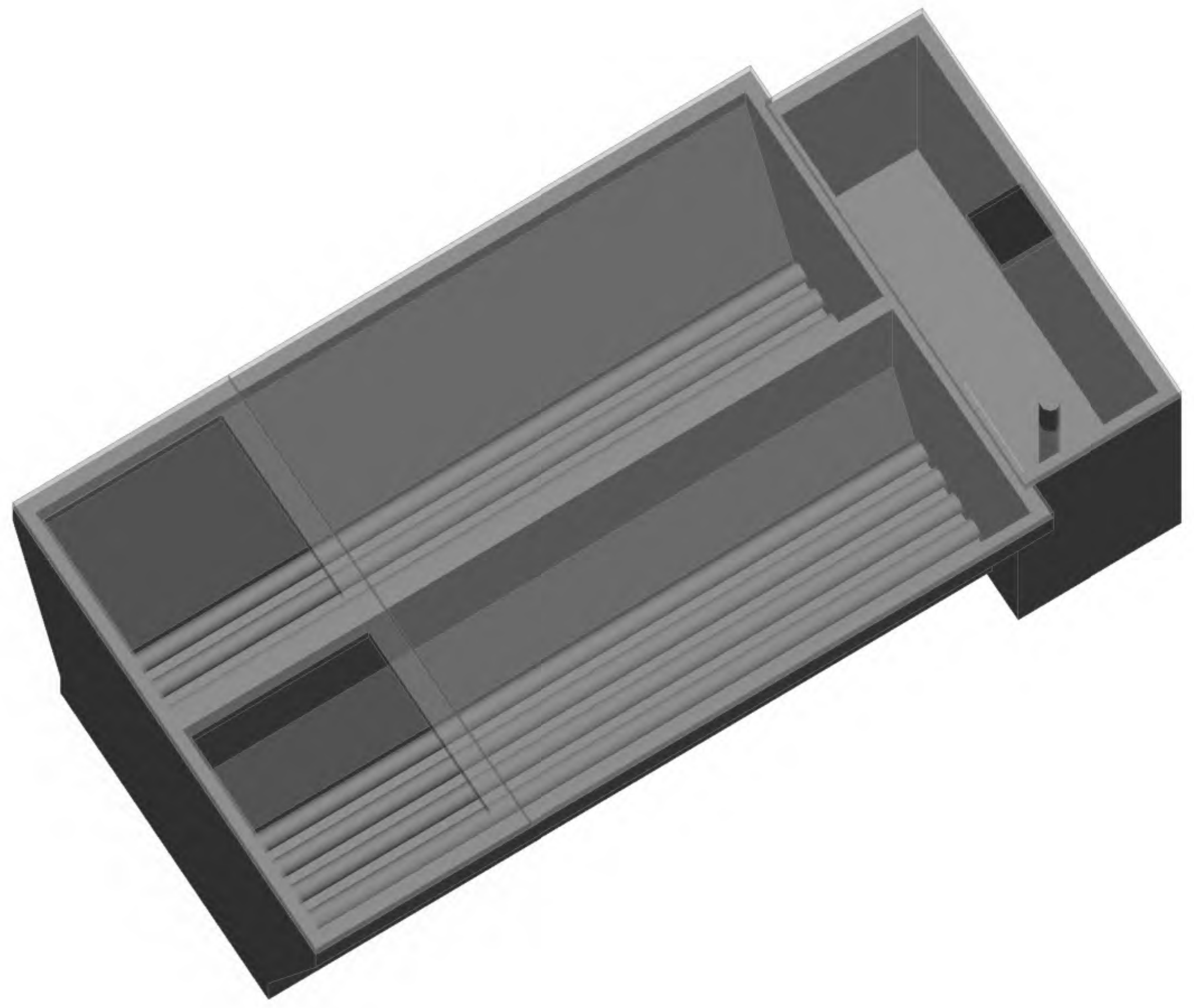
3 CROSS SECTION @ SHALLOW PIT
1/8" = 1'-0"



4 LONGITUDINAL SECTION @ PITS
1/8" = 1'-0"



1 PIT PLAN
1/8" = 1'-0"



5 PIT AXO

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PIT DETAILS

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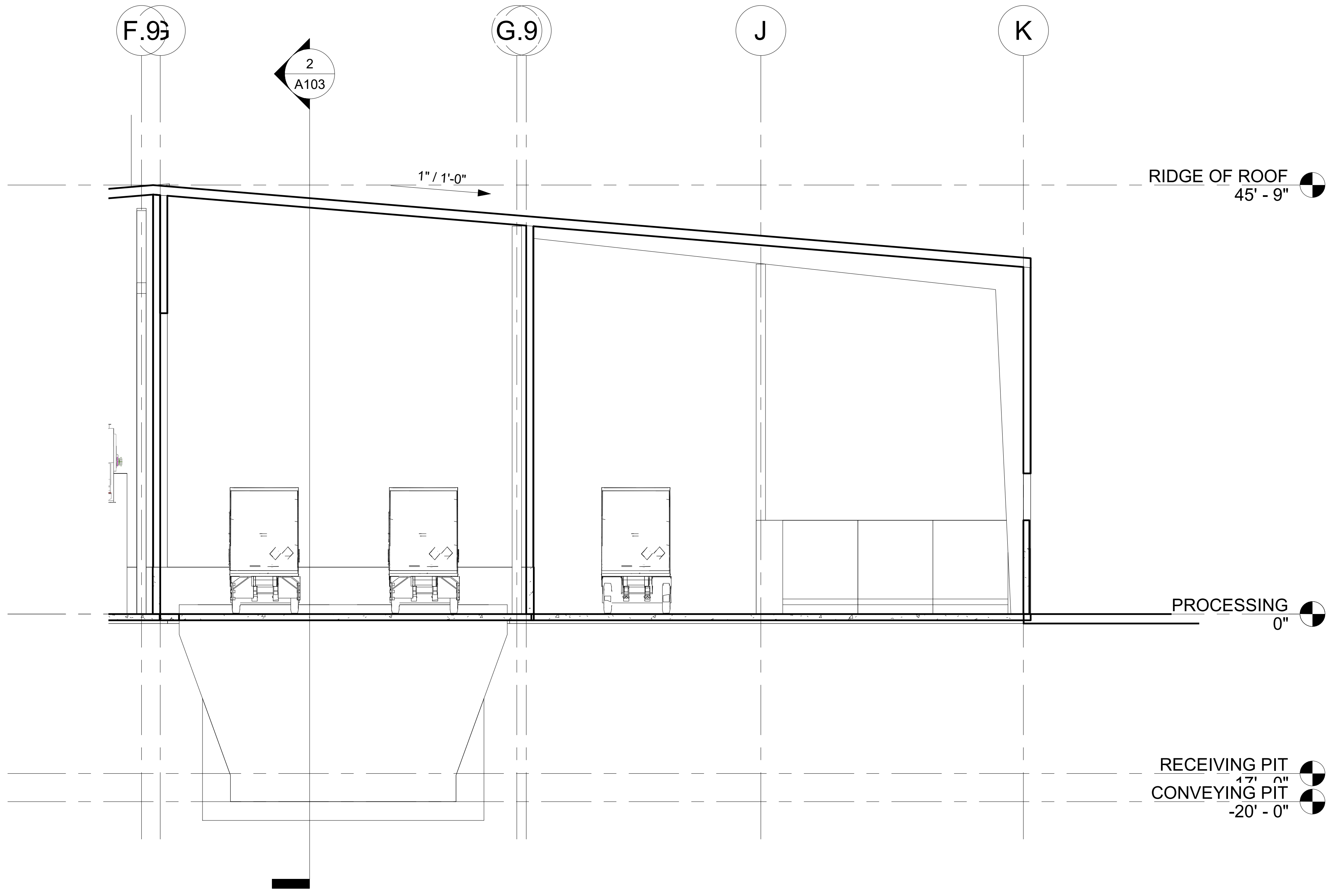
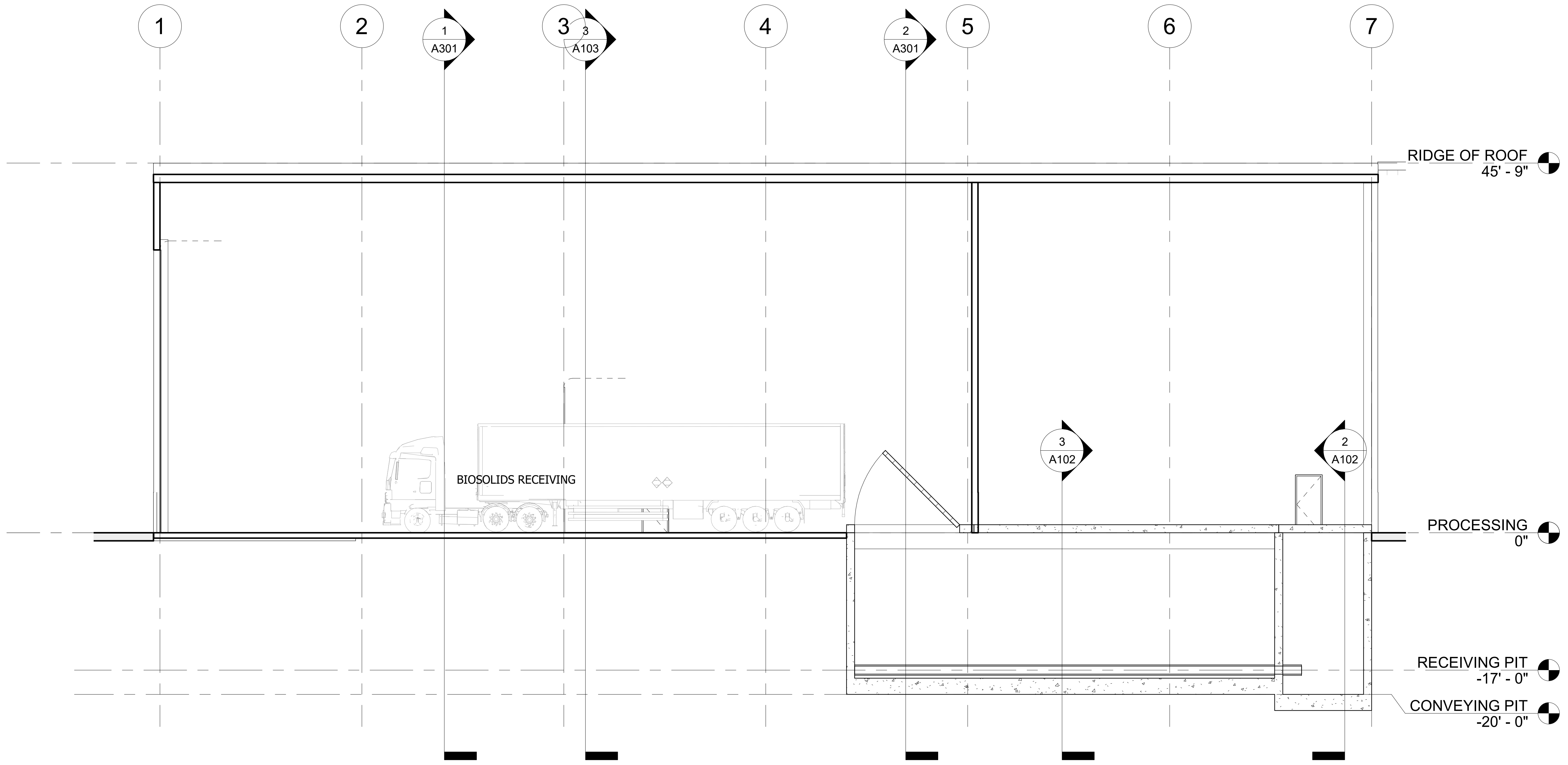
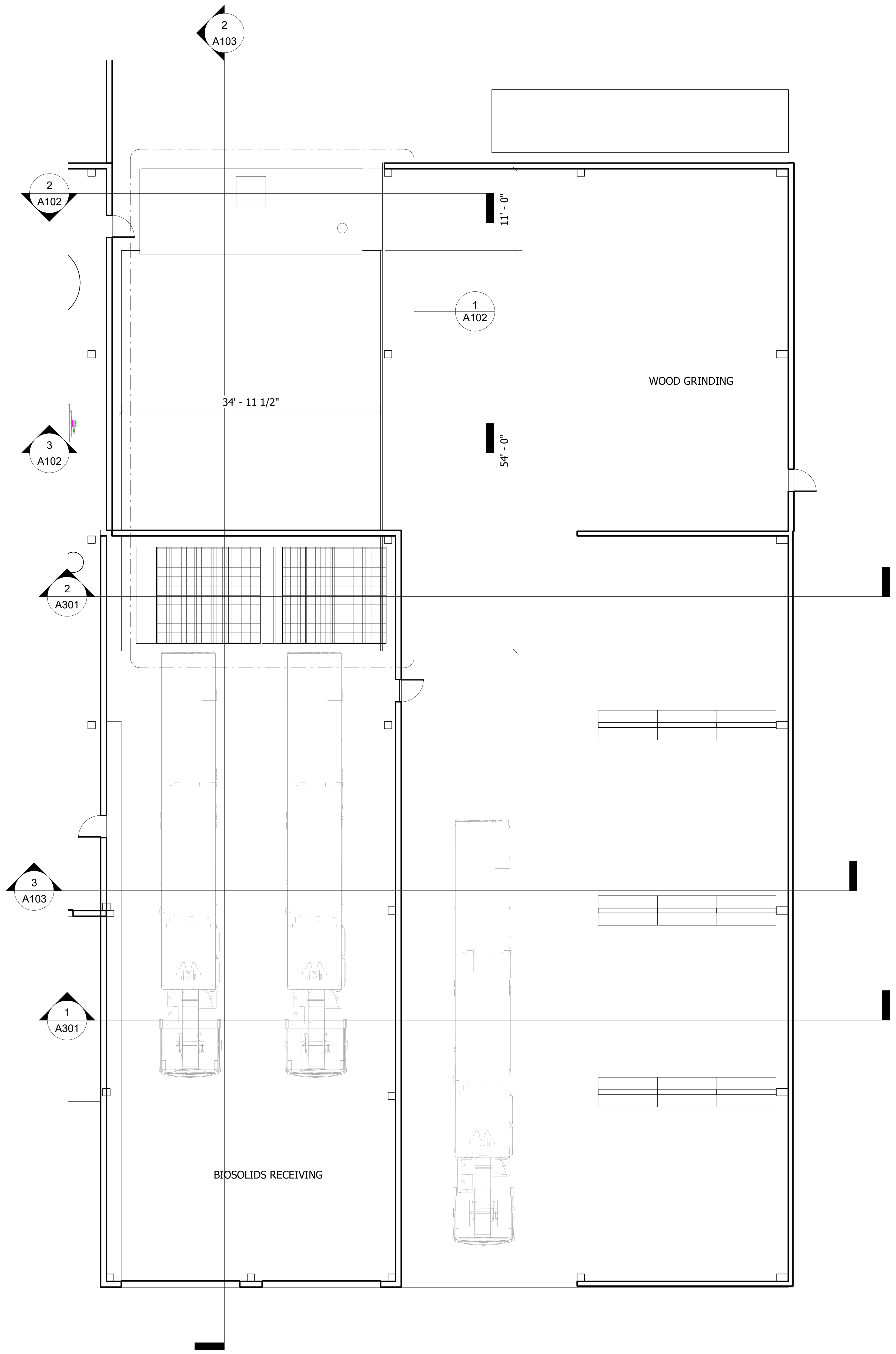


3 TRASNVERSE SECTION @ BIOSOLIDS RECEIVING
3/32" = 1'-0"



2 LONGITUDINAL SECTION @ BIOSOLIDS RECEIVING
3/32" = 1'-0"



1 RECEIVING AREA PLAN
3/32" = 1'-0"

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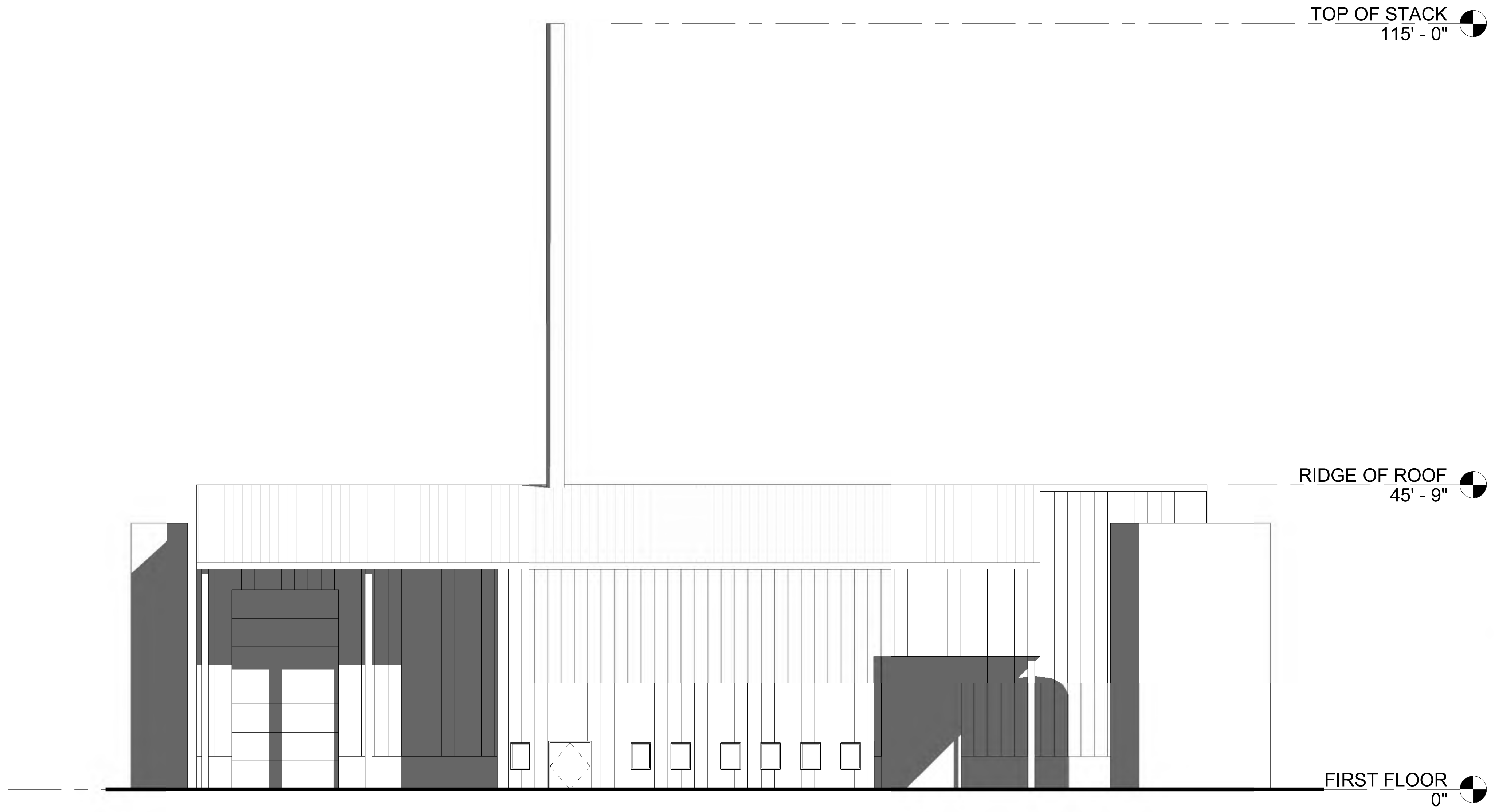
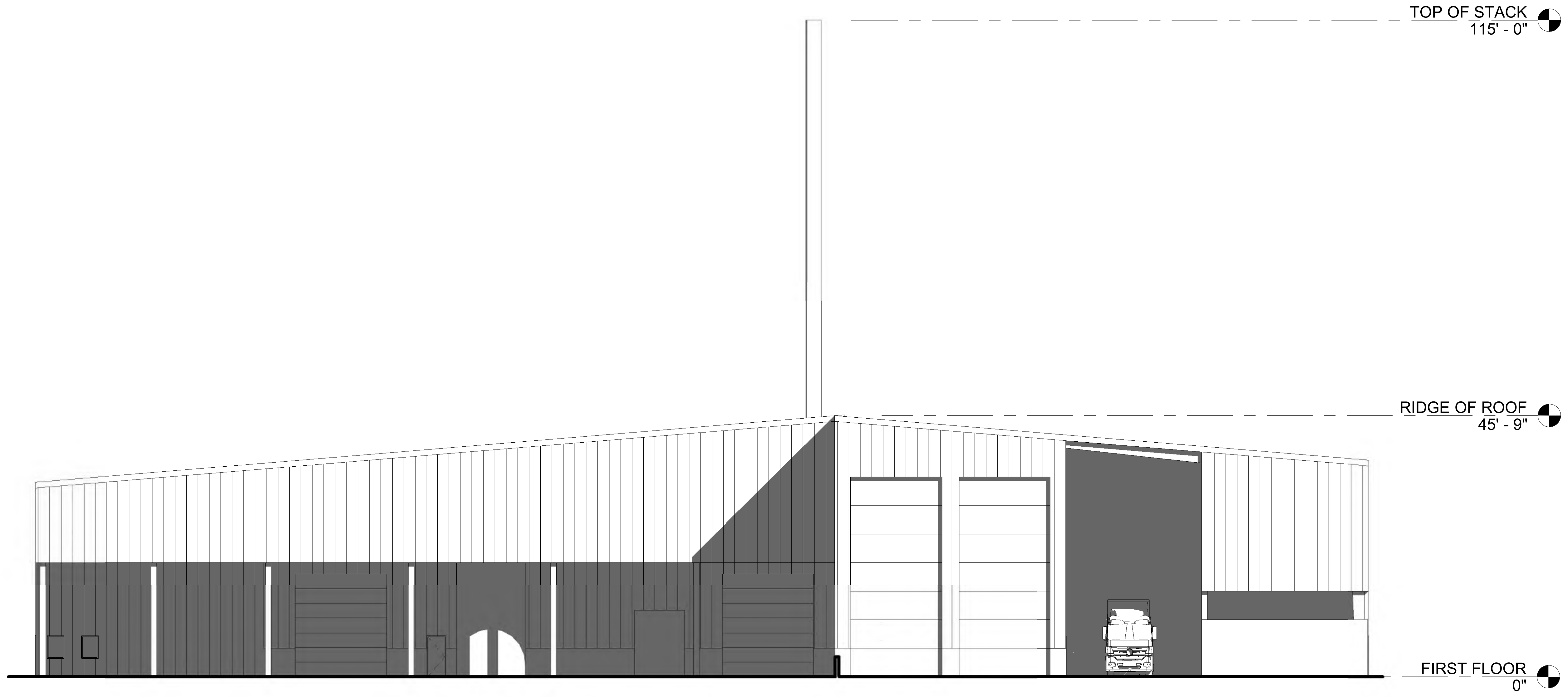
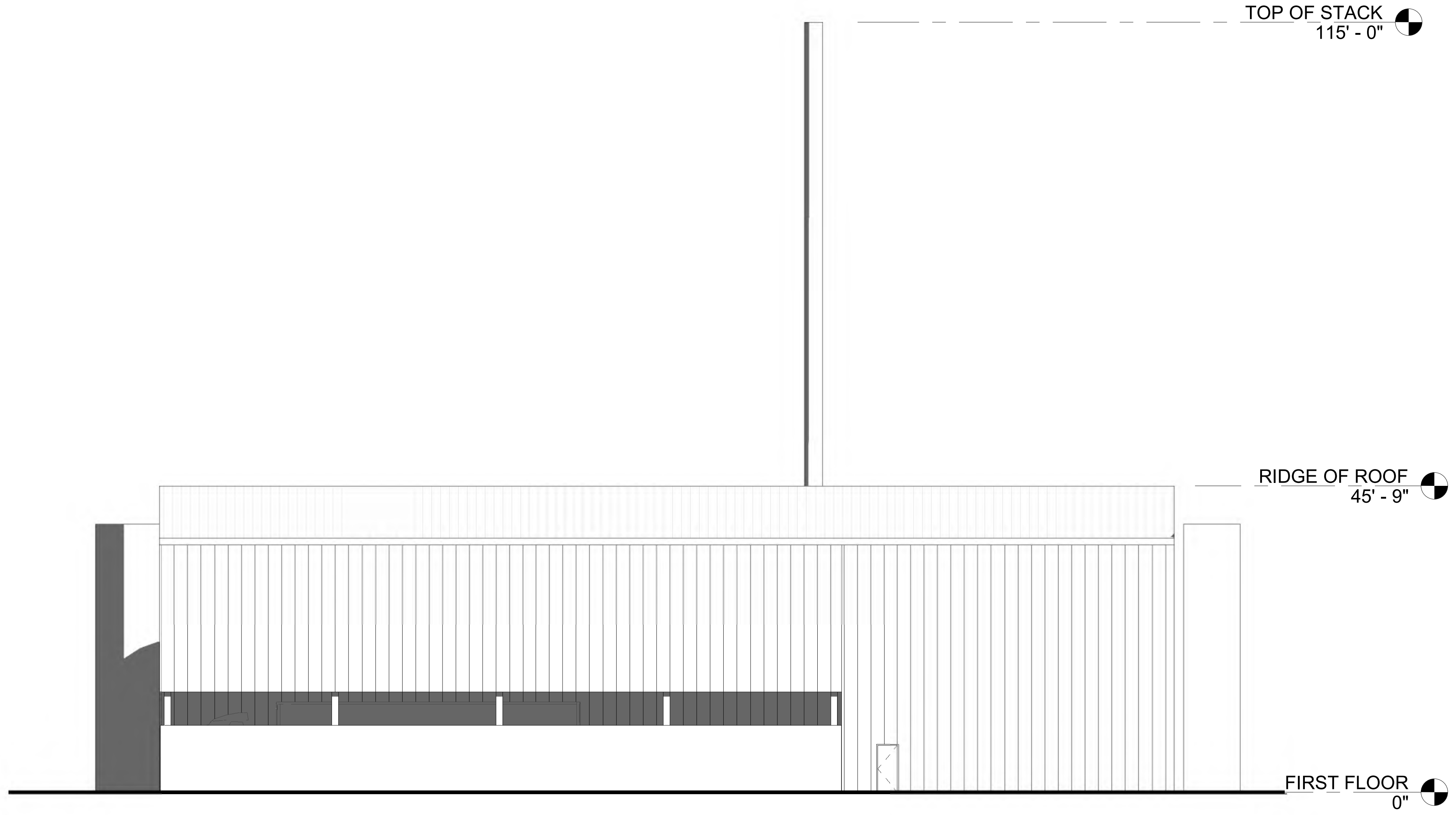


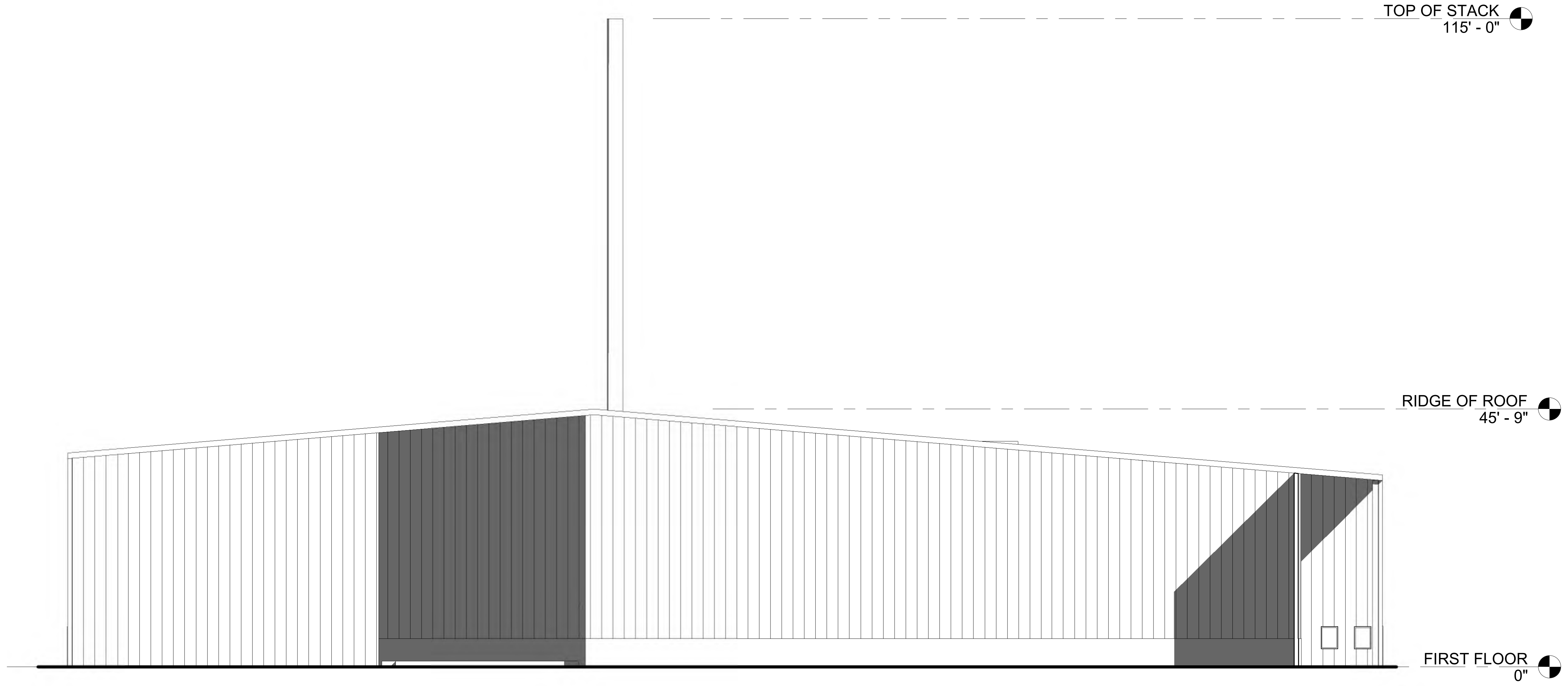
1 EXTERIOR ELEVATION - WEST
1/16" = 1'-0"



2 EXTERIOR ELEVATION - SOUTH
1/16" = 1'-0"



3 EXTERIOR ELEVATION - EAST
1/16" = 1'-0"



4 EXTERIOR ELEVATION - NORTH
1/16" = 1'-0"

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EXTERIOR
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ATTACHMENT 3

THERMAL OXIDIZER DESIGN DOCUMENTATION

ATTACHMENT 4

FACILITY EMISSIONS SUMMARY

SARATOGA BIOCHAR SOLUTIONS, LLC
CARBON FERTILIZER MANUFACTURING FACILITY
MOREAU, NY

FACILITY EMISSIONS SUMMARY - EMISSION RATE POTENTIAL (ERP)

Biosolids input at 23% solids content and wood waste input at 60% solids. Syngas heating value at 8,616 BTU/lb (Case 1A).

Description: **Carbon Fertilizer Manufacturing Facility**
Fuel: **Natural Gas & Syngas[3]**
Capacity: **10** **wet tons/hour biosolids (per process line)**
Process Operations: **8,760** **hours/year (24 hr/day, 365 day/year)**
Air Extraction: **34,146** **actual cubic feet per minute (acfm, per process line)**

Description/ CAS number	Chemical name	Source Emission Rate[1] mg/m^3	Source Emission Rate lb/ft^3	Single Process Line Emission Rate Potential (ERP)			Maximum Facility ERP (Three Process Lines)		
				lb/hr	(lb/yr)	(ton/yr)	lb/hr	(lb/yr)	(ton/yr)
Criteria Pollutants:									
NY075-00-0	Particulate Matter (PM)[2]	50.50	3.15E-06	6.46	56,582	28.29	19.38	169,745	84.9
0NY210-00-0	Nitrogen Oxides (NOx)	25.02	1.56E-06	3.20	28,032	14.02	9.60	84,096	42.0
007446-09-5	Sulfur Dioxide (SO_2)	684.95	4.28E-05	87.61	767,438	383.72	262.8	2,302,313	1,151.2
00630-08-0	Carbon Monoxide (CO)	15.96	9.97E-07	2.04	17,887	8.94	6.1	53,662	26.8
07439-92-1	Lead	1.94	1.21E-07	0.25	2,176	1.09	0.75	6,527	3.3
Non-Criteria Pollutants:									
00124-38-9	Carbon Dioxide (CO_2)	49,636	3.10E-03	6,349	55,613,240	27,807	19,046	166,839,720	83,420
10024-97-2	Nitrous Oxide (N_2O)[4]	25.02	1.56E-06	3.20	28,032	14.02	9.60	84,096	42.0
07644-41-7	Ammonia (NH3)	112.50	7.02E-06	14.39	126,048	63.02	43.2	378,144	189.1
07783-06-4	Hydrogen Sulfide (H2S)	25.00	1.56E-06	3.20	28,011	14.01	9.6	84,032	42.0
multiple	Methyl and Ethylamines	11.30	7.05E-07	1.45	12,661	6.33	4.3	37,982	19.0
07647-01-0	Hydrochloric Acid	0.90	5.62E-08	0.12	1,008	0.50	0.3	3,025	1.5
00064-19-7	Acetic Acid	0.60	3.75E-08	0.08	672	0.34	0.2	2,017	1.0
multiple	Methyl Disulfides and Trisulfides	6.60	4.12E-07	0.84	7,395	3.70	2.5	22,184	11.1
00091-20-3	Naphthalene	1,136	7.09E-05	145.3	1,272,828	636.4	436	3,818,484	1,909
07440-38-2	Arsenic	0.193	1.20E-08	2.47E-02	216	0.1	0.074	648	0.32
07440-43-9	Cadmium	0.162	1.01E-08	2.07E-02	181	0.1	0.062	544	0.27
07439-97-6	Mercury	0.0226	1.41E-09	2.90E-03	25.4	0.013	0.0087	76.1	0.038
00335-67-1	PFOA	5.43E-03	3.39E-10	6.95E-04	6.09	0.003	0.0021	18.26	0.0091
07664-39-3	Hydroflruoric Acid (HF)	5.43E-03	3.39E-10	6.95E-04	6.09	0.003	0.0021	18.26	0.0091

Notes:

1. Source Emission Rates provided by facility designer based on bench tests with representative biosolids. To be verified after startup of first process line.
2. All particulate matter assumed to be PM-2.5
3. Natural gas is only used in the pyrolysis reactor. Under normal operations, renewable syngas generated by the facility will fuel drying equipment.
4. Nitrous Oxide emissions included for greenhouse gas emissions assessment and conservatively assumed to be 100% of NOx emmission. PTE calculation assumes 99% N2O reduction through multi-stage thermal oxidizer.

FACILITY EMISSIONS SUMMARY - POTENTIAL TO EMIT (PTE)

Biosolids input at 23% solids content and wood waste input at 60% solids. Syngas heating value at 8,616 BTU/lb (Case 1A).

Description: **Carbon Fertilizer Manufacturing Facility**
Fuel: **Natural Gas & Syngas**[3]
Capacity: **10** **wet tons/hour biosolids (per process line)**
Process Operations: **8,760** **hours/year (24 hr/day, 365 day/year)**
Air Extraction: **34,146** **actual cubic feet per minute (acfm, per process line)**

Description/ CAS number	Chemical name	Source Emission Rate[1] mg/m^3	Source Emission Rate lb/ft^3	Single Process Line Potential to Emit (PTE) lb/hr	(lb/yr)	(ton/yr)	Maximum Facility PTE (Three Process Lines) lb/hr	(lb/yr)	(ton/yr)
Criteria Pollutants:									
NY075-00-0	Particulate Matter (PM)[2]	5.00	3.12E-07	0.64	5,602	2.80	1.92	16,806	8.40
0NY210-00-0	Nitrogen Oxides (NOx)	25.02	1.56E-06	3.20	28,032	14.02	9.60	84,096	42.0
007446-09-5	Sulfur Dioxide (SO_2)	34.25	2.14E-06	4.38	38,372	19.19	13.14	115,116	57.6
00630-08-0	Carbon Monoxide (CO)	15.96	9.97E-07	2.04	17,887	8.94	6.13	53,662	26.8
07439-32-1	Lead	1.94E-02	1.21E-09	2.48E-03	21.76	1.09E-02	7.45E-03	65.3	3.26E-02
Non-Criteria Pollutants:									
00124-38-9	Carbon Dioxide (CO_2)	49,636	3.10E-03	6,349	55,613,240	27,807	19,046	166,839,720	83,420
10024-97-2	Nitrous Oxide (N_2O)[4]	0.25	1.56E-08	0.032	280	0.14	0.10	841	0.42
07644-41-7	Ammonia (NH3)	5.00	3.12E-07	0.64	5,602	2.80	1.9	16,806	8.4
07783-06-4	Hydrogen Sulfide (H2S)	1.00	6.24E-08	0.13	1,120	0.56	0.4	3,361	1.7
multiple	Methyl and Ethylamines	2.00	1.25E-07	0.26	2,241	1.12	0.8	6,723	3.4
07647-01-0	Hydrochloric Acid	0.90	5.62E-08	0.12	1,008	0.50	0.3	3,025	1.5
00064-19-7	Acetic Acid	0.60	3.75E-08	0.08	672	0.34	0.2	2,017	1.0
multiple	Methyl Disulfides and Trisulfides	1.00	6.24E-08	0.13	1,120	0.56	0.4	3,361	1.7
00091-20-3	Naphthalene	5.68	3.55E-07	0.73	6,364	3.18	2.18	19,092	9.5
07440-38-2	Arsenic	1.93E-03	1.20E-10	2.47E-04	2.2	0.001	7.40E-04	6.48	3.24E-03
07440-43-9	Cadmium	1.62E-03	1.01E-10	2.07E-04	1.8	0.001	6.21E-04	5.44	2.72E-03
07439-97-6	Mercury	2.26E-02	1.41E-09	2.90E-03	25.4	0.013	8.69E-03	76.1	3.80E-02
00335-67-1	PFOA	5.43E-07	3.39E-14	6.95E-08	6.09E-04	3.04E-07	2.08E-07	1.83E-03	9.13E-07
07664-39-3	Hydroflruoric Acid (HF)	3.13E-04	1.95E-11	4.00E-05	3.50E-01	1.75E-04	1.20E-04	1.05	5.25E-04

Notes:

1. Source Emission Rates provided by facility designer based on bench tests with representative biosolids. To be verified after startup of first process line.
2. All particulate matter assumed to be PM-2.5
3. Natural gas is only used in the pyrolysis reactor. Under normal operations, renewable syngas generated by the facility will fuel drying equipment.
4. Nitrous Oxide emissions included for greenhouse gas emissions assessment and conservatively assumed to be 100% of NOx emmission. PTE calculation assumes 99% N2O reduction through multi-stage thermal oxidizer.

ATTACHMENT 5

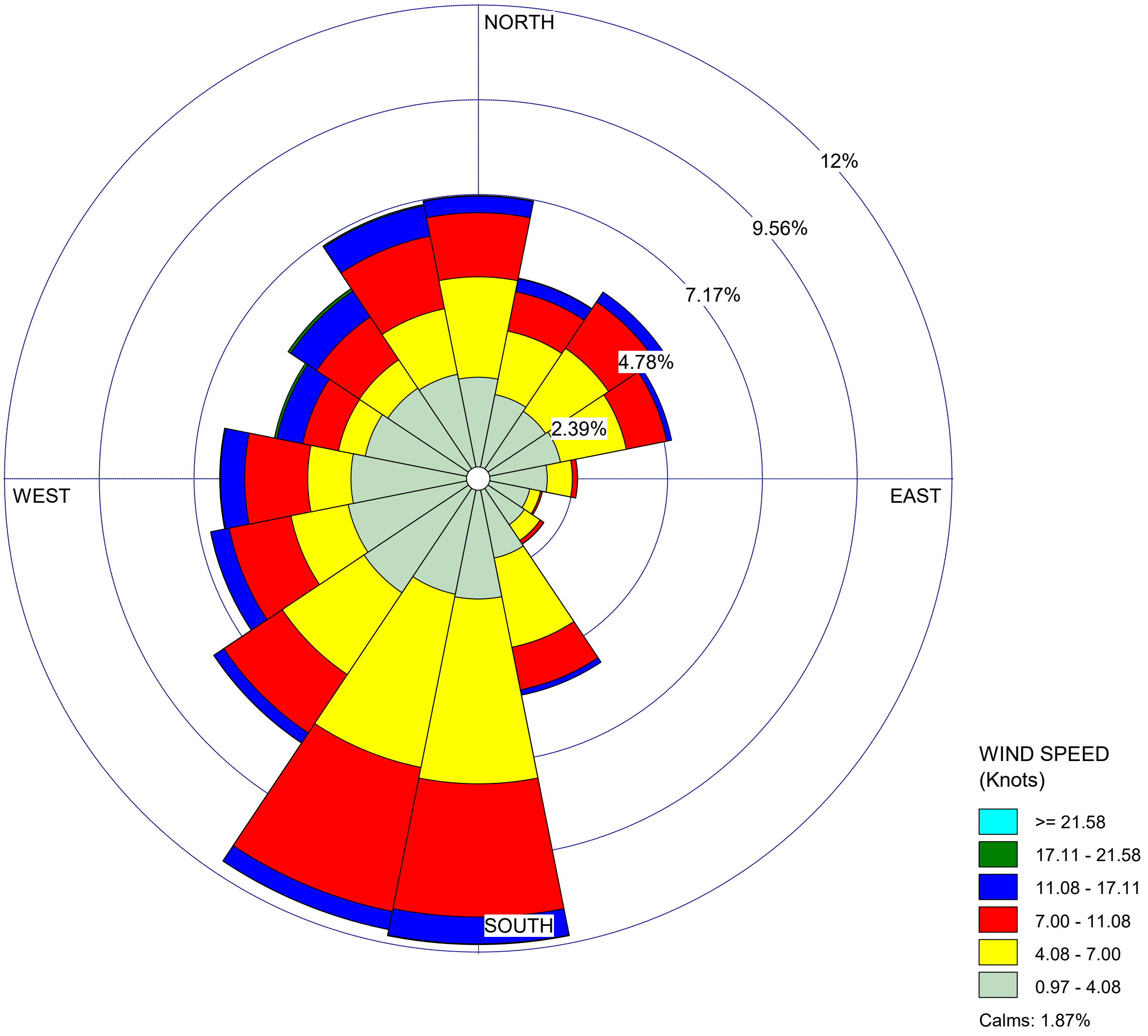
AERMOD OUTPUT

WIND ROSE PLOT:

KGFL - Glens Falls Airport, Glens Falls, NY
2017-2021

DISPLAY:

Wind Speed
Direction (blowing from)



COMMENTS:

DATA PERIOD:

Start Date: 1/1/2017 - 00:00
End Date: 12/31/2021 - 23:59

COMPANY NAME:

MODELER:

CALM WINDS:

1.87%

TOTAL COUNT:

43458 hrs.

AVG. WIND SPEED:

5.39 Knots

DATE:

7/7/2022

PROJECT NO.:

WRPLOT View - Lakes Environmental Software

ATTACHMENT 5A

PARTICULATE MATTER (PM-2.5)

Results Summary

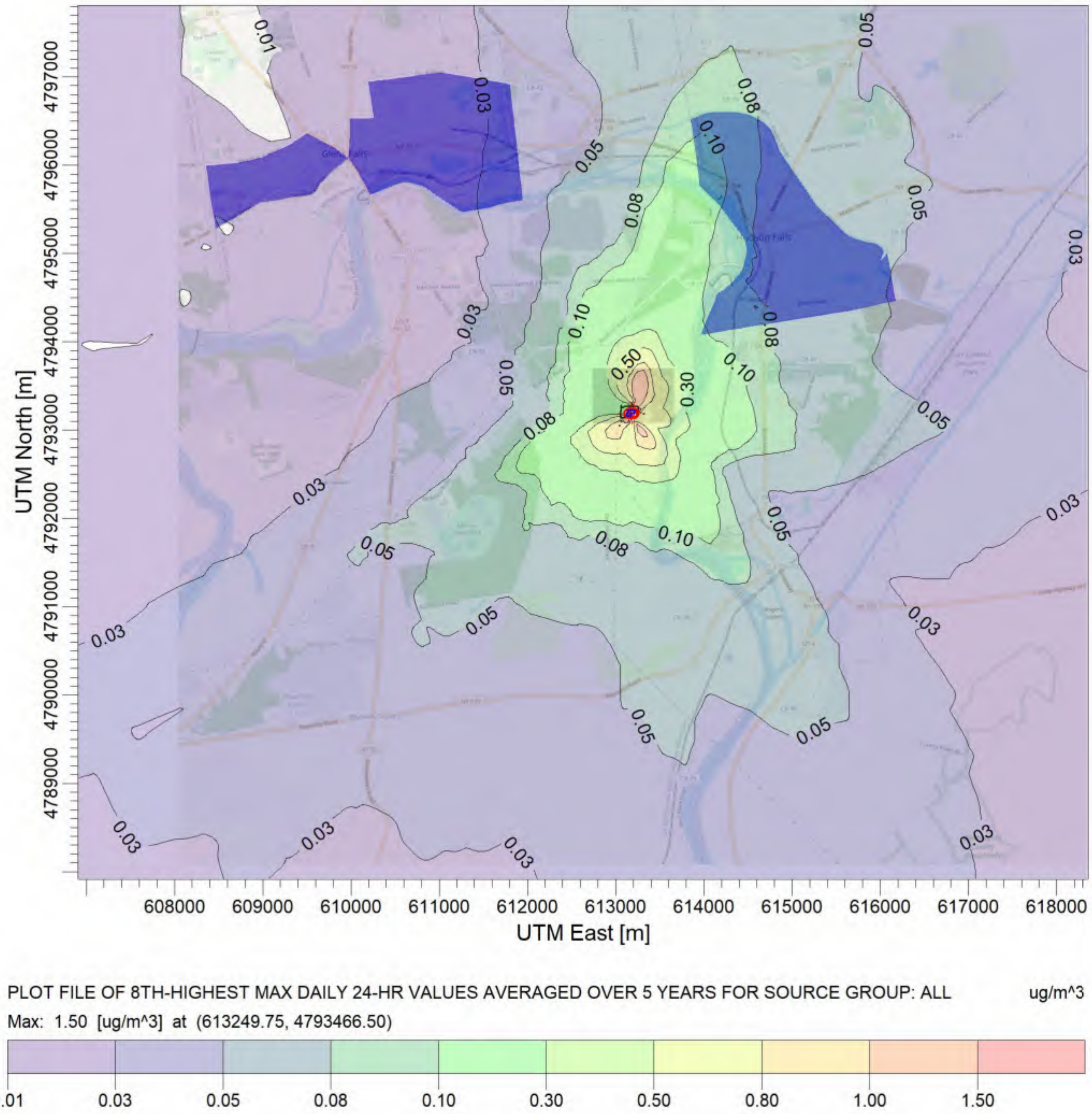
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

PM-2.5 NAAQS - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR	1ST	2.66861	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	
24-HR	8TH	1.49937	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL		0.29780	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.30904	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.30283	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.29687	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.32001	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.26026	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



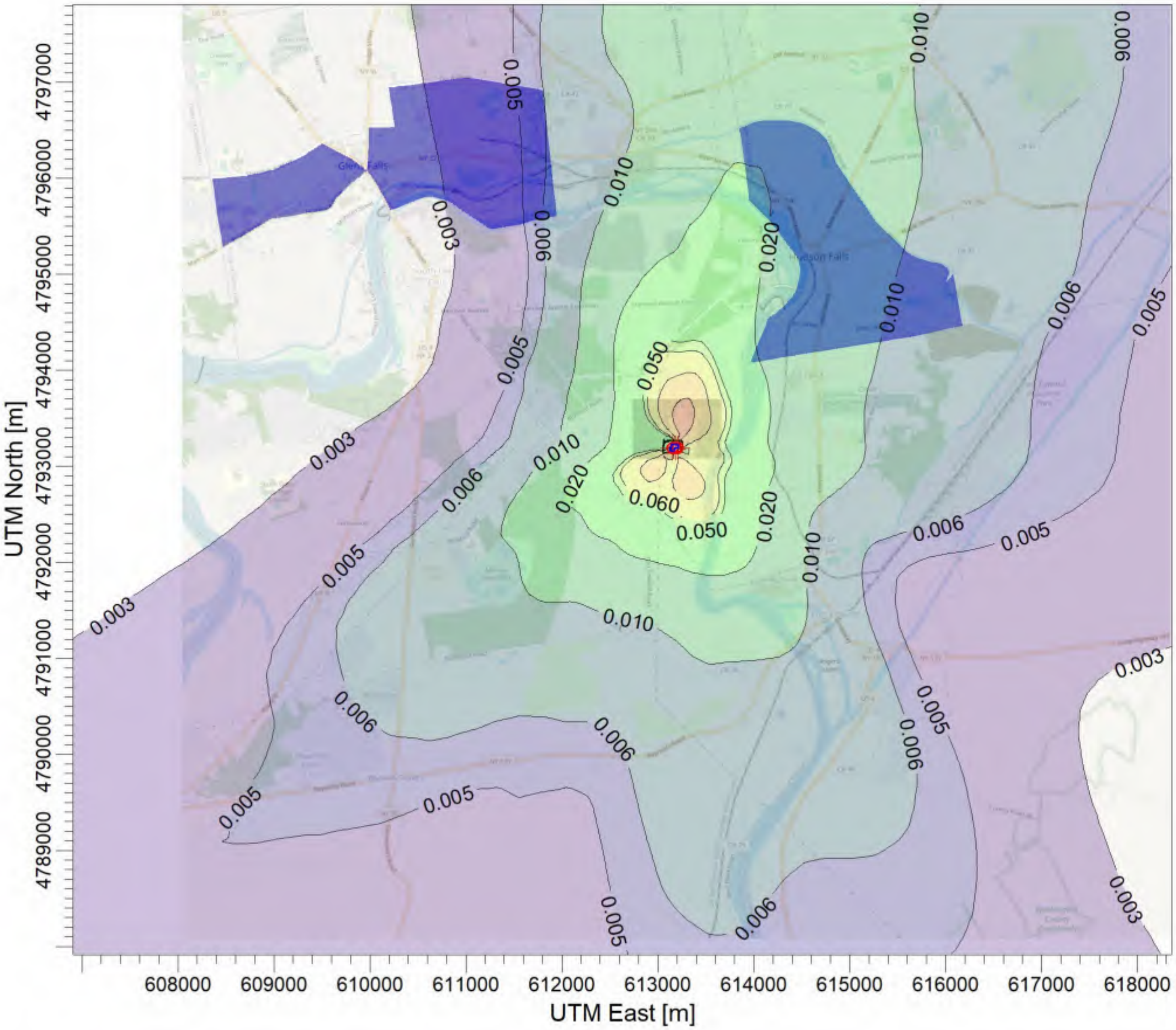
PLOT FILE OF 8TH-HIGHEST MAX DAILY 24-HR VALUES AVERAGED OVER 5 YEARS FOR SOURCE GROUP: ALL

Max: 1.50 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS: PM-2.5 - 24-Hour NAAQS	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km
	MAX: **1.50 ug/m^3**	DATE: **5/8/2023**
		PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 0.298 [ug/m^3] at (613249.75, 4793466.50)

0.003 0.005 0.006 0.010 0.020 0.050 0.060 0.100 0.200 0.298

COMMENTS:

PM-2.5 - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

0.298 ug/m^3

DATE:

5/8/2023

PROJECT NO.:

2020-20

AERMOD View - Lakes Environmental Software

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ATTACHMENT 5B

PARTICULATE MATTER (PM-10)

Results Summary

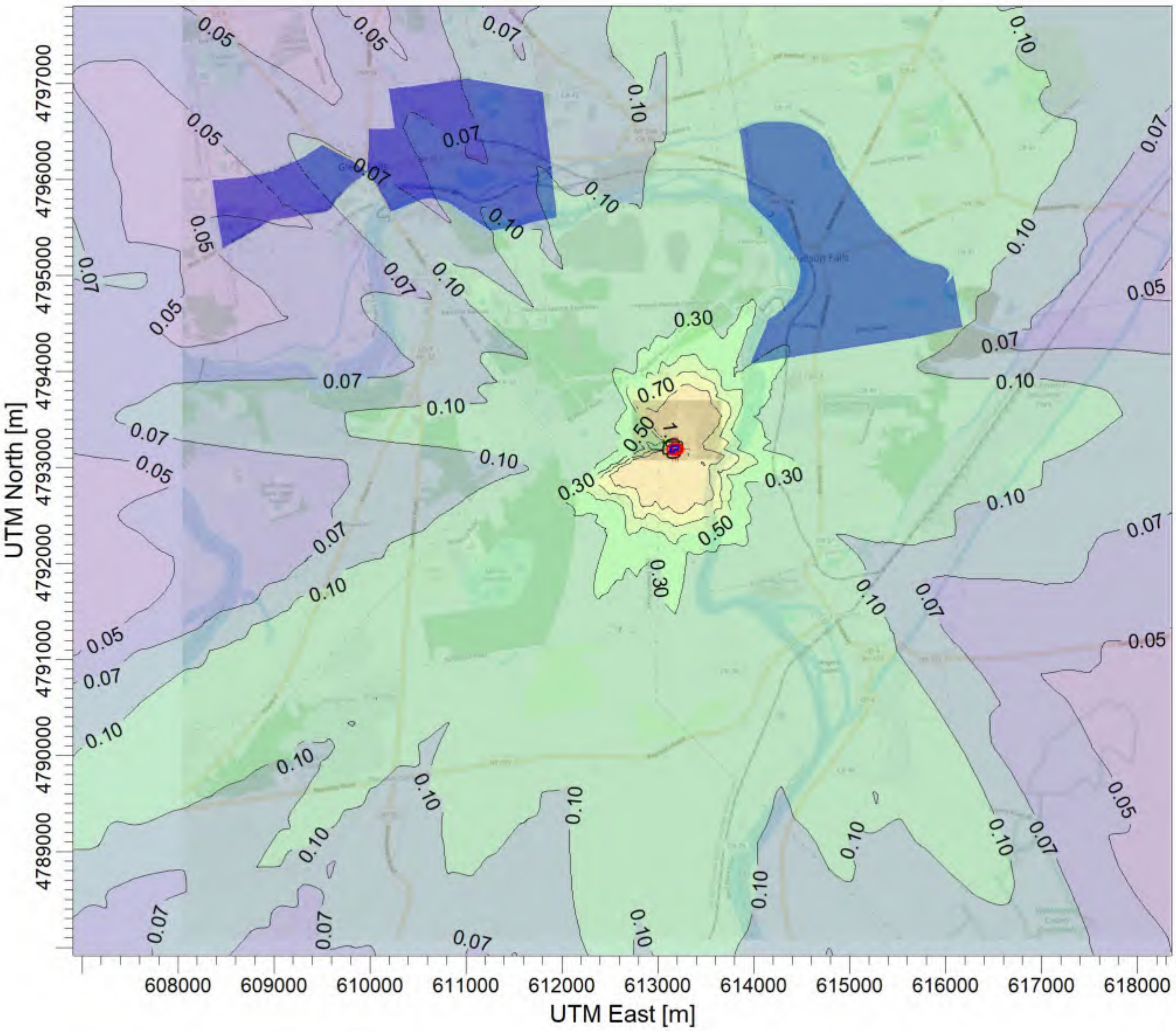
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

PM10 - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
24-HR	1ST	3.52515	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/16/2018, 24
24-HR	8TH	2.38239	ug/m^3	613132.54	4793144.32	73.50	0.00	73.50	10/27/2021, 24
ANNUAL		0.29780	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.30904	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.30283	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.29687	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.32001	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.26026	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 24-HR VALUES FOR SOURCE GROUP: ALL ug/m^3

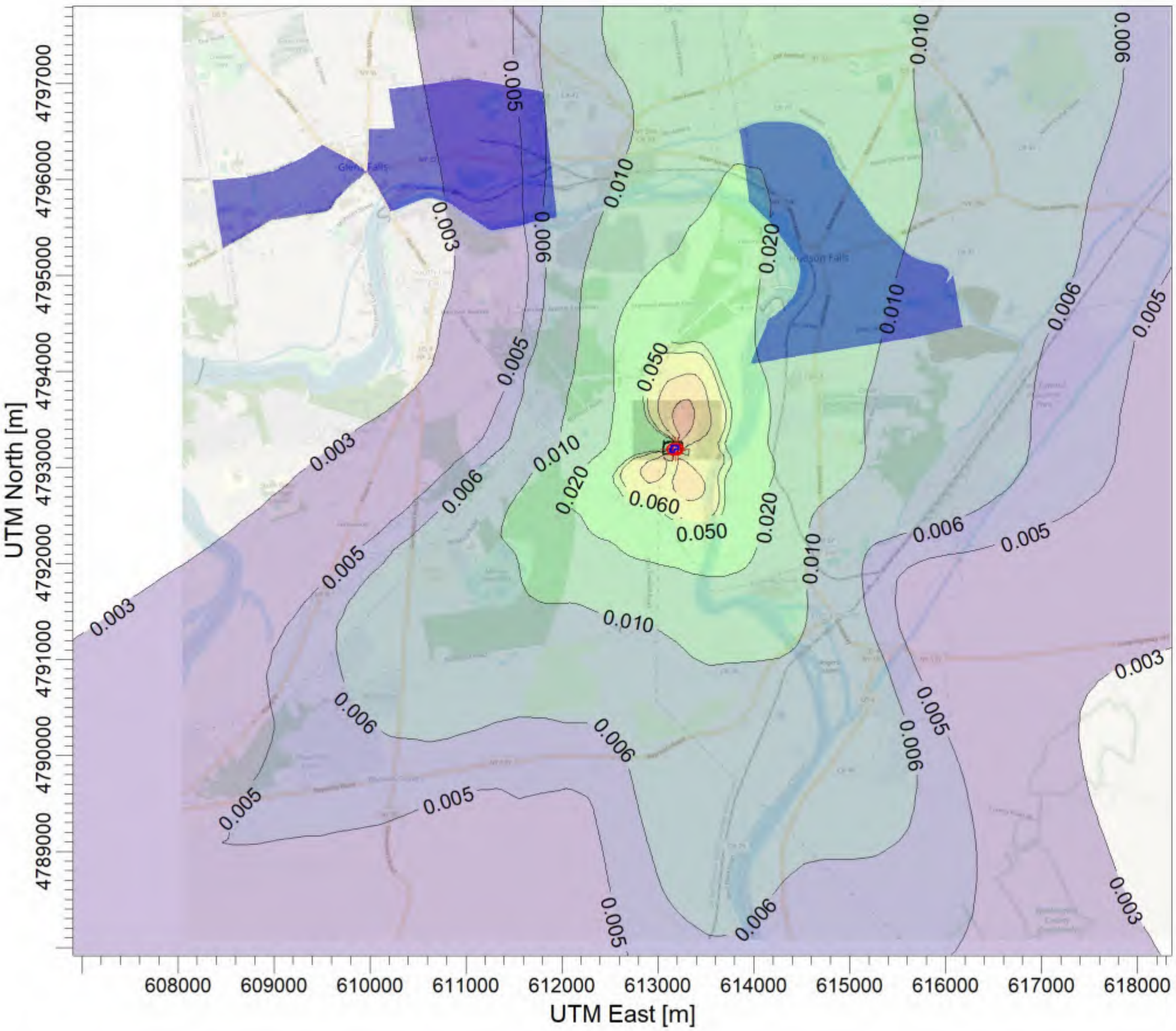
Max: 3.53 [ug/m^3] at (613112.25, 4793123.00)

0.04 0.05 0.07 0.10 0.30 0.50 0.70 1.00 3.00 3.53

COMMENTS: PM-10 - 24 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km
	MAX: **3.53 ug/m^3**	DATE: **5/8/2023**
		PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 0.298 [ug/m^3] at (613249.75, 4793466.50)

0.003	0.005	0.006	0.010	0.020	0.050	0.060	0.100	0.200	0.298

COMMENTS: PM-10 - Annual	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **0.298 ug/m^3**	DATE: **5/8/2023**	PROJECT NO.: **2020-20**

ATTACHMENT 5C

NITROGEN DIOXIDE (NO_2)

Results Summary

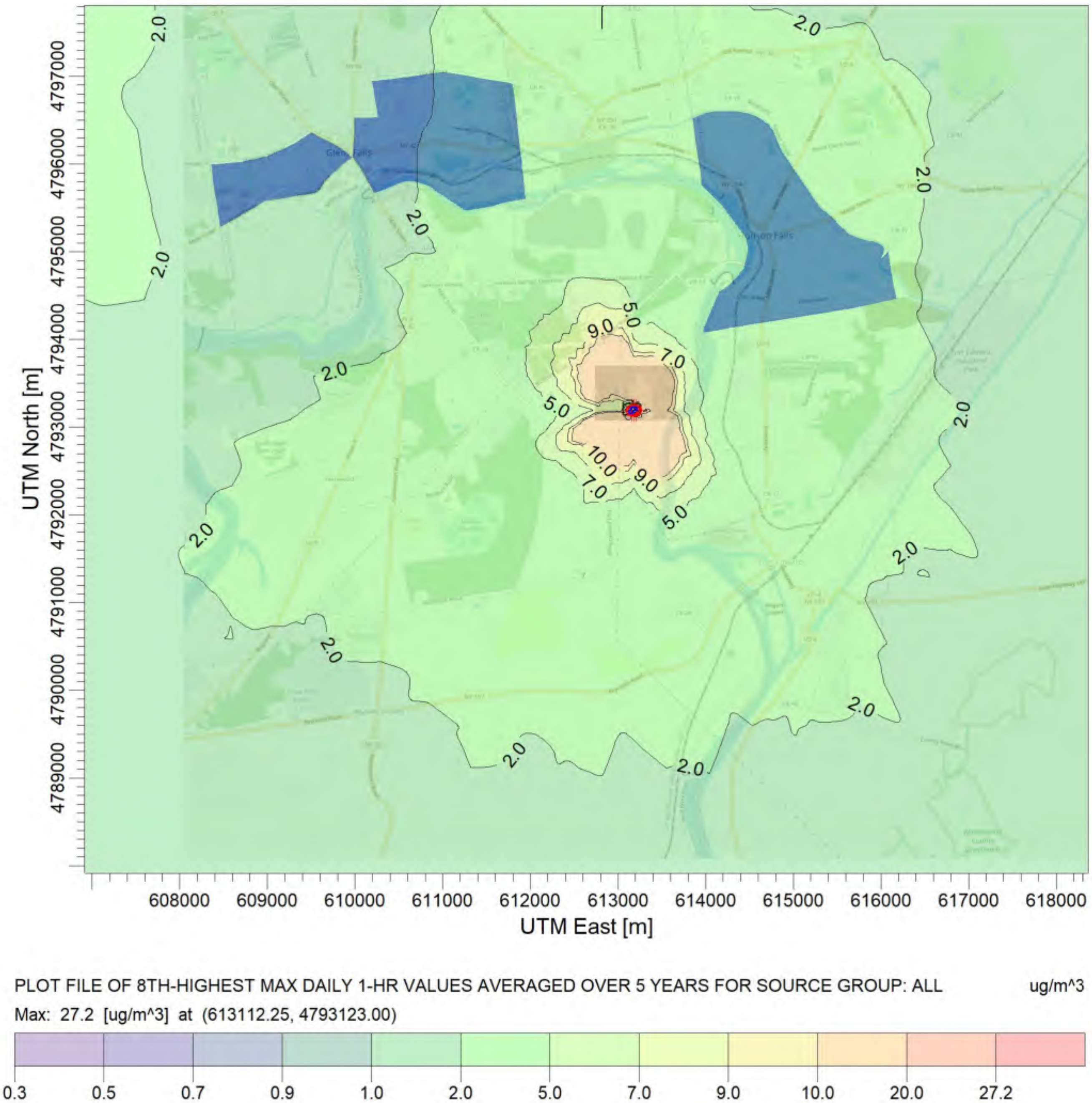
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

NO2 - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	30.63347	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	
1-HR	8TH	27.15259	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	
ANNUAL		1.48900	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		1.54519	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		1.51416	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		1.48435	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		1.60003	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		1.30129	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF 8TH-HIGHEST MAX DAILY 1-HR VALUES AVERAGED OVER 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 27.2 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS:
NO2 - NAAQS

SOURCES:
3

COMPANY NAME:
Sterling Environmental Engineering, P.C.

RECEPTORS:
5165

MODELER:
AMM

OUTPUT TYPE:
Concentration

SCALE: 1:71,992
0 2 km

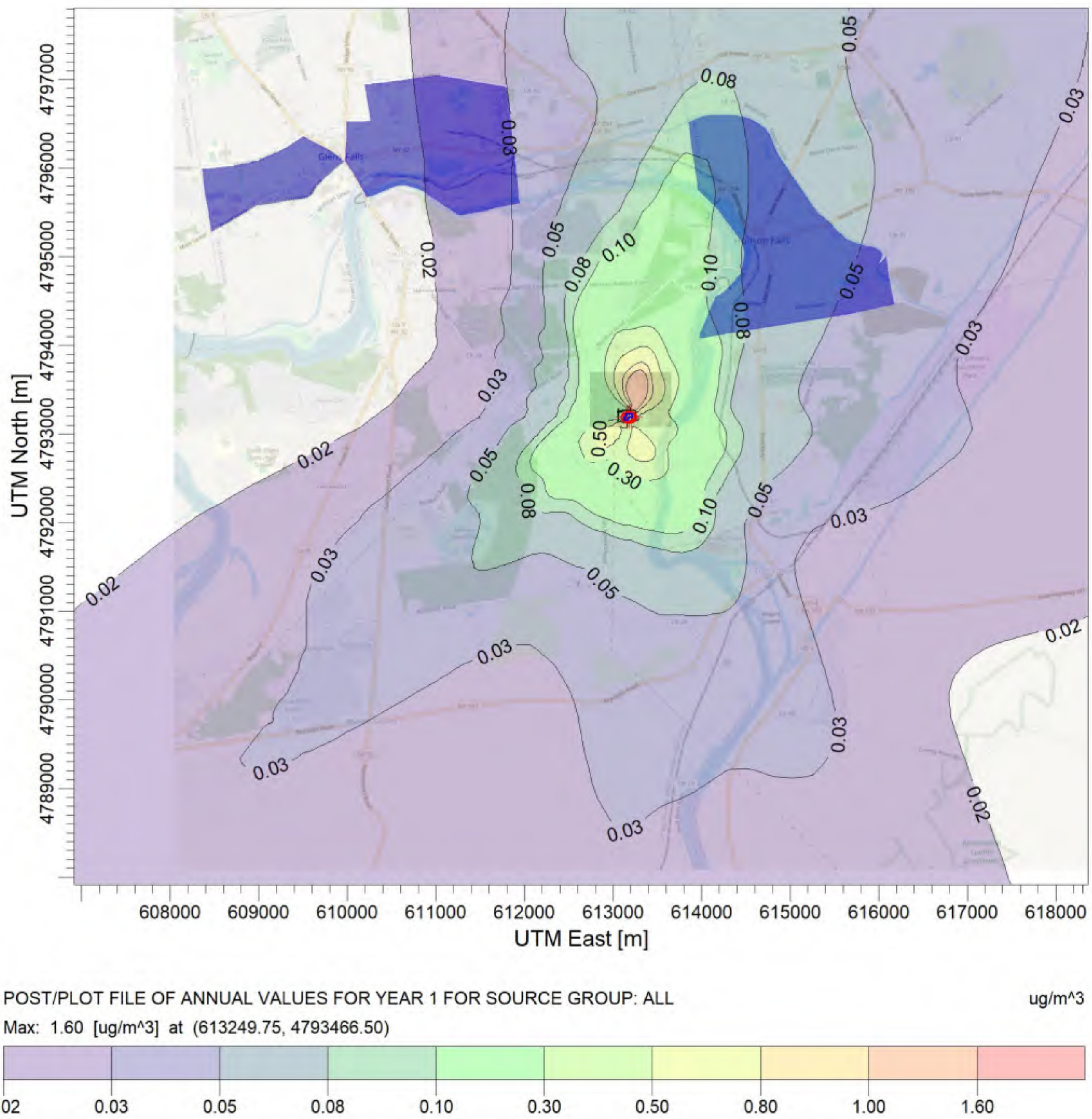
MAX:
27.2 ug/m^3

DATE:
9/5/2023

PROJECT NO.:
2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



COMMENTS: NO2 - Annual (Year 4 Maximum Concentration)	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km
	MAX: **1.60 ug/m^3**	DATE: **9/5/2023**
		PROJECT NO.: **2020-20**

AERMOD View - Lakes Environmental Software

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ATTACHMENT 5D

SULFUR DIOXIDE (SO_2)

Results Summary

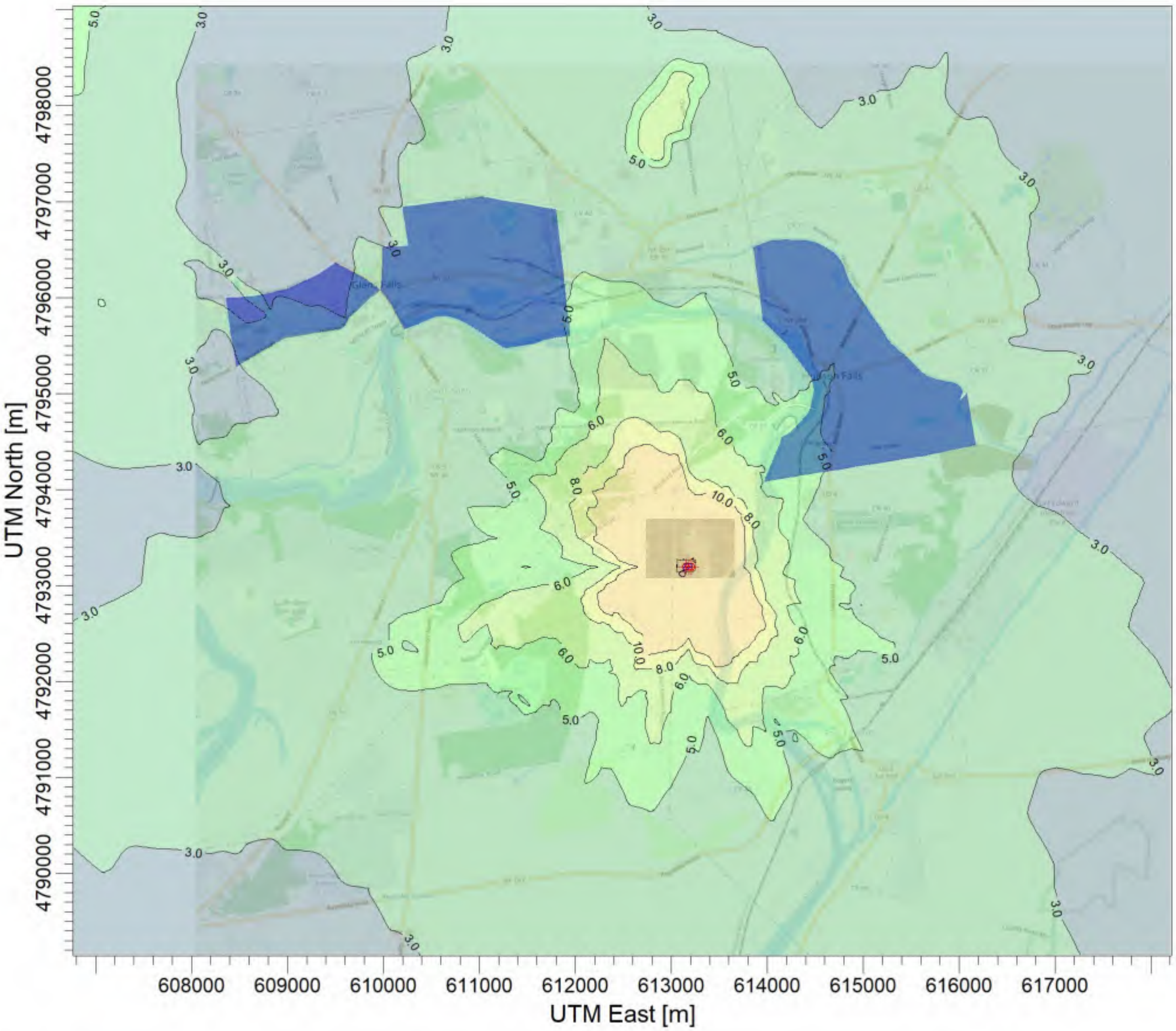
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

SO2 - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	41.92956	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	
1-HR	4TH	39.55148	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	
1-HR	8TH	37.16511	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	
ANNUAL		2.03807	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		2.11497	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		2.07251	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		2.03170	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		2.19003	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		1.78114	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF 4TH-HIGHEST MAX DAILY 1-HR VALUES AVERAGED OVER 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 39.6 [ug/m^3] at (613112.25, 4793123.00)

0.6 0.8 1.0 3.0 5.0 6.0 8.0 10.0 30.0 39.6

COMMENTS:
SO2 - 1 Hour

SOURCES:
3

COMPANY NAME:
Sterling Environmental Engineering, P.C.

RECEPTORS:
5165

MODELER:
AMM

OUTPUT TYPE:
Concentration

SCALE: 1:71,992
0 2 km

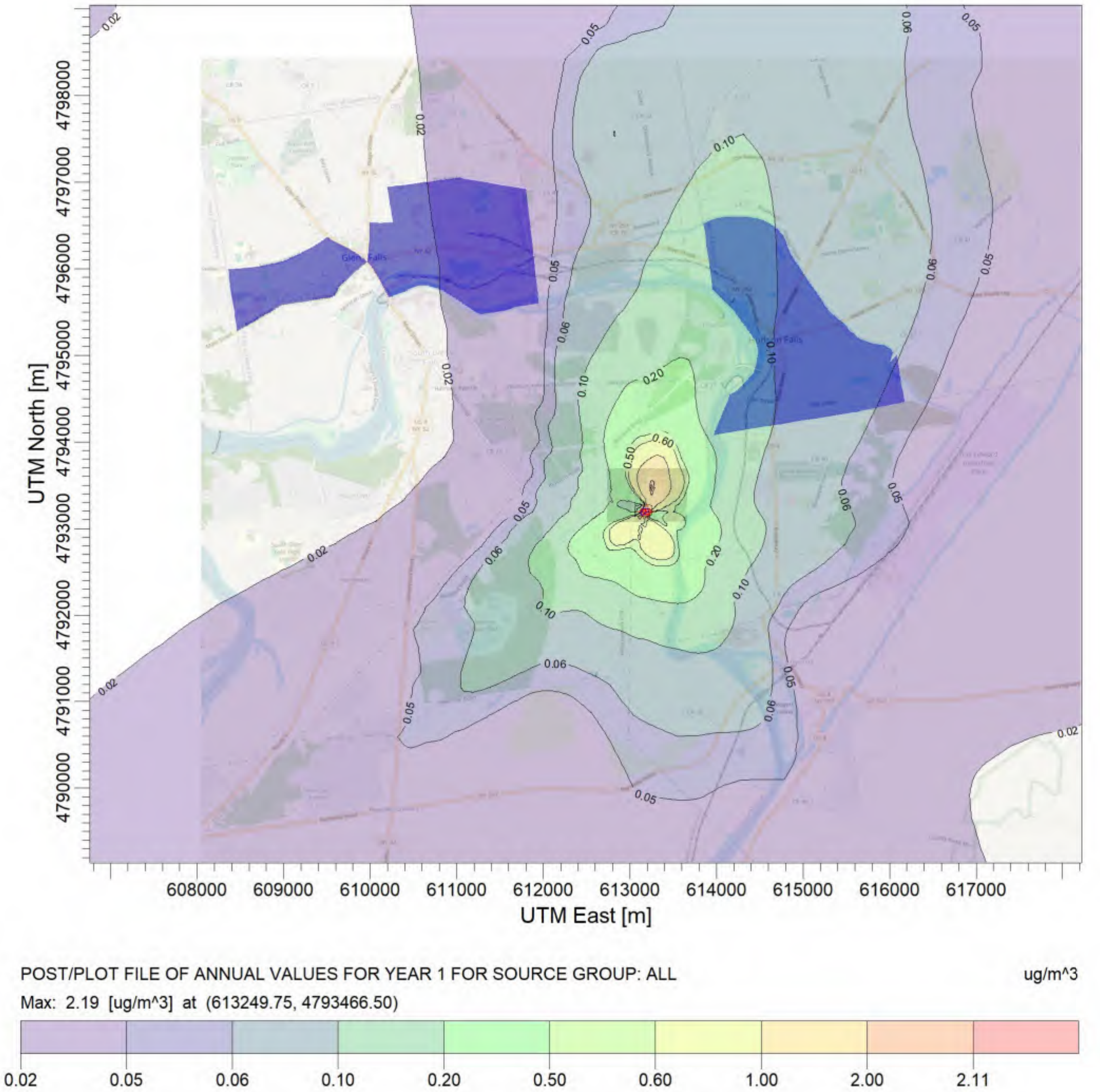
MAX:
39.6 ug/m^3

DATE:
5/3/2023

PROJECT NO.:
2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



POST/PLOT FILE OF ANNUAL VALUES FOR YEAR 1 FOR SOURCE GROUP: ALL

Max: 2.19 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS:

SO2 - Annual (Year 4 Max Concentration)

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:72,053

0 2 km

MAX:

2.19 ug/m^3

DATE:

5/3/2023

PROJECT NO.:

2020-20

Results Summary

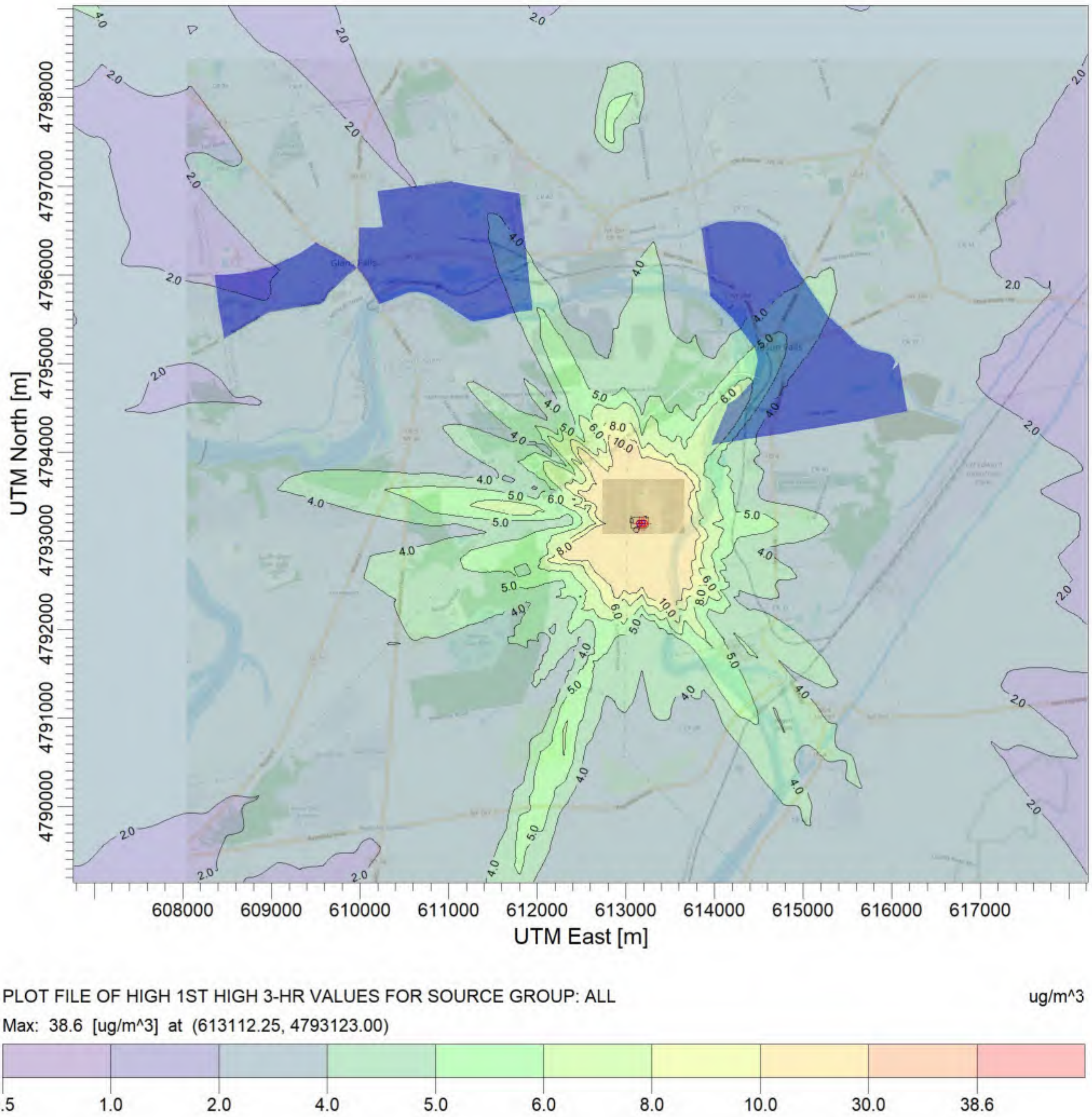
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

SO2 - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
3-HR	1ST	38.55889	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/16/2018, 6
24-HR	1ST	24.12526	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/16/2018, 24
24-HR	8TH	16.30451	ug/m^3	613132.54	4793144.32	73.50	0.00	73.50	10/27/2021, 24

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



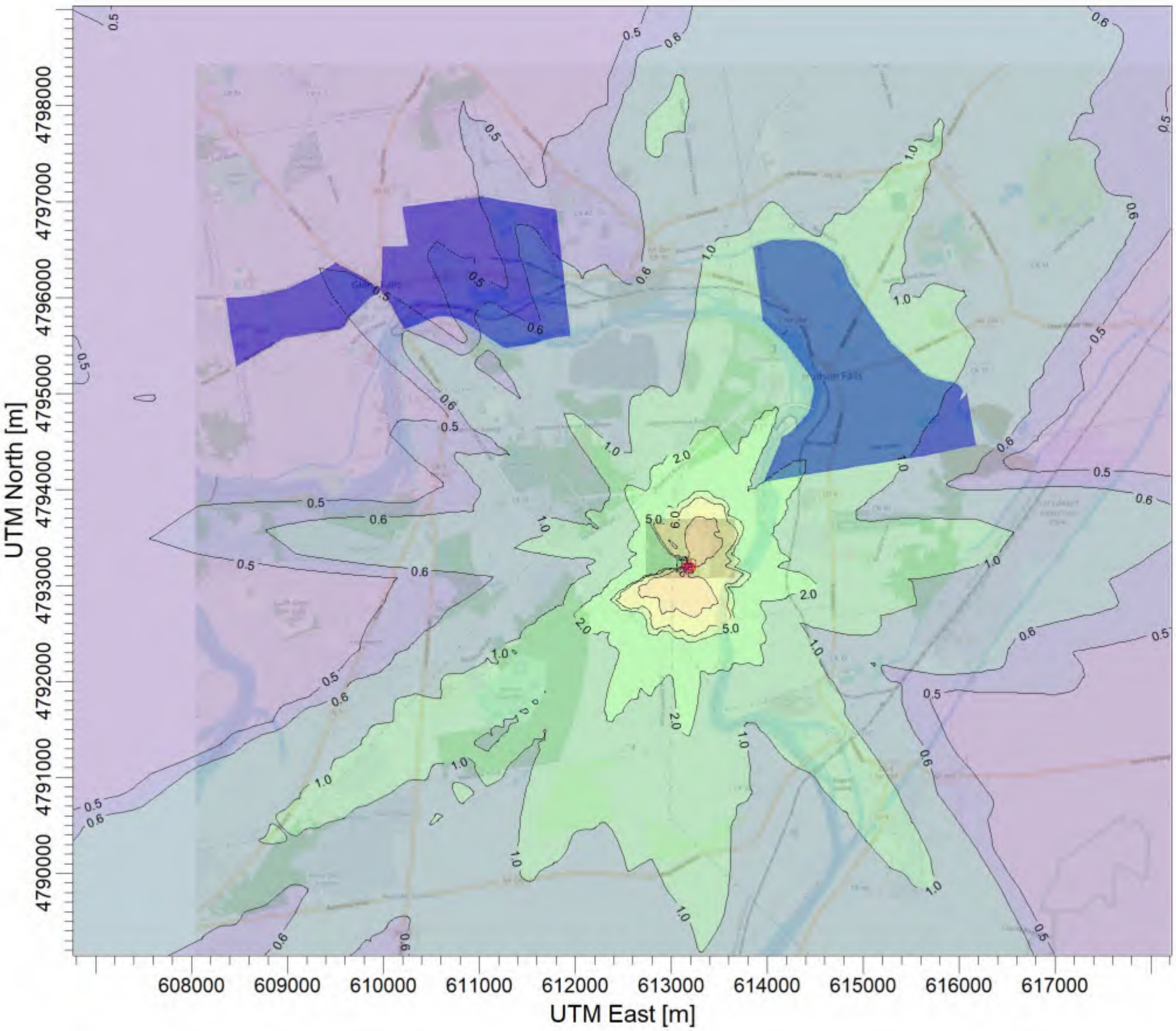
PLOT FILE OF HIGH 1ST HIGH 3-HR VALUES FOR SOURCE GROUP: ALL

Max: 38.6 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS: SO2 - 3 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **38.6 ug/m^3**	DATE: **5/3/2023**	PROJECT NO.: **2020-20**

PROJECT TITLE:

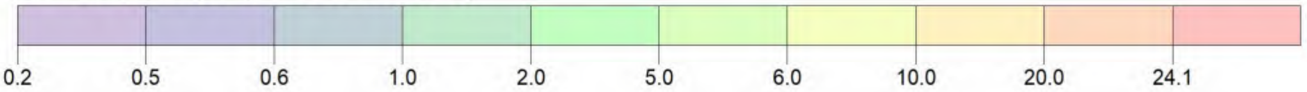
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 24-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

Max: 24.1 [ug/m^3] at (613112.25, 4793123.00)



COMMENTS:

SO2 - 24 Hour

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE:

1:71,992

0 2 km

MAX:

24.1 ug/m^3

DATE:

5/3/2023

PROJECT NO.:

2020-20

ATTACHMENT 5E

CARBON MONOXIDE

Results Summary

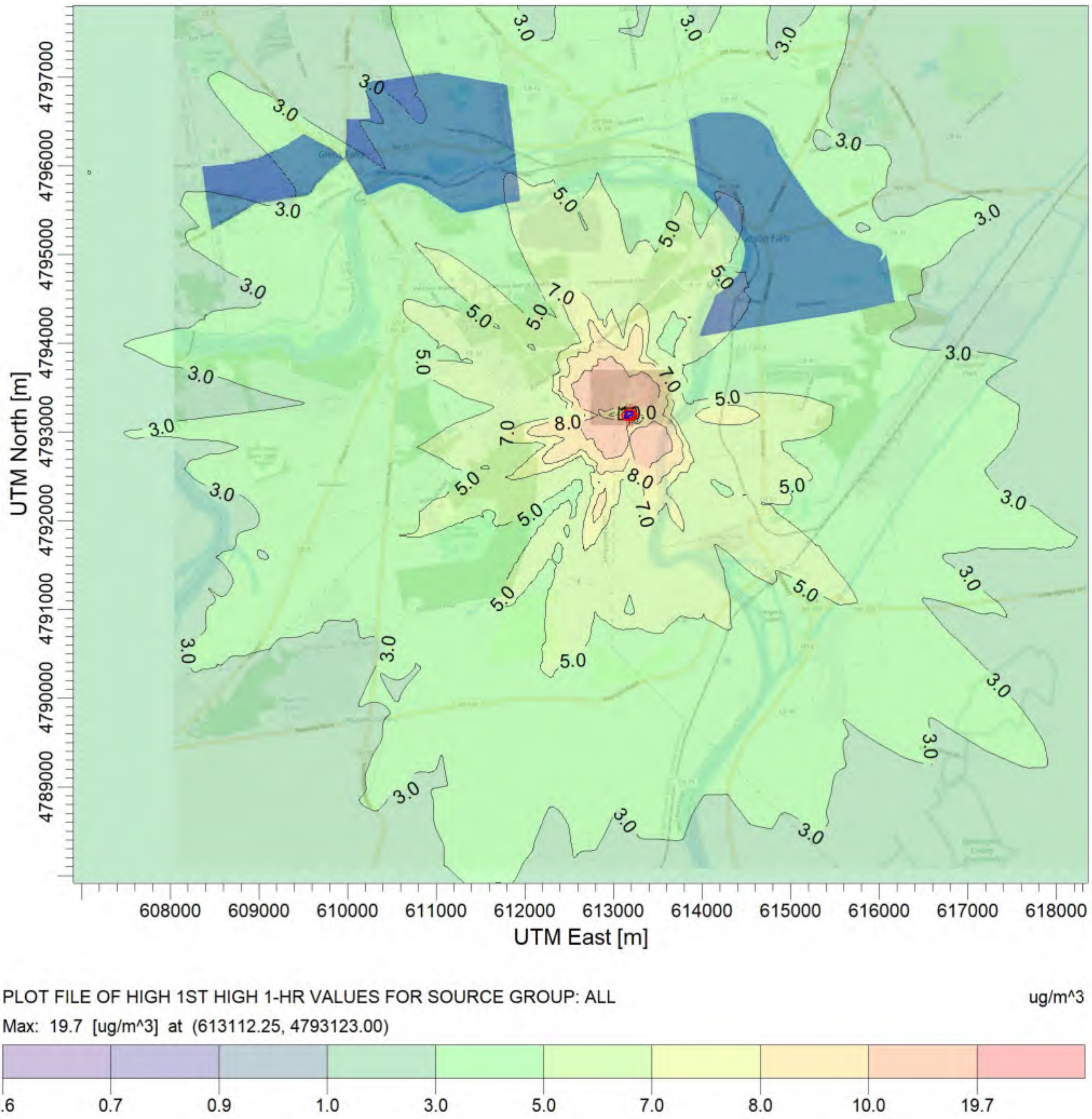
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

CO - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	19.68065	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
8-HR	1ST	15.26952	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/16/2018, 8

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



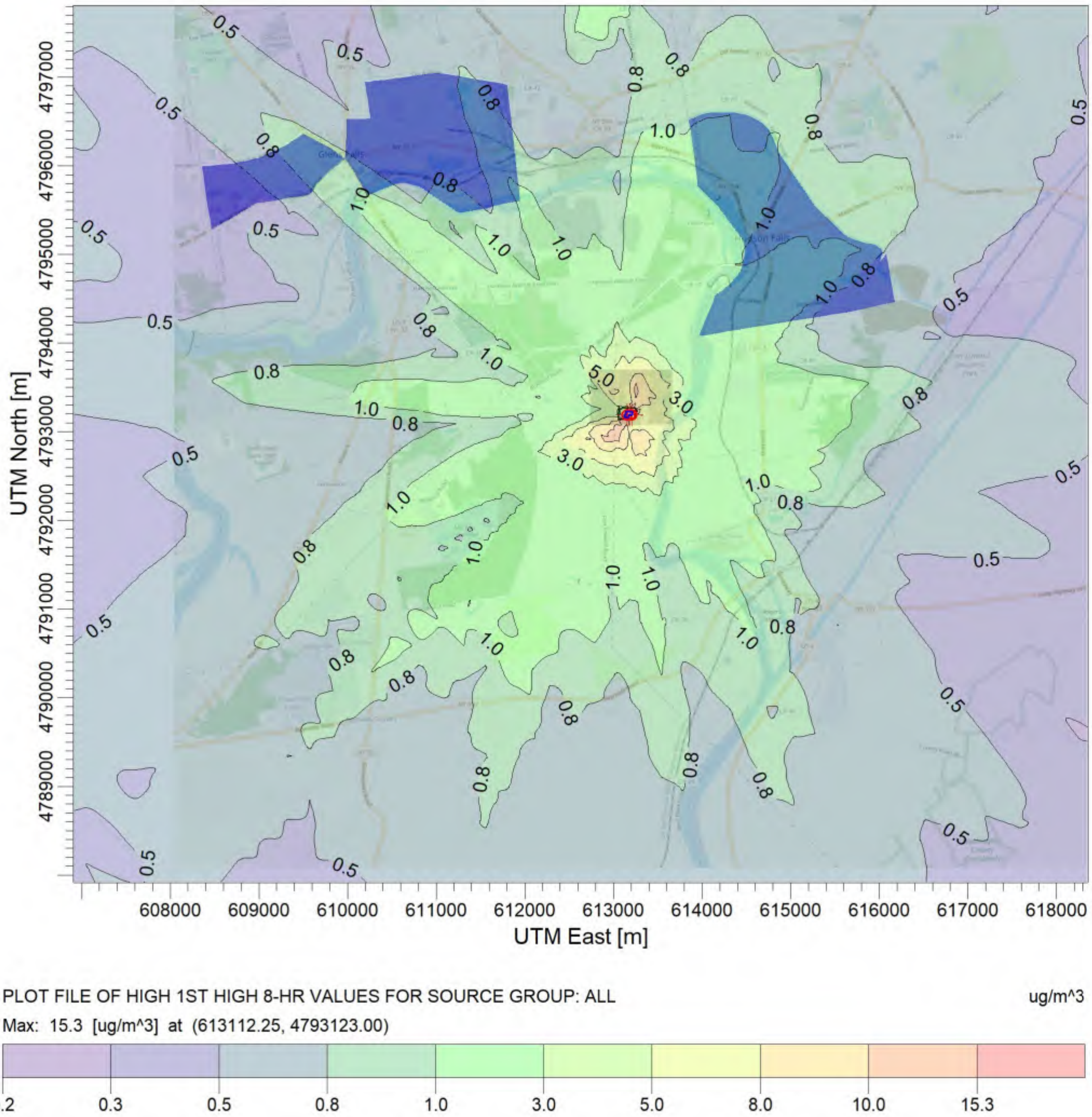
PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

Max: 19.7 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS: CO - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **19.7 ug/m^3**	DATE: **9/5/2023**	PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 8-HR VALUES FOR SOURCE GROUP: ALL

Max: 15.3 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS: CO - 8 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km
	MAX: **15.3 ug/m^3**	DATE: **9/5/2023**
		PROJECT NO.: **2020-20**

AERMOD View - Lakes Environmental Software

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ATTACHMENT 5F

NAPHTHALENE

Results Summary

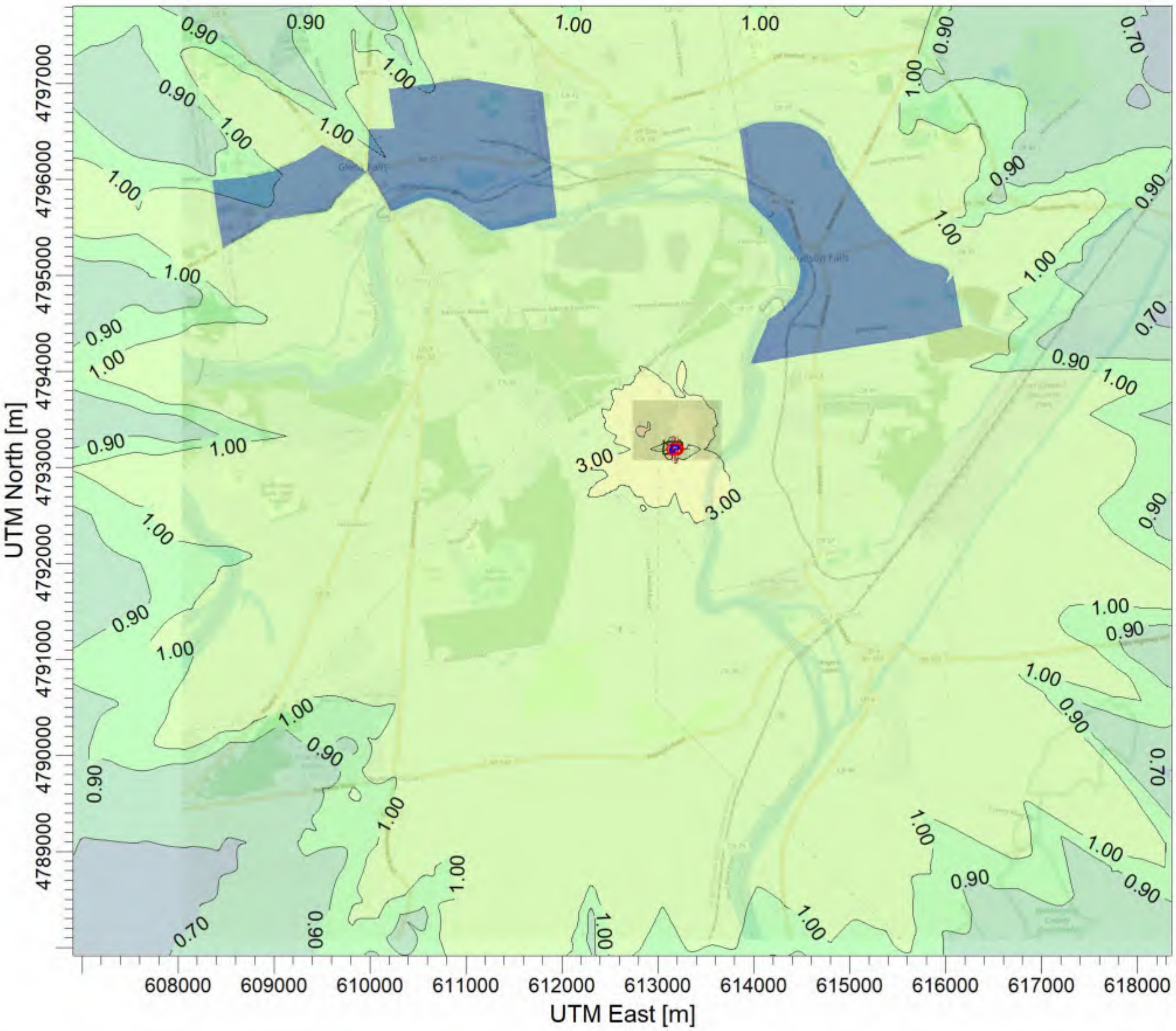
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

NAPH - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	7.04259	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.33968	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.35250	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.34542	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.33862	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.36501	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.29686	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

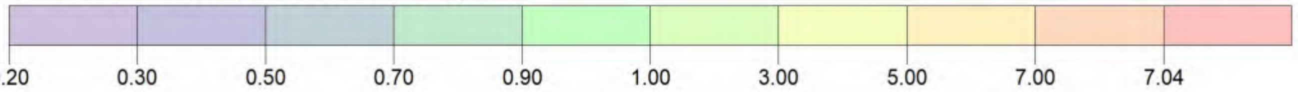
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

Max: 7.04 [ug/m^3] at (613112.25, 4793123.00)



COMMENTS:

Naphthalene - 1 Hour

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

7.04 ug/m^3

DATE:

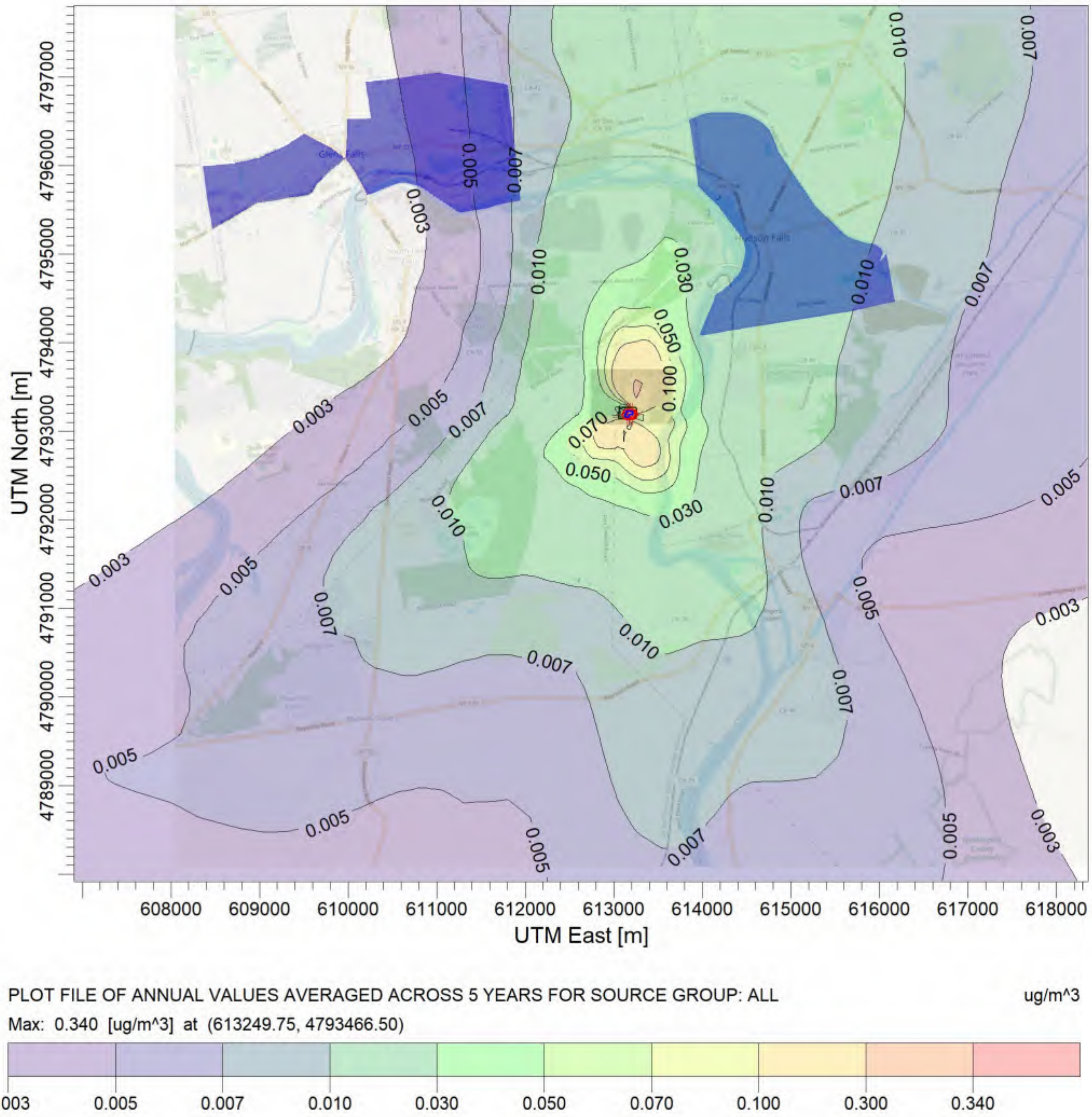
5/5/2023

PROJECT NO.:

2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL

Max: 0.340 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS: Naphthalene - Annual	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **0.340 ug/m^3**	DATE: **5/5/2023**	PROJECT NO.: **2020-20**

ATTACHMENT 5G

HYDROGEN SULFIDE

Results Summary

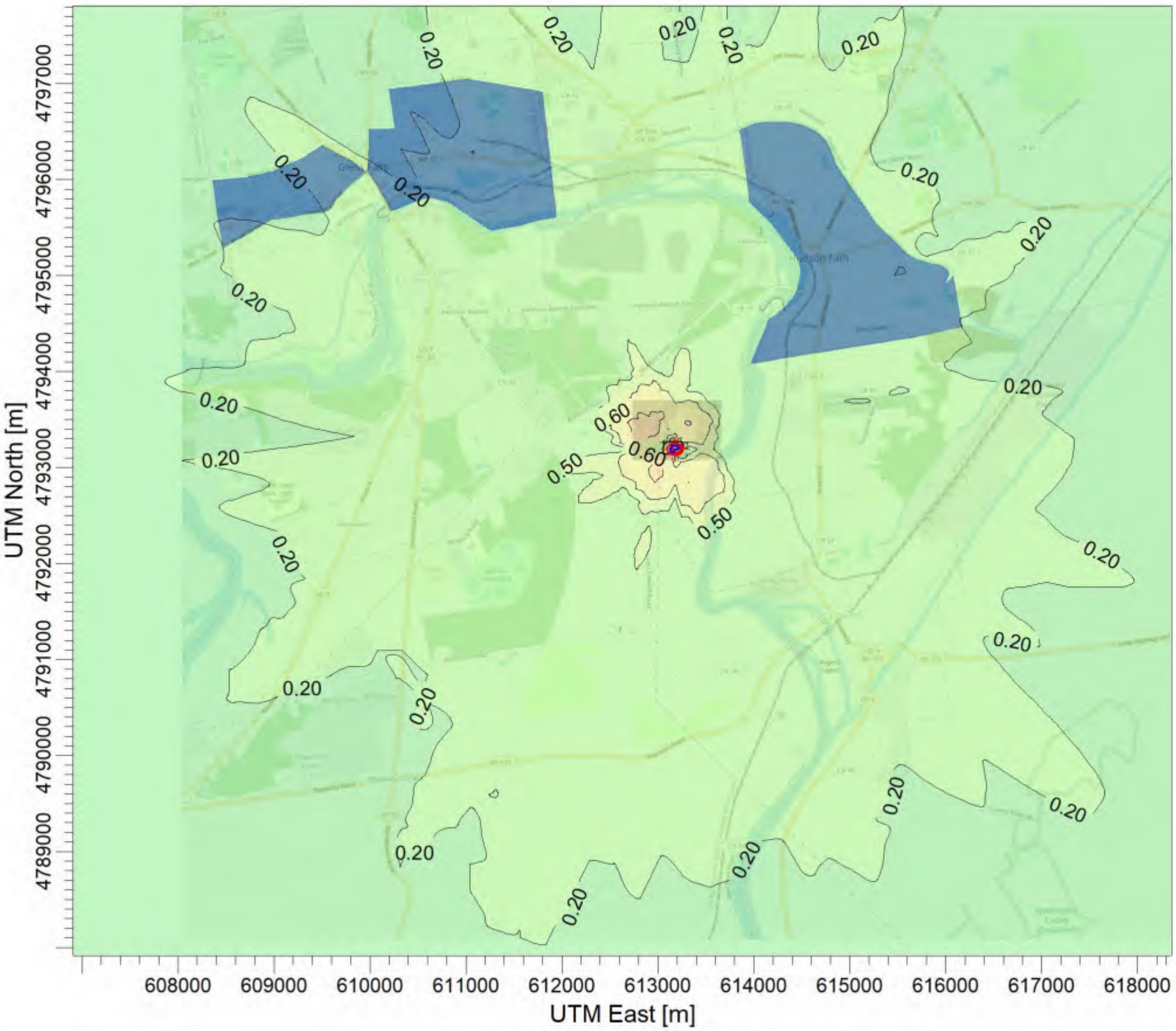
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

H2S - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	1.25416	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.06049	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.06277	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.06151	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.06030	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.06500	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.05287	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

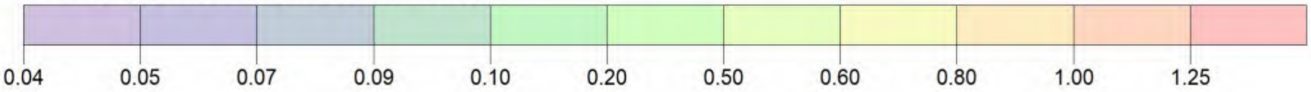
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

Max: 1.25 [ug/m^3] at (613112.25, 4793123.00)



COMMENTS:

H2S - 1 Hour

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

1.25 ug/m^3

DATE:

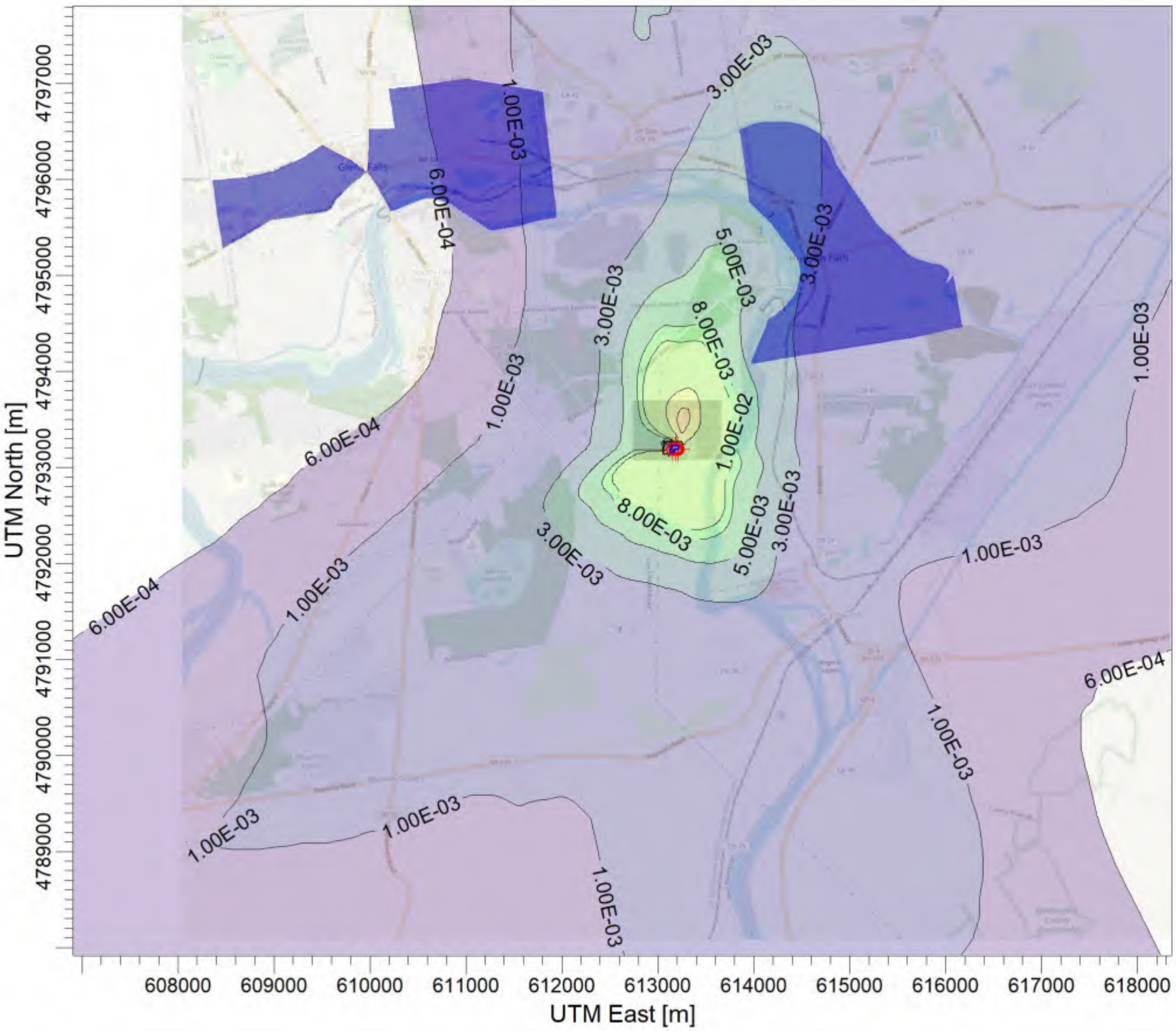
5/5/2023

PROJECT NO.:

2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL — ug/m^3

Max: 6.05E-02 [ug/m^3] at (613249.75, 4793466.50)

6.00E-04 1.00E-03 3.00E-03 5.00E-03 8.00E-03 1.00E-02 3.00E-02 5.00E-02 6.00E-02 6.05E-02

COMMENTS:

H2S - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

6.05E-02 ug/m^3

DATE:

5/5/2023

PROJECT NO.:

2020-20

AERMOD View - Lakes Environmental Software

C:\Lakes\AERMOD View\SBSMoreau\SBSMoreau.isc

ATTACHMENT 5H

ARSENIC

Results Summary

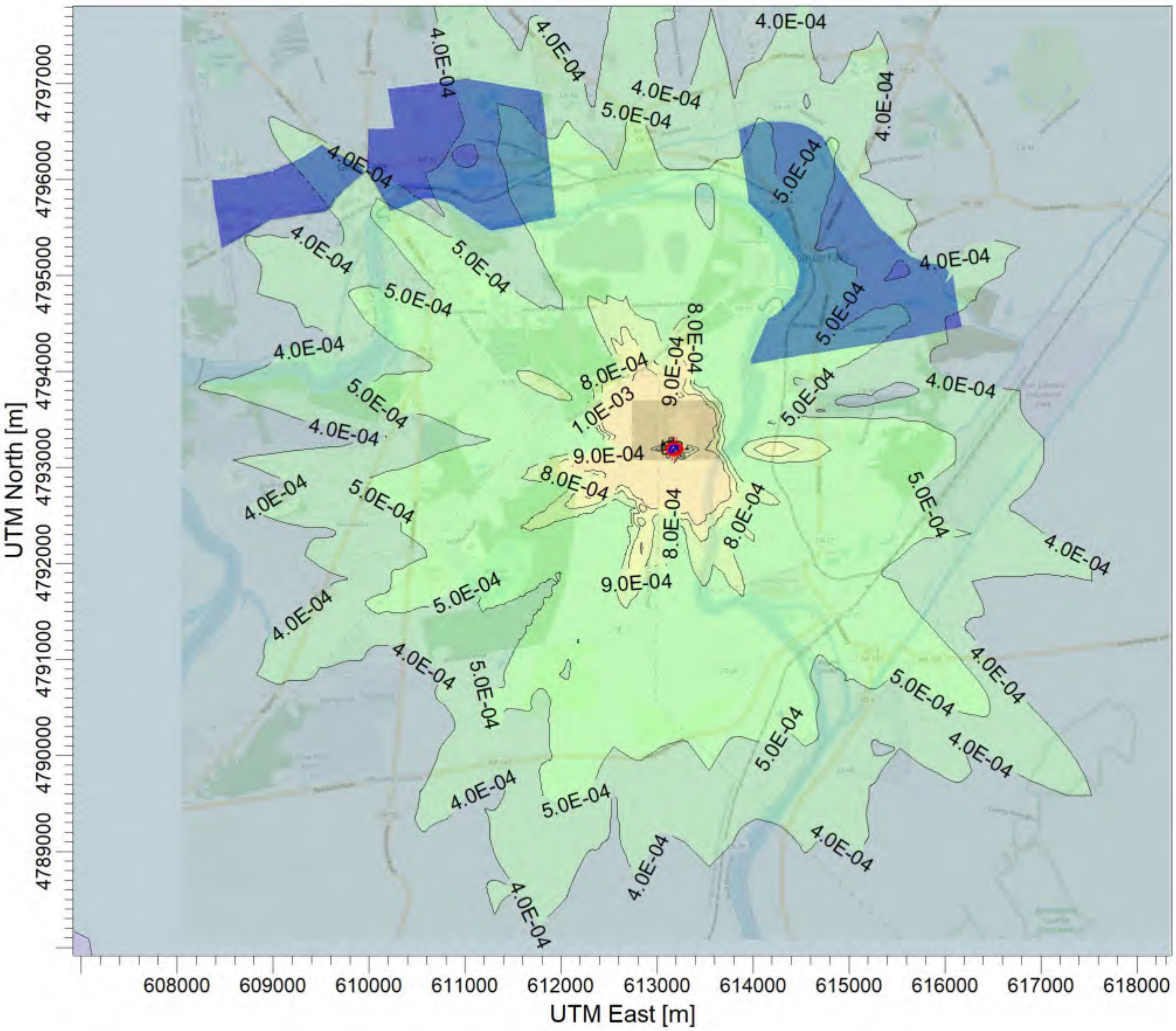
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

ARSENIC - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	0.00238	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
1-HR	8TH	0.00235	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/30/2017, 2
ANNUAL		0.00011	ug/m^3	613249.75	4793398.00	71.44	0.00	71.44	
ANNUAL Y1		0.00012	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.00012	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.00011	ug/m^3	613249.75	4793398.00	71.44	0.00	71.44	
ANNUAL Y4		0.00012	ug/m^3	613249.75	4793398.00	71.44	0.00	71.44	
ANNUAL Y5		0.00010	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL ug/m^3

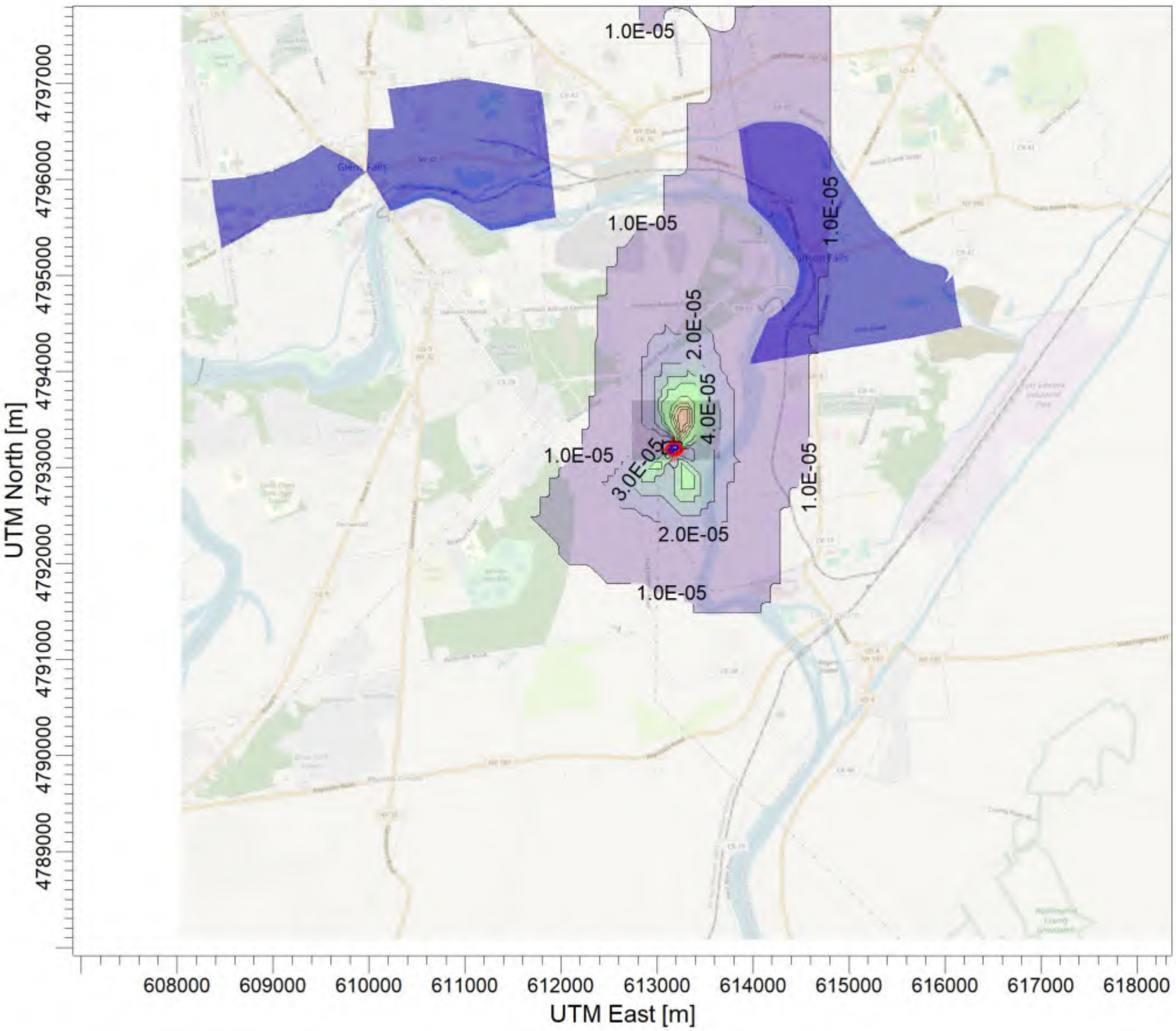
Max: 2.4E-03 [ug/m^3] at (613112.25, 4793123.00)

7.0E-05 1.0E-04 2.0E-04 4.0E-04 5.0E-04 8.0E-04 9.0E-04 1.0E-03 2.0E-03 2.4E-03

COMMENTS: Arsenic - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 ▬ 2 km
	MAX: **2.4E-03 ug/m^3**	DATE: **9/5/2023**
		PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 1.1E-04 [ug/m^3]

1.0E-05 2.0E-05 3.0E-05 4.0E-05 5.0E-05 7.0E-05 8.0E-05 9.0E-05 1.0E-04 1.1E-04

COMMENTS:

Arsenic - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

1.1E-04 ug/m^3

DATE:

9/5/2023

PROJECT NO.:

2020-20

ATTACHMENT 5I

CADMIUM

Results Summary

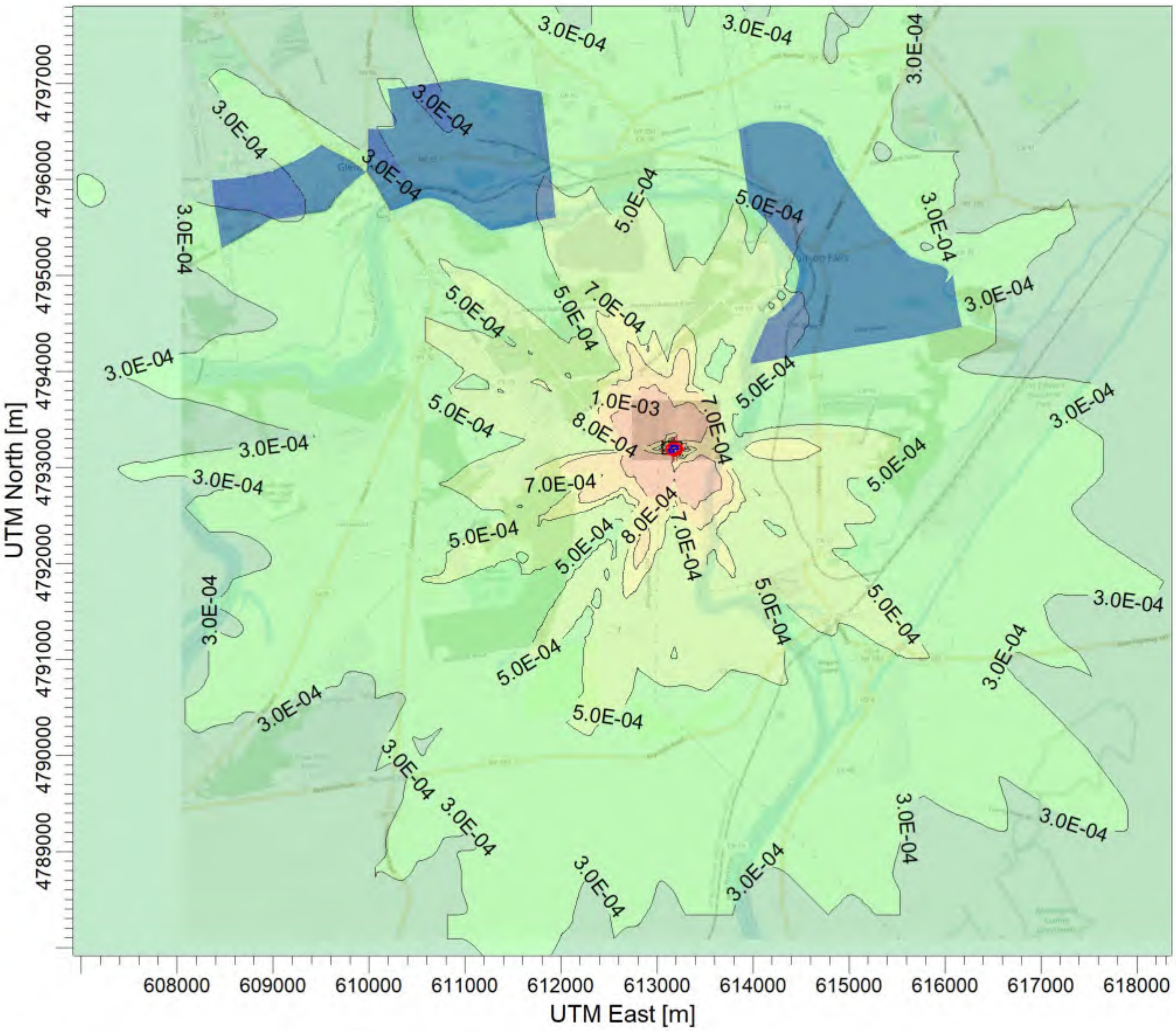
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

CADMIUM - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	0.00200	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
1-HR	8TH	0.00197	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/30/2017, 2
ANNUAL		0.00010	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.00010	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.00010	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.00010	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.00010	ug/m^3	613249.75	4793398.00	71.44	0.00	71.44	
ANNUAL Y5		0.00008	ug/m^3	613249.75	4793398.00	71.44	0.00	71.44	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL ug/m^3

Max: 2.0E-03 [ug/m^3] at (613112.25, 4793123.00)

6.0E-05 7.0E-05 9.0E-05 1.0E-04 3.0E-04 5.0E-04 7.0E-04 8.0E-04 1.0E-03 2.0E-03

COMMENTS:

Cadmium - 1 Hour

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

2.0E-03 ug/m^3

DATE:

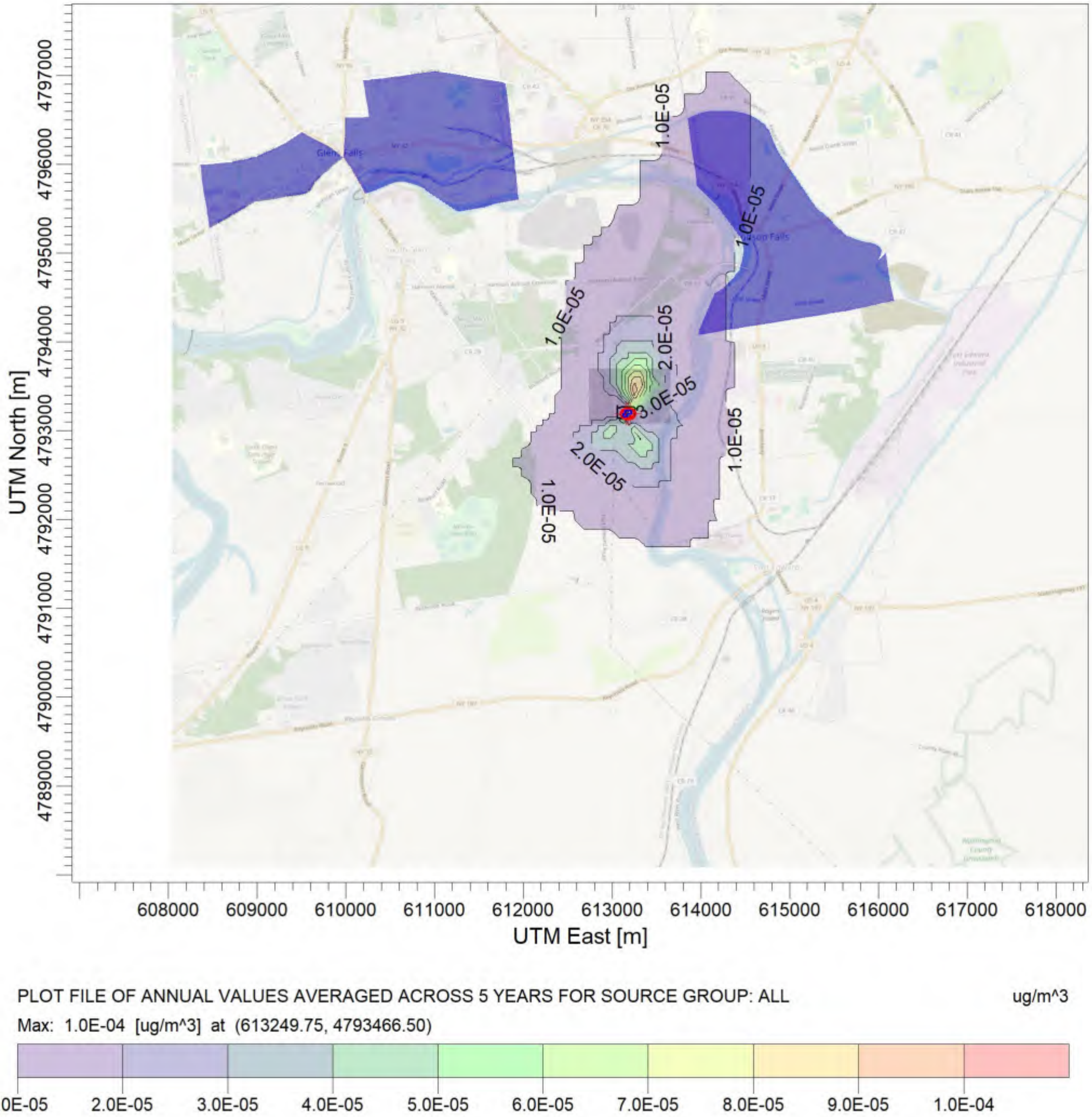
9/5/2023

PROJECT NO.:

2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 1.0E-04 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS:

Cadmium - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

1.0E-04 ug/m^3

DATE:

9/5/2023

PROJECT NO.:

2020-20

ATTACHMENT 5J

LEAD

Results Summary

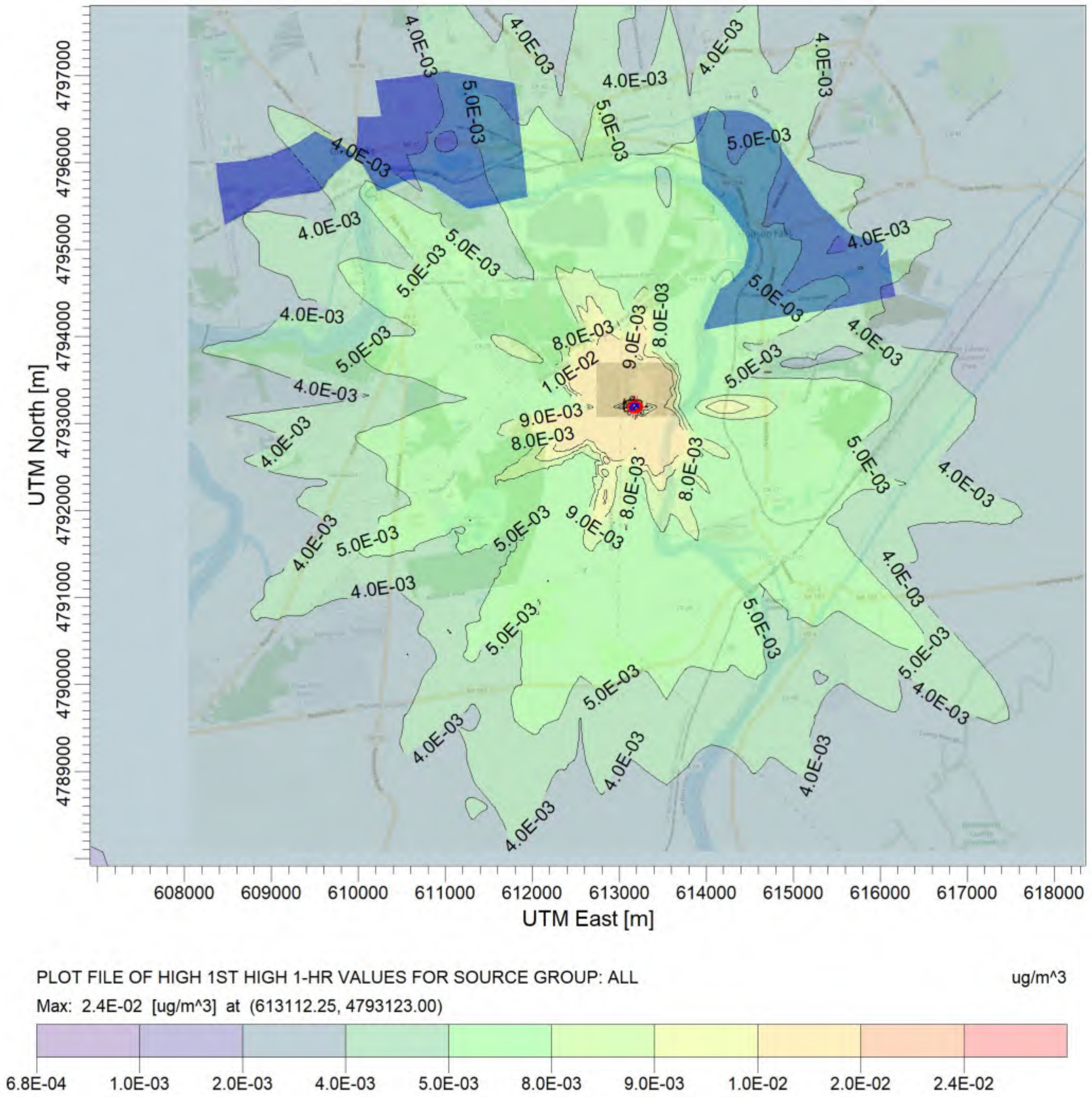
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

LEAD - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	0.02393	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
MONTH	1ST	0.00215	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	6/30/2021, 24
1-HR	8TH	0.02358	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/30/2017, 2
ANNUAL		0.00115	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.00120	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.00117	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.00115	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.00124	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.00101	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



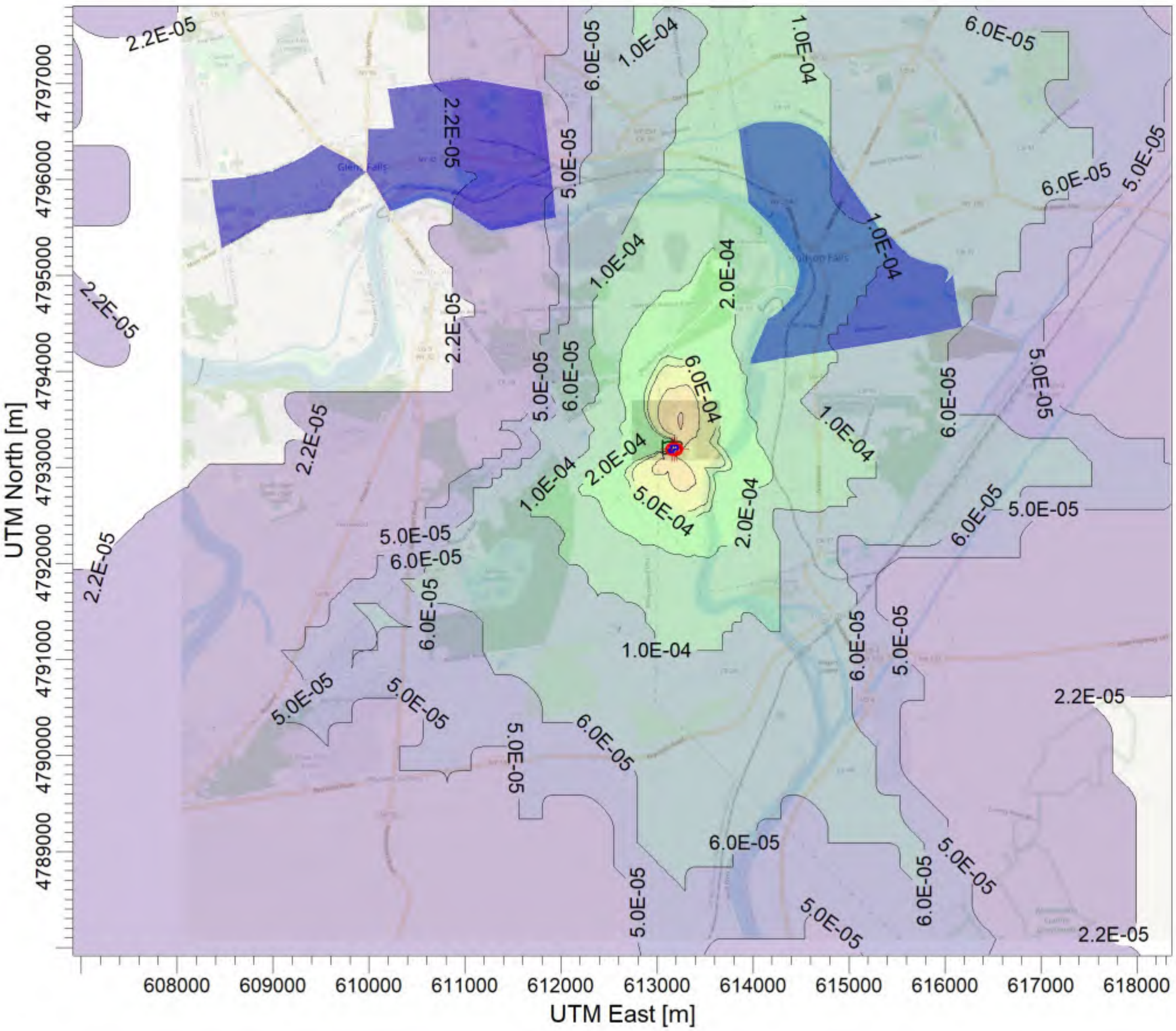
PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

Max: 2.4E-02 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS: Lead - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **2.4E-02 ug/m^3**	DATE: **9/5/2023**	PROJECT NO.: **2020-20**

PROJECT TITLE:

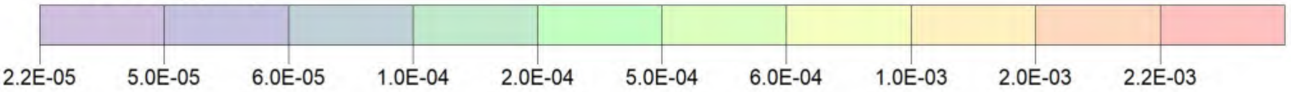
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH MONTH VALUES FOR SOURCE GROUP: ALL

ug/m^3

Max: 2.2E-03 [ug/m^3]



COMMENTS:

Lead - Month

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE:

1:71,992

0 2 km

MAX:

2.2E-03 ug/m^3

DATE:

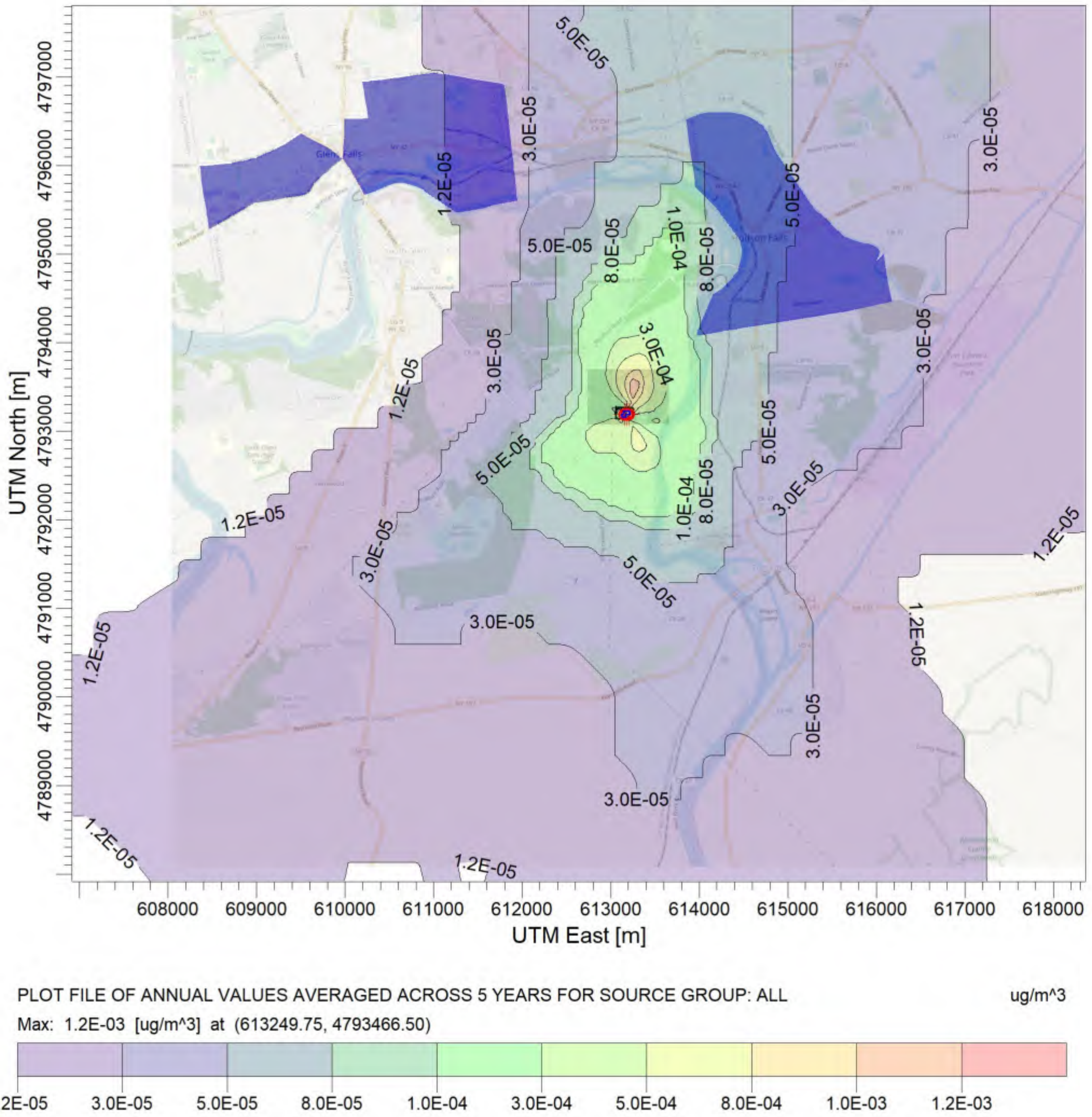
9/5/2023

PROJECT NO.:

2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL

Max: 1.2E-03 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS:

Lead - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

1.2E-03 ug/m^3

DATE:

9/5/2023

PROJECT NO.:

2020-20

ATTACHMENT 5K

MERCURY

Results Summary

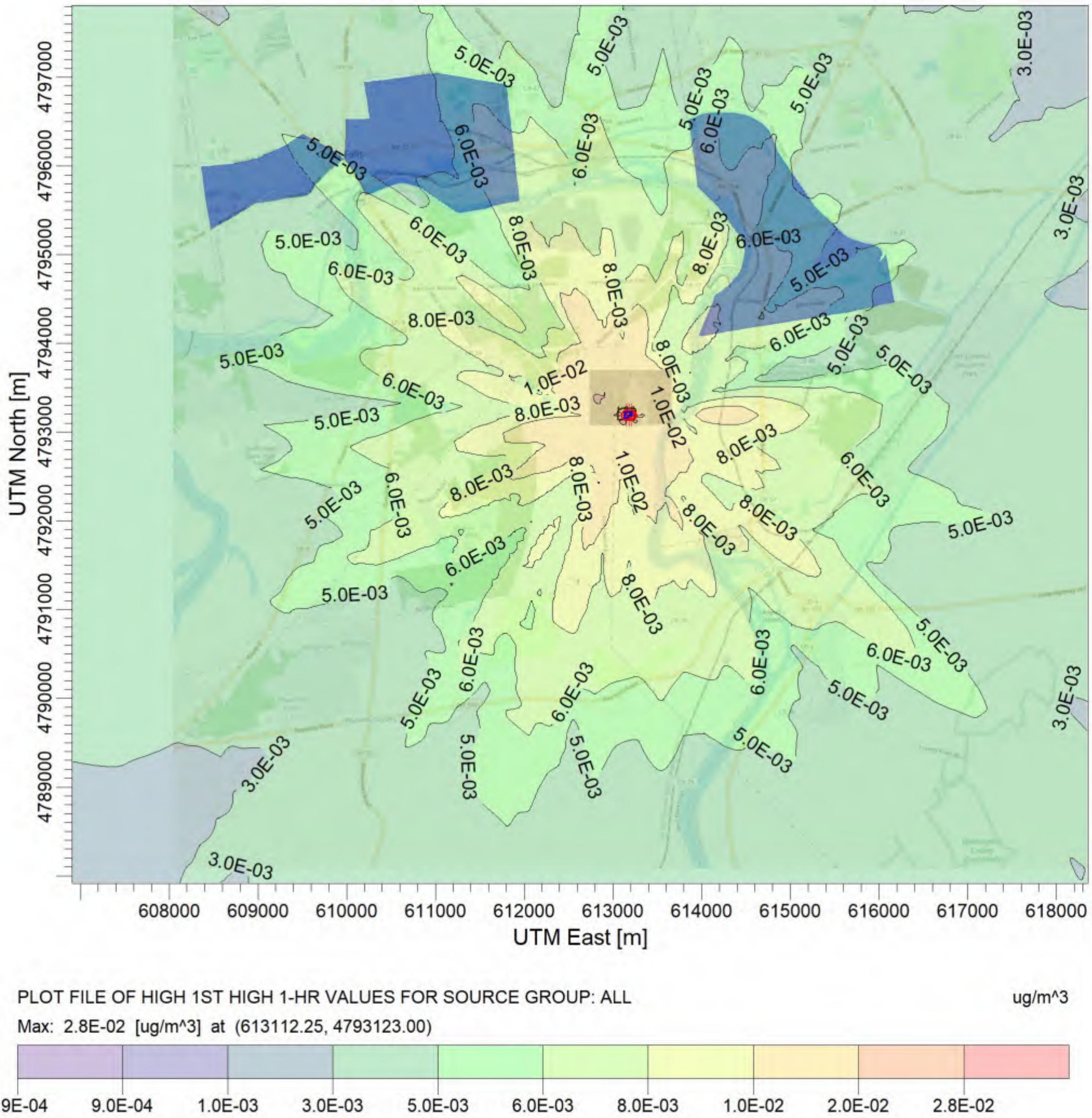
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

HG - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	0.02798	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.00135	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.00140	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.00137	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.00135	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.00145	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.00118	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

Max: 2.8E-02 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS:
Mercury - 1 Hour

SOURCES:
3

COMPANY NAME:
Sterling Environmental Engineering, P.C.

RECEPTORS:
5165

MODELER:
AMM

OUTPUT TYPE:
Concentration

SCALE: 1:71,992
0 2 km

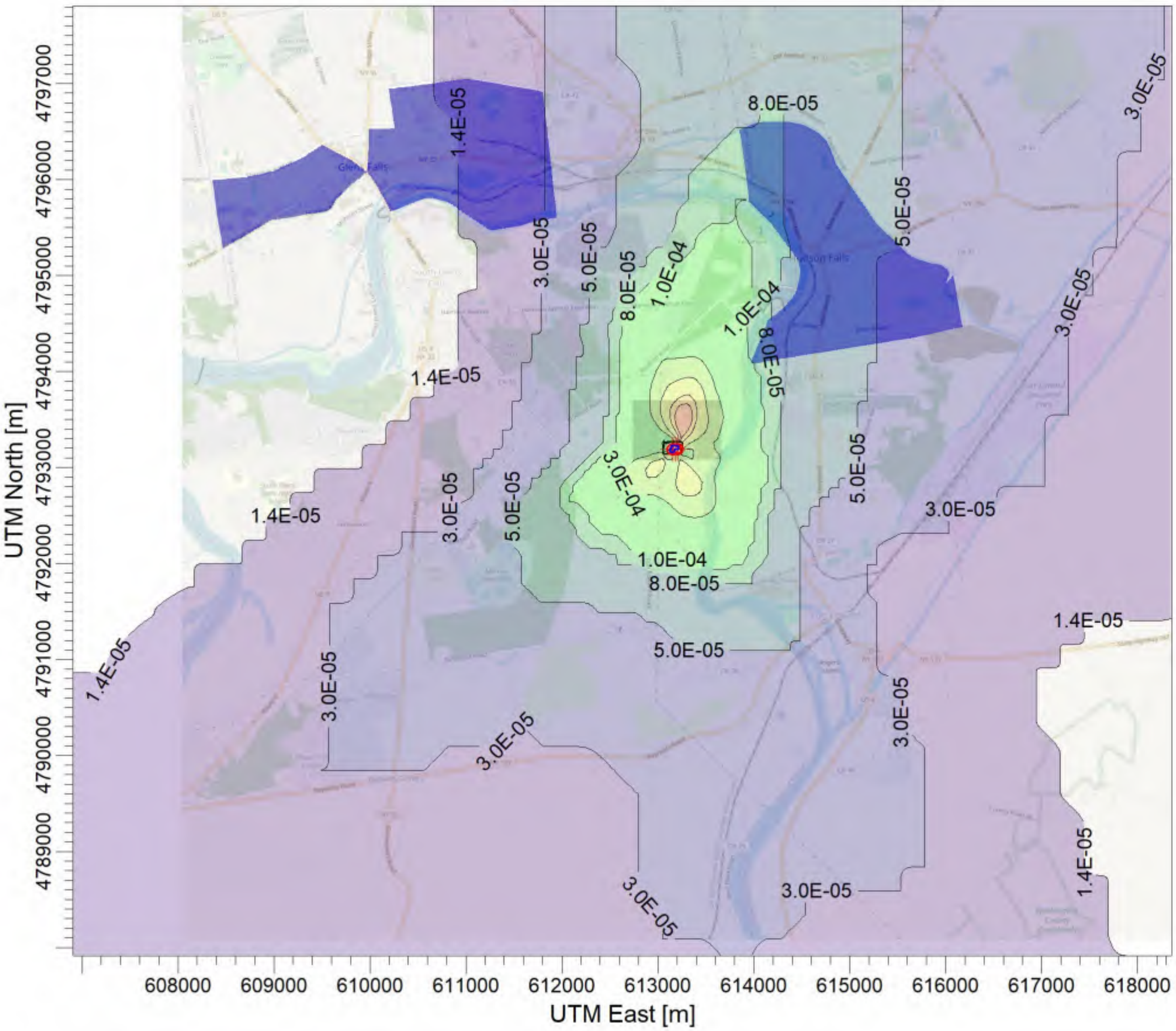
MAX:
2.8E-02 ug/m^3

DATE:
5/5/2023

PROJECT NO.:
2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 1.4E-03 [ug/m^3] at (613249.75, 4793466.50)

1.4E-05	3.0E-05	5.0E-05	8.0E-05	1.0E-04	3.0E-04	5.0E-04	8.0E-04	1.0E-03	1.4E-03

COMMENTS:

Mercury - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

1.4E-03 ug/m^3

DATE:

5/5/2023

PROJECT NO.:

2020-20

ATTACHMENT 5L

METHYL DISULFIDES & TRISULFIDES

Results Summary

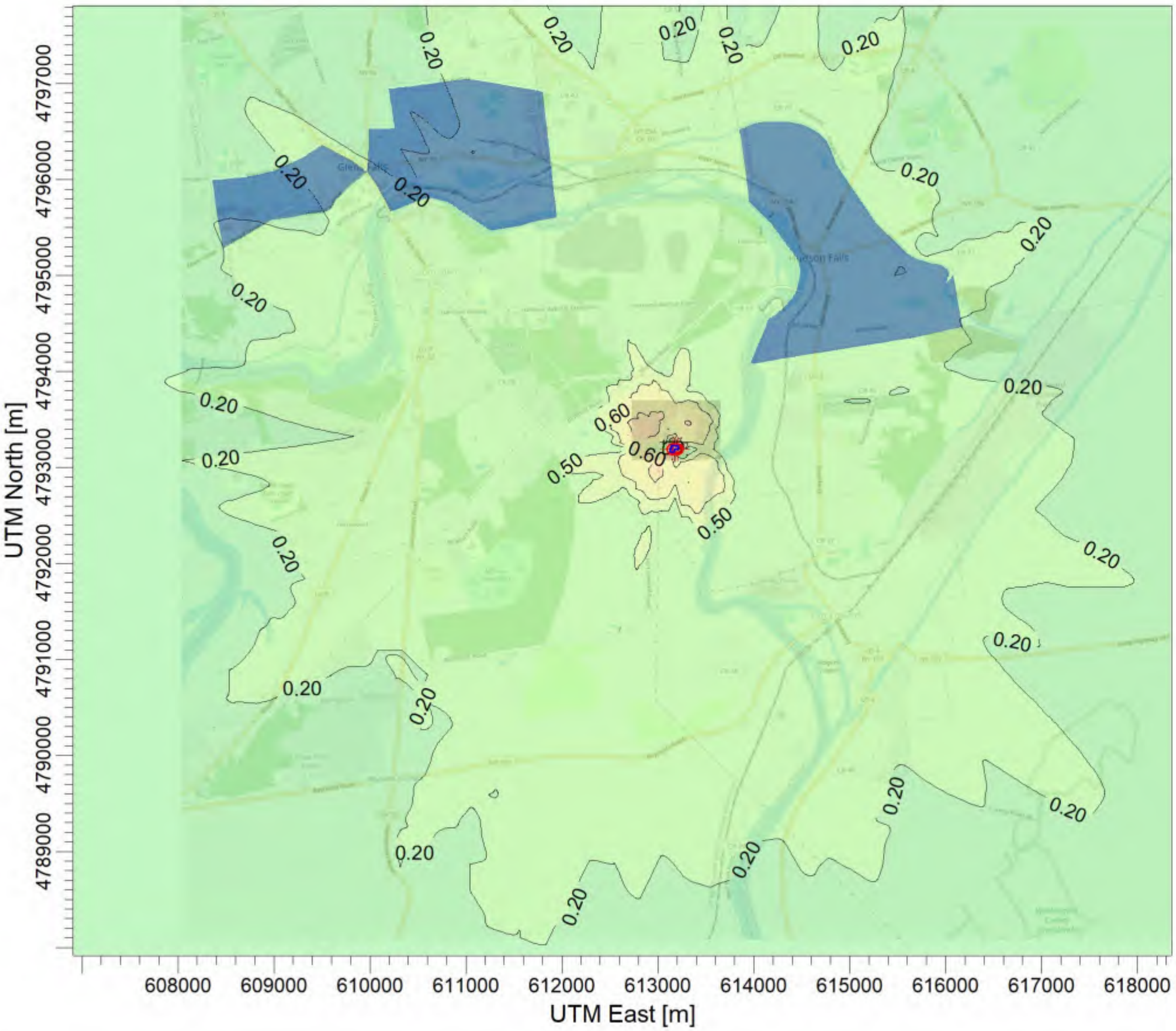
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

SULFIDES - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	1.25416	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
1-HR	8TH	1.23591	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	4/30/2017, 2
ANNUAL		0.06049	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.06277	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.06151	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.06030	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.06500	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.05287	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

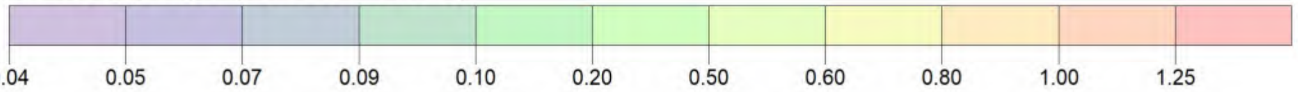
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

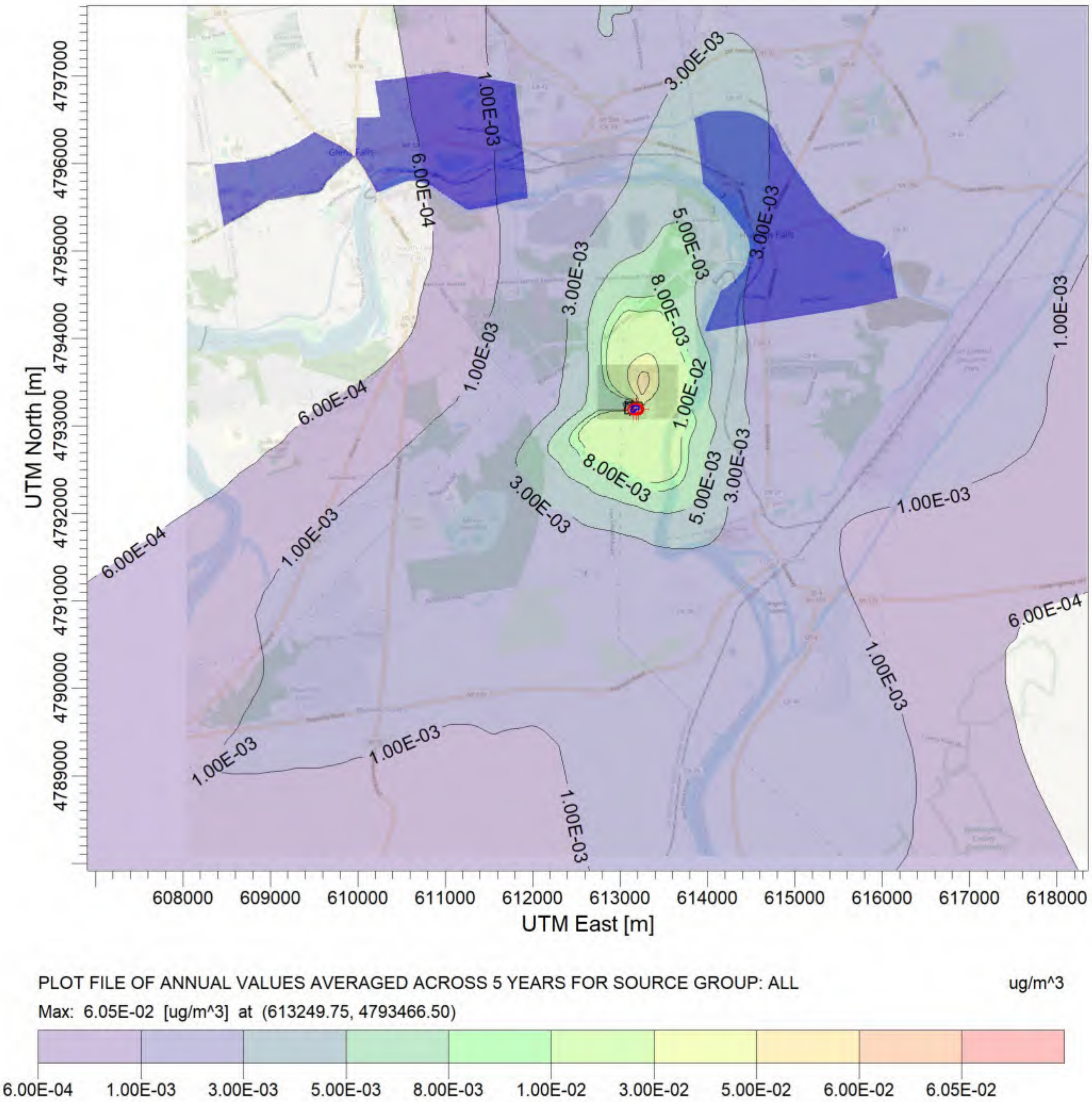
Max: 1.25 [ug/m^3] at (613112.25, 4793123.00)



COMMENTS: Sulfides - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **1.25 ug/m^3**	DATE: **5/8/2023**	PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL

Max: 6.05E-02 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS:

Sulfides - Annual

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

6.05E-02 ug/m^3

DATE:

5/8/2023

PROJECT NO.:

2020-20

ATTACHMENT 5M

AMMONIA

Results Summary

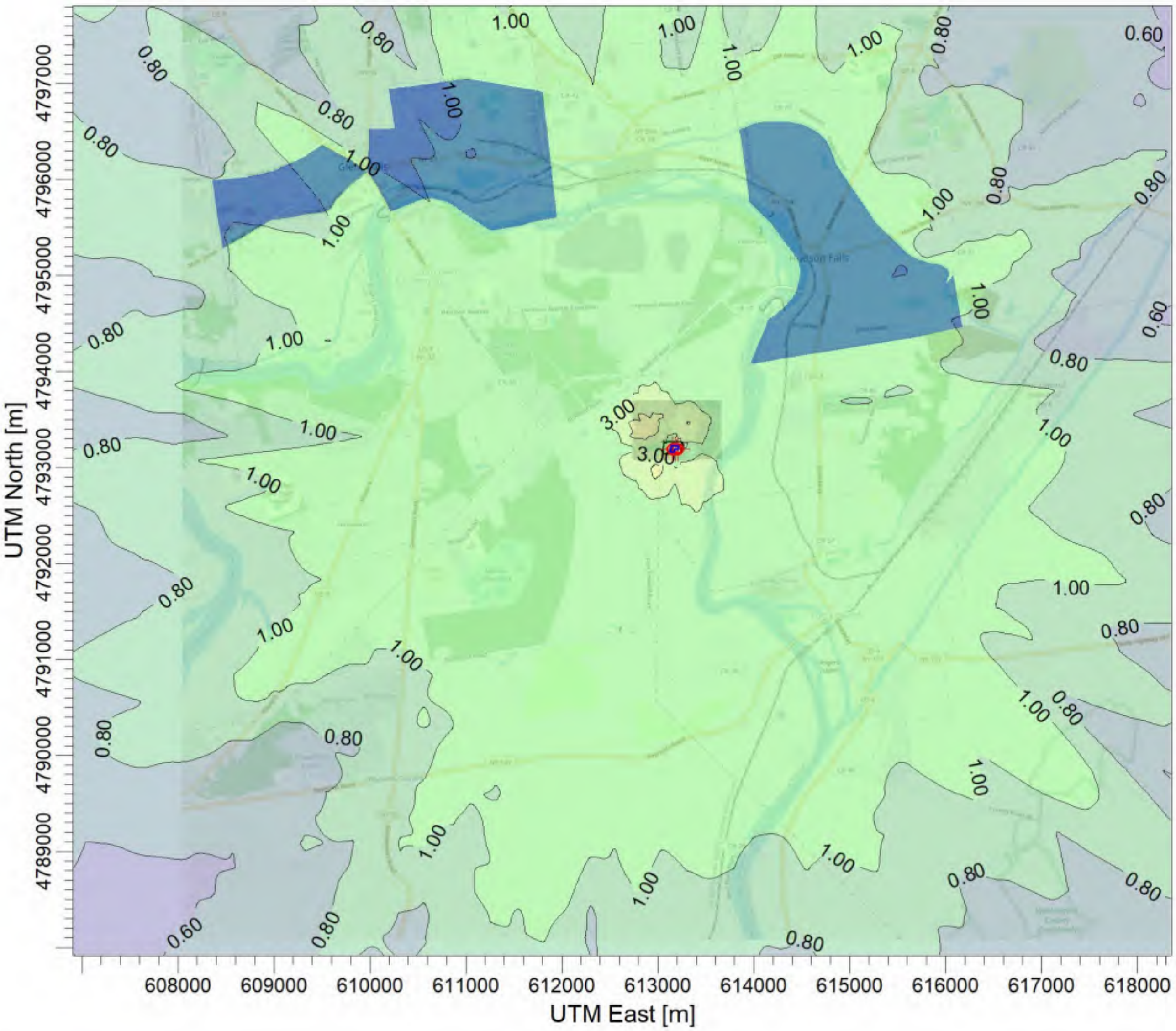
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

NH3 - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	6.17432	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.29780	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.30904	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.30283	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.29687	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.32001	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.26026	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

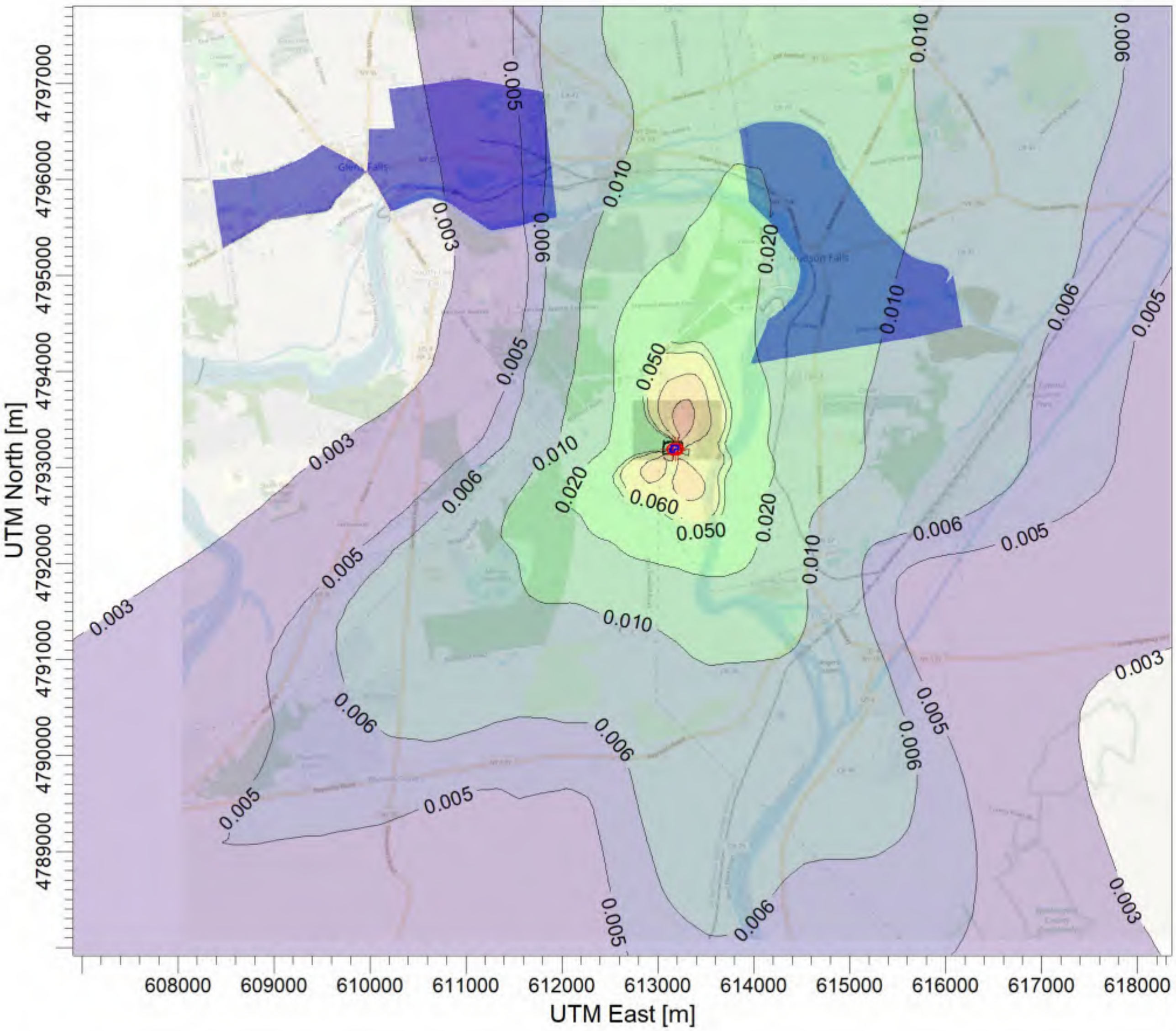
Max: 6.17 [ug/m^3] at (613112.25, 4793123.00)

0.18	0.50	0.60	0.80	1.00	3.00	4.00	5.00	6.00	6.17

COMMENTS: Ammonia - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 — 2 km	
	MAX: **6.17 ug/m^3**	DATE: **5/5/2023**	PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 0.298 [ug/m^3] at (613249.75, 4793466.50)

0.003 0.005 0.006 0.010 0.020 0.050 0.060 0.100 0.200 0.298

COMMENTS: Ammonia - Annual	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **0.298 ug/m^3**	DATE: **5/5/2023**	PROJECT NO.: **2020-20**

ATTACHMENT 5N

METHYL & ETHYLAMINES

Results Summary

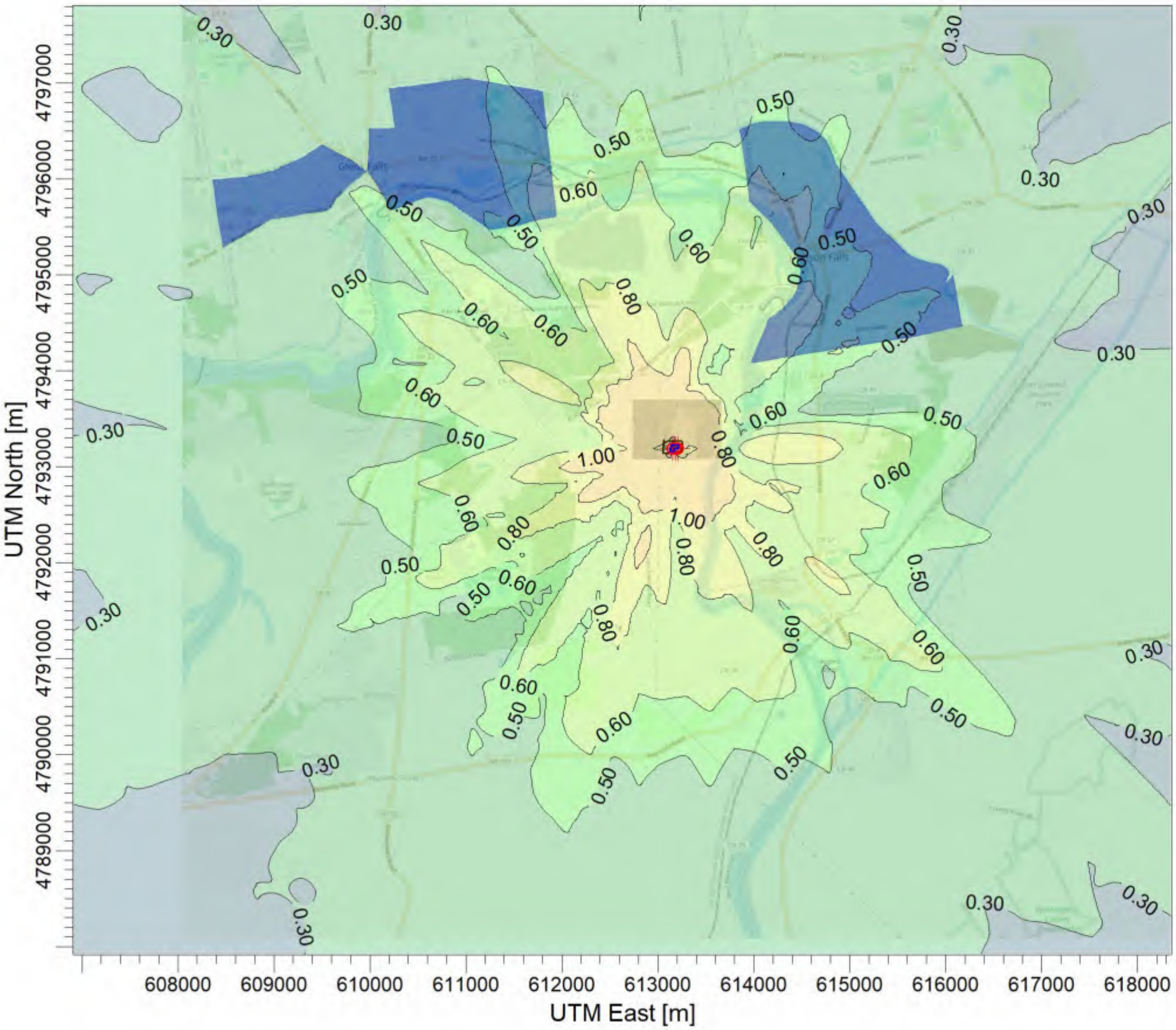
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

AMINES - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	2.50832	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.12098	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.12555	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.12303	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.12060	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.13000	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.10573	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

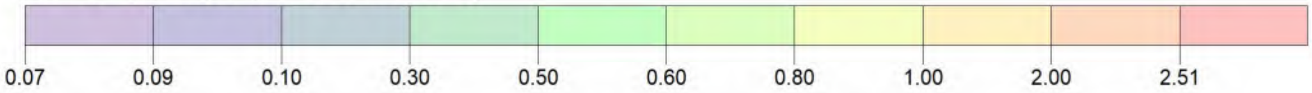
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

Max: 2.51 [ug/m^3] at (613112.25, 4793123.00)



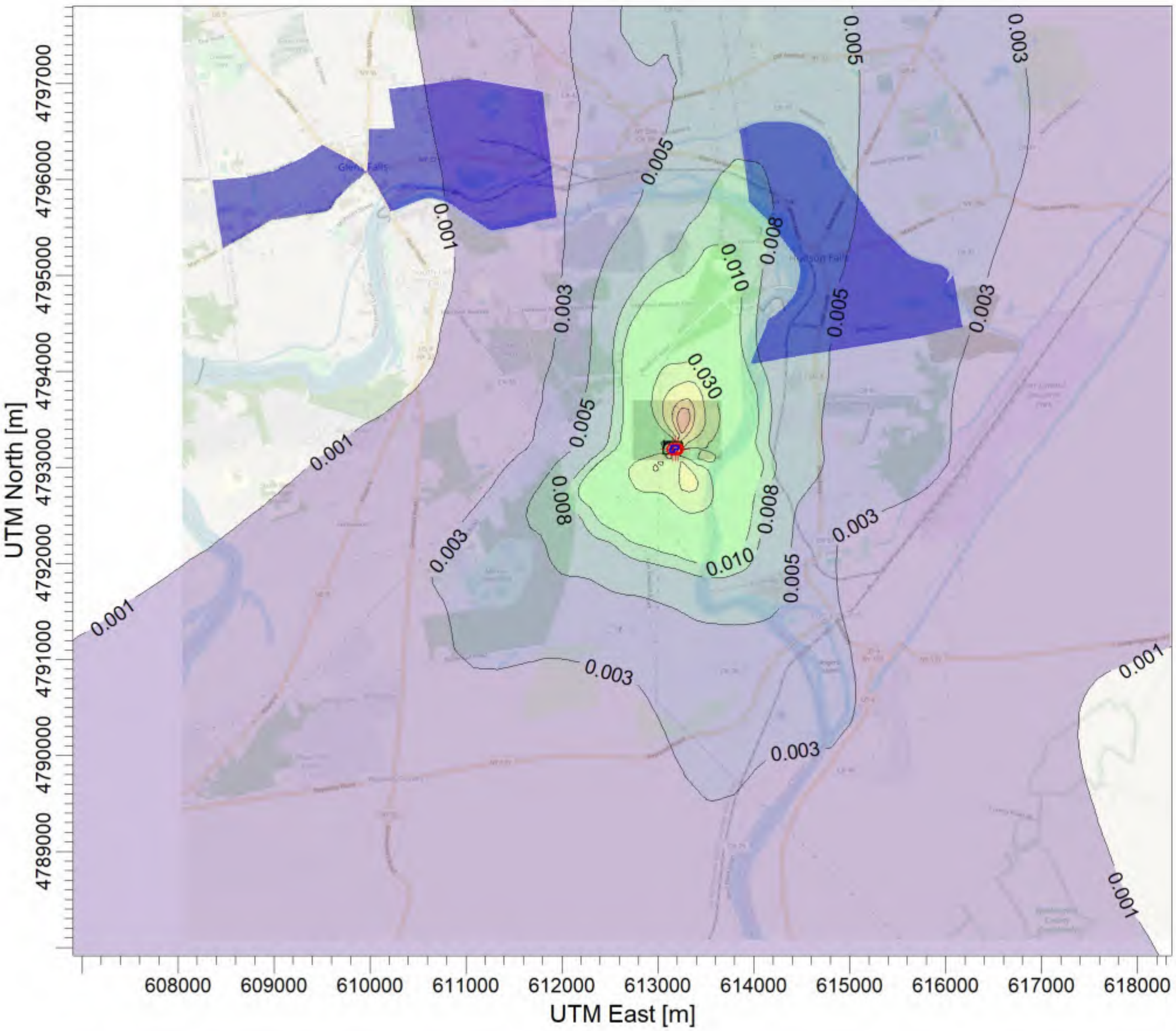
COMMENTS: Amines - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **2.51 ug/m^3**	DATE: **5/5/2023**	PROJECT NO.: **2020-20**

AERMOD View - Lakes Environmental Software

C:\Lakes\AERMOD View\SBSMoreau\SBSMoreau.isc

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 0.121 [ug/m^3] at (613249.75, 4793466.50)

0.001 0.003 0.005 0.008 0.010 0.030 0.050 0.080 0.100 0.121

COMMENTS: Amines - Annual	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km
	MAX: **0.121 ug/m^3**	DATE: **5/5/2023**
		PROJECT NO.: **2020-20**

ATTACHMENT 5O

HYDROGEN CHLORIDE

Results Summary

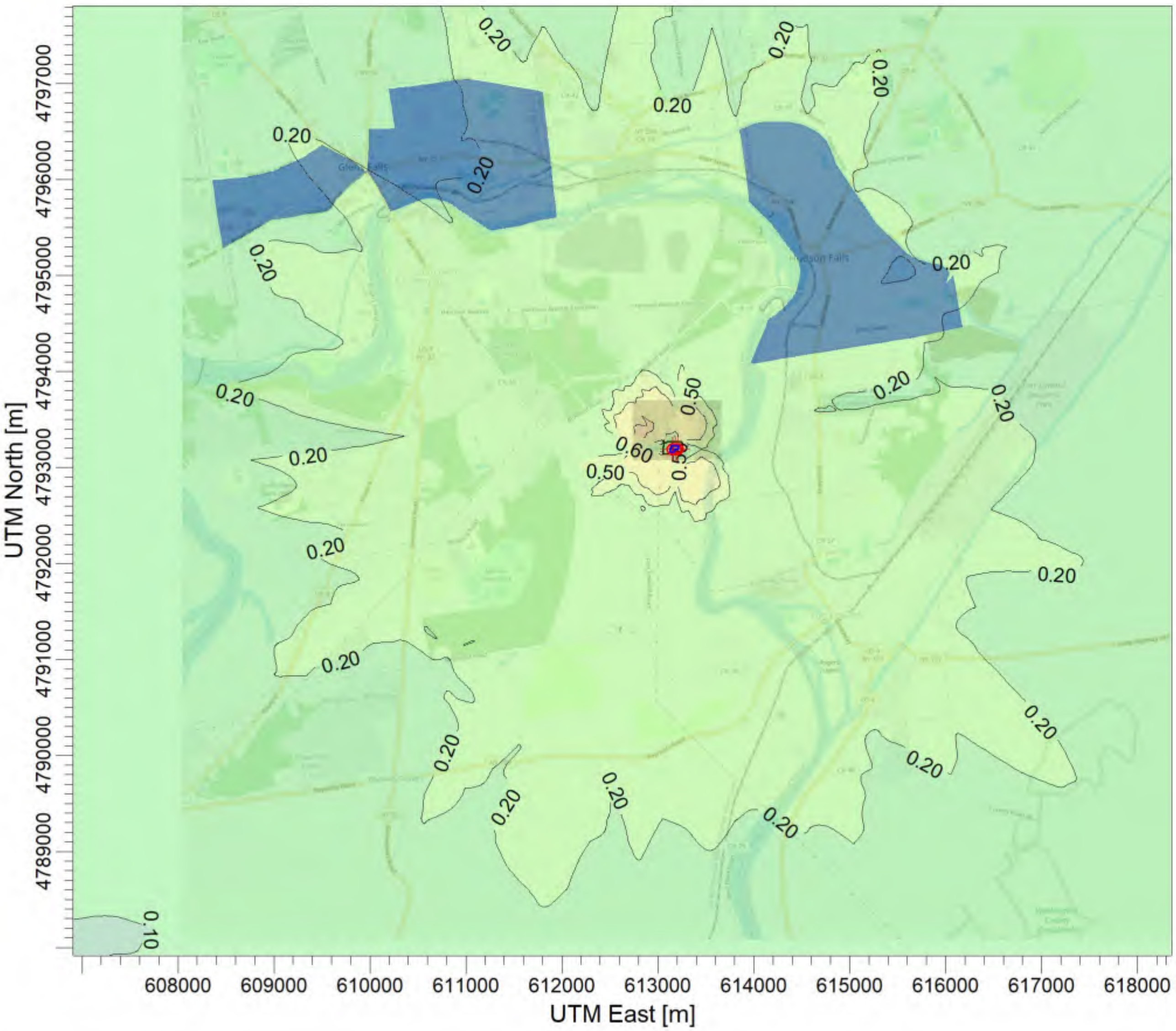
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

HCL - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	1.15769	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.05584	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.05794	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.05678	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.05566	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.06000	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.04880	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

ug/m^3

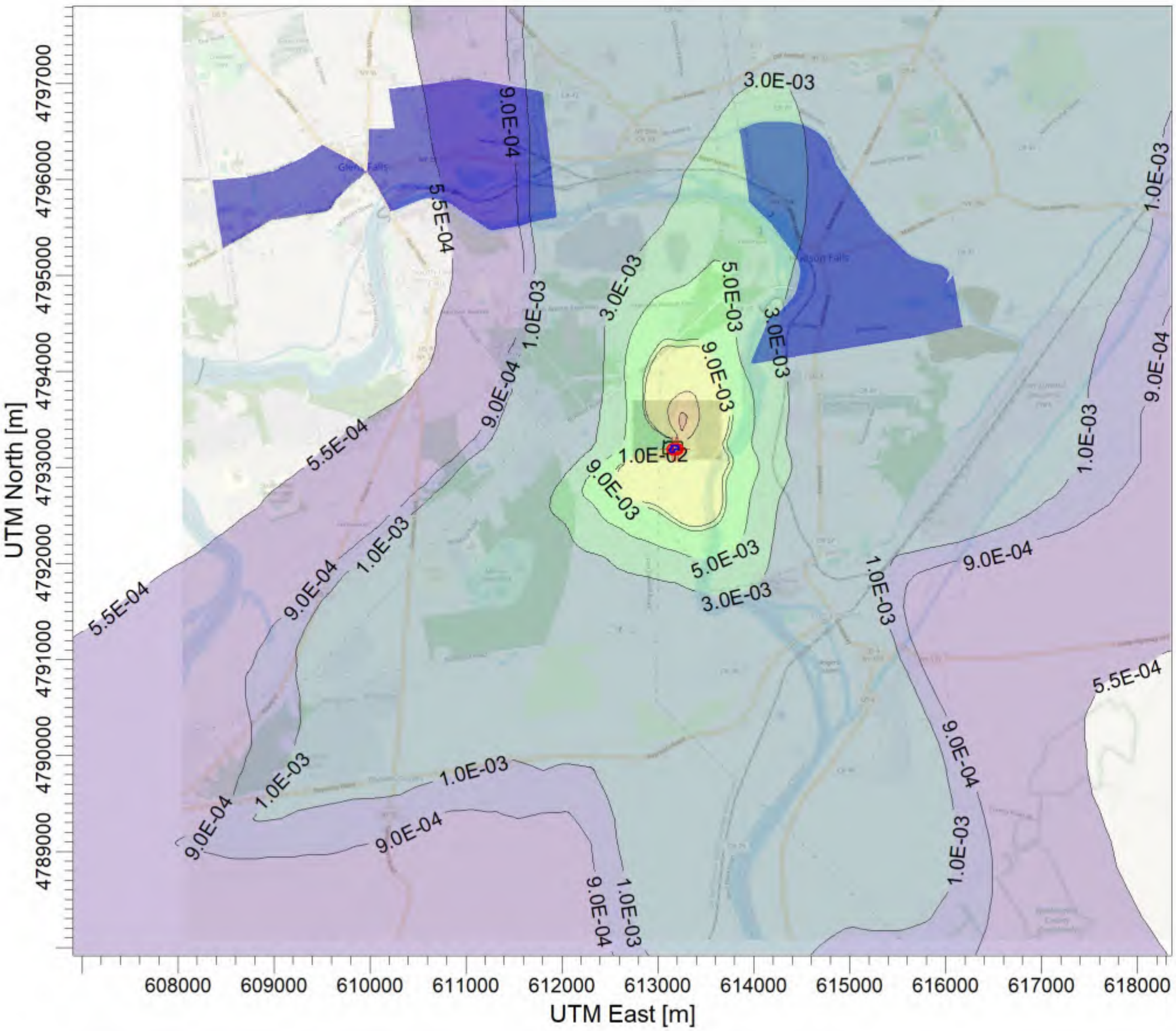
Max: 1.16 [ug/m^3] at (613112.25, 4793123.00)

0.03 0.05 0.07 0.09 0.10 0.20 0.50 0.60 0.80 1.00 1.16

COMMENTS: HCL - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 — 2 km
	MAX: **1.16 ug/m^3**	DATE: **5/5/2023**
		PROJECT NO.: **2020-20**

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 5.6E-02 [ug/m^3] at (613249.75, 4793466.50)

5.5E-04 9.0E-04 1.0E-03 3.0E-03 5.0E-03 9.0E-03 1.0E-02 3.0E-02 5.0E-02 5.6E-02

COMMENTS: HCL - Annual	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **5.6E-02 ug/m^3**	DATE: **5/5/2023**	PROJECT NO.: **2020-20**

ATTACHMENT 5P

ACETIC ACID

Results Summary

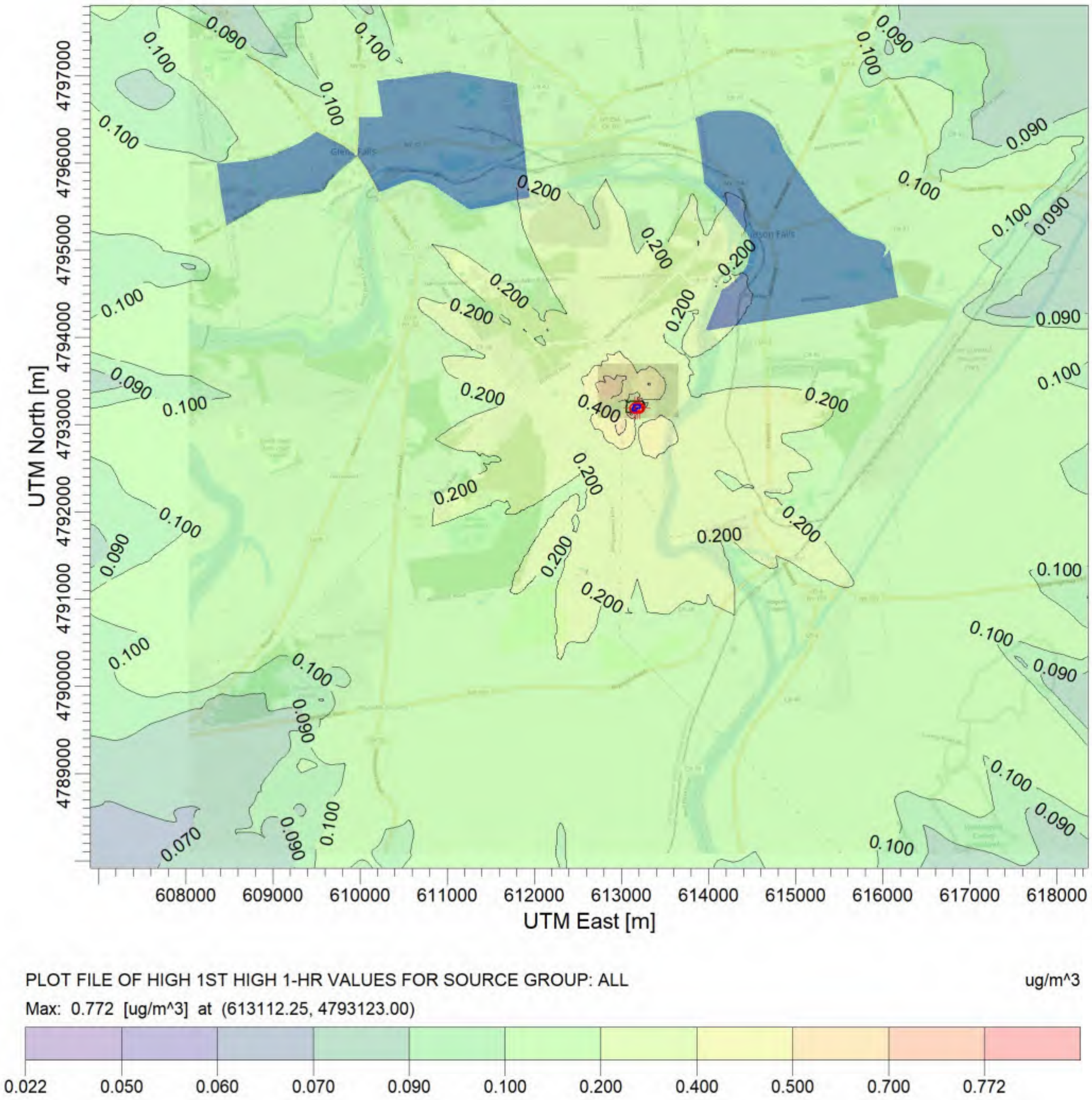
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

ACETIC - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	0.77179	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.03723	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.03863	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.03785	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.03711	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.04000	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.03253	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

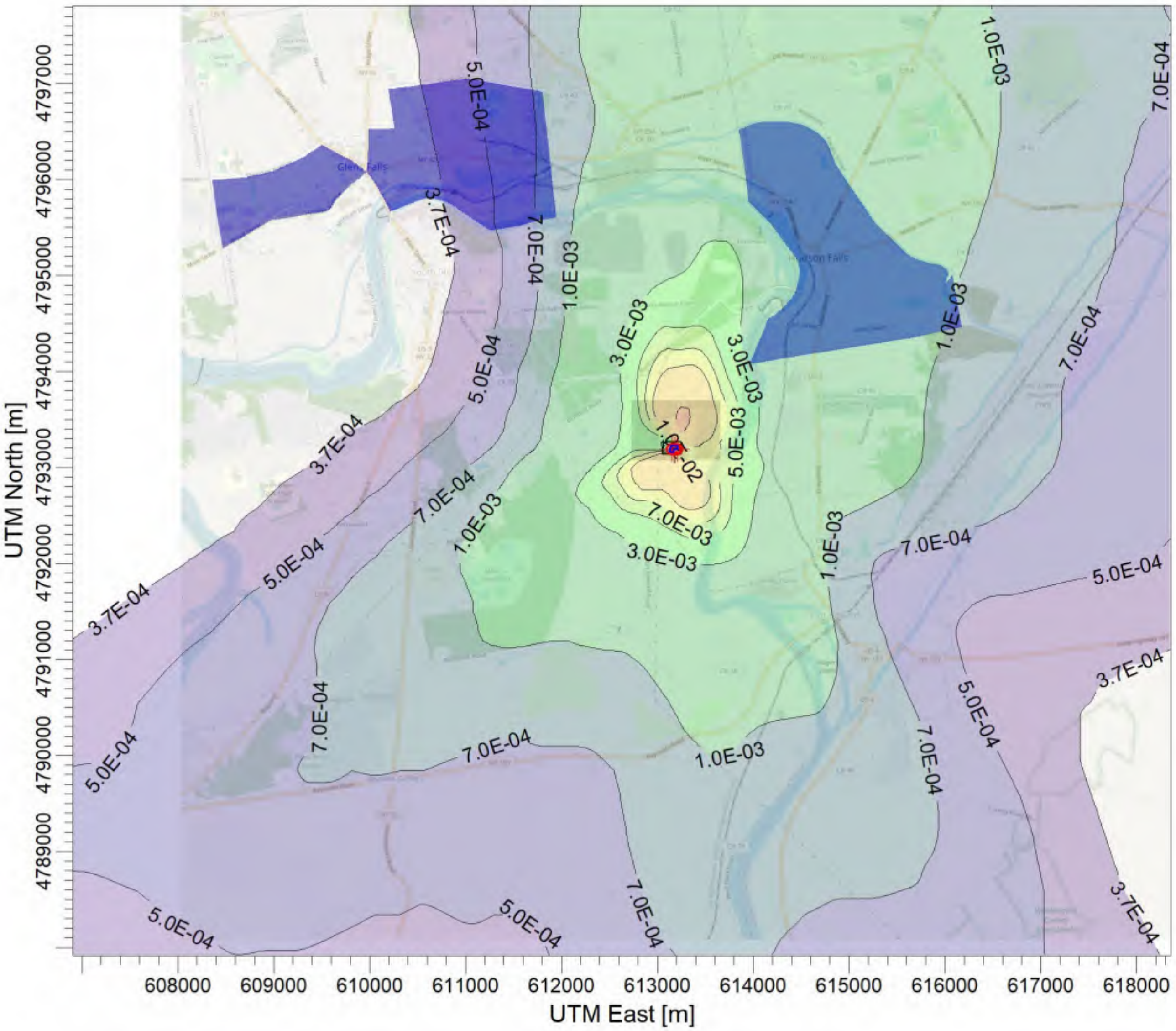
Max: 0.772 [ug/m^3] at (613112.25, 4793123.00)

COMMENTS: Acetic Acid - 1 Hour	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**
	RECEPTORS: **5165**	MODELER: **AMM**
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km
	MAX: **0.772 ug/m^3**	DATE: **5/5/2023**
		PROJECT NO.: **2020-20**

AERMOD View - Lakes Environmental Software C:\Lakes\AERMOD View\SBSMoreau\SBSMoreau.isc

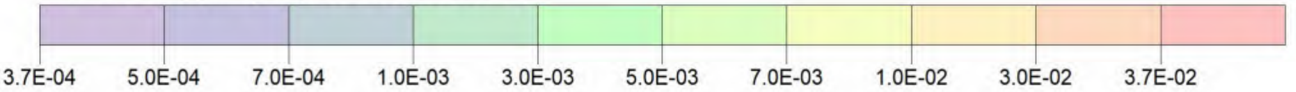
PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL ug/m^3

Max: 3.7E-02 [ug/m^3] at (613249.75, 4793466.50)



COMMENTS: Acetic Acid - Annual	SOURCES: **3**	COMPANY NAME: **Sterling Environmental Engineering, P.C.**	
	RECEPTORS: **5165**	MODELER: **AMM**	
	OUTPUT TYPE: **Concentration**	SCALE: 1:71,992 0 2 km	
	MAX: **3.7E-02 ug/m^3**	DATE: **5/5/2023**	PROJECT NO.: **2020-20**

ATTACHMENT 5Q

PERFLUOROOCTANOIC ACID (PFOA)
&
HYDROGEN FLUORIDE (HF)

Results Summary

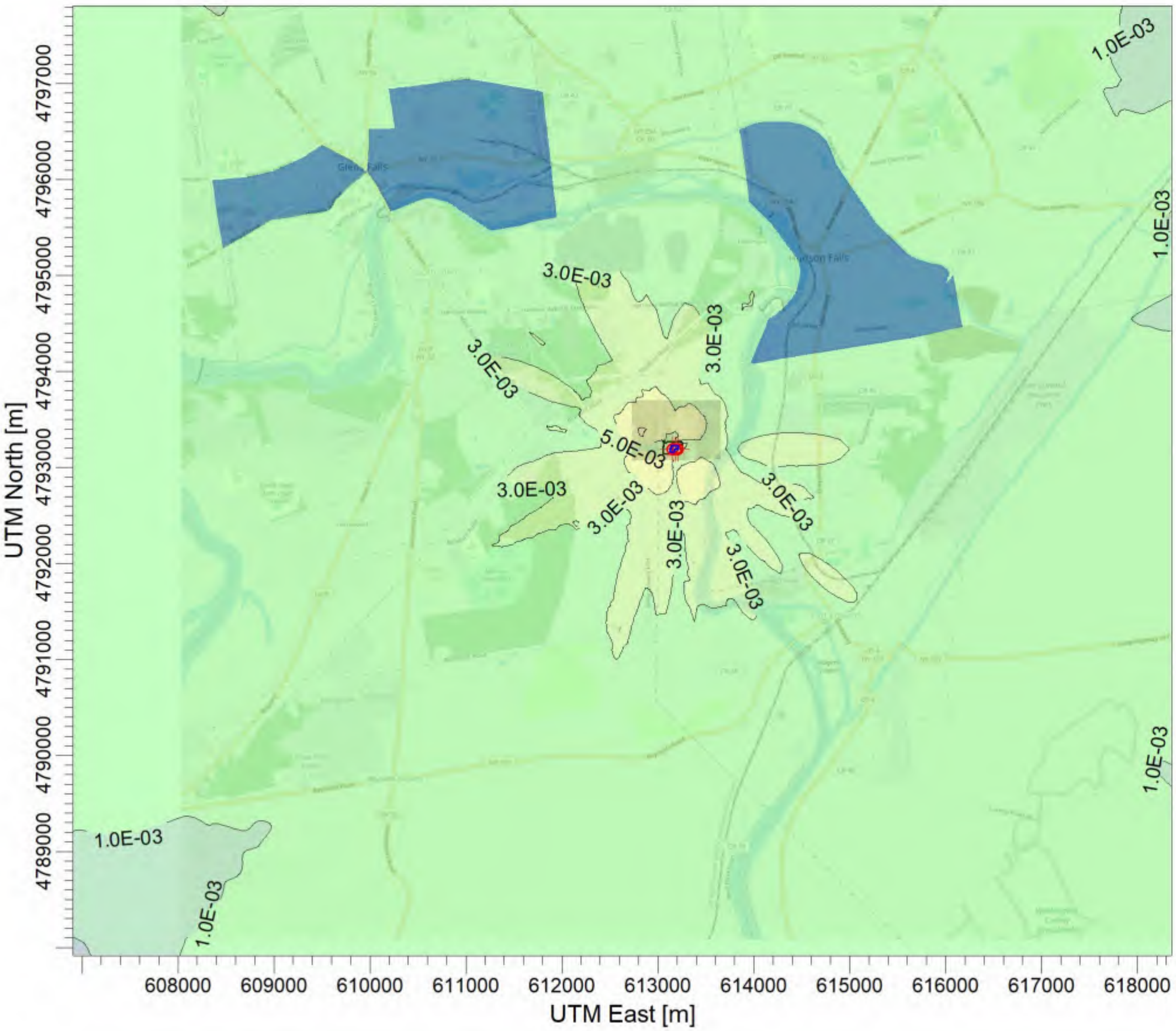
Saratoga Biochar Solutions - Moreau Facility - Stack Emissions

PFOA - Concentration - Source Group: ALL

Averaging Period	Rank	Peak	Units	X (m)	Y (m)	ZELEV (m)	ZFLAG (m)	ZHILL (m)	Peak Date, Start Hour
1-HR	1ST	0.00965	ug/m^3	613112.25	4793123.00	73.89	0.00	73.89	3/31/2020, 12
ANNUAL		0.00047	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y1		0.00048	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y2		0.00047	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y3		0.00046	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y4		0.00050	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	
ANNUAL Y5		0.00041	ug/m^3	613249.75	4793466.50	72.27	0.00	72.27	

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL ug/m^3

Max: 9.7E-03 [ug/m^3] at (613112.25, 4793123.00)

2.7E-04 5.0E-04 6.0E-04 8.0E-04 1.0E-03 3.0E-03 5.0E-03 7.0E-03 9.0E-03 9.7E-03

COMMENTS:

PFOA - 1 Hour

SOURCES:

3

COMPANY NAME:

Sterling Environmental Engineering, P.C.

RECEPTORS:

5165

MODELER:

AMM

OUTPUT TYPE:

Concentration

SCALE: 1:71,992

0 2 km

MAX:

9.7E-03 ug/m^3

DATE:

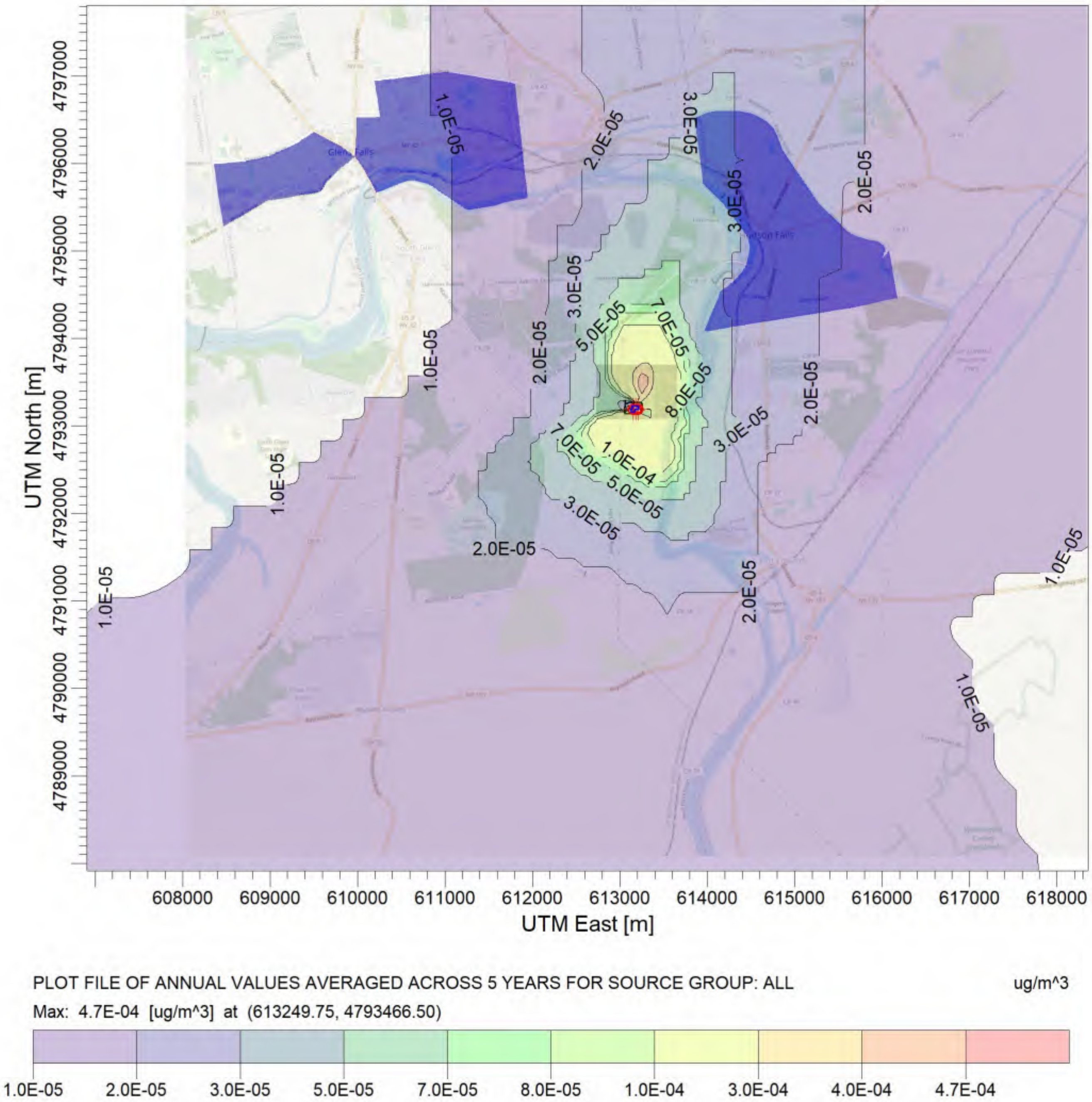
5/4/2023

PROJECT NO.:

2020-20

PROJECT TITLE:

Saratoga Biochar Solutions - Moreau Facility - Stack Emissions



PLOT FILE OF ANNUAL VALUES AVERAGED ACROSS 5 YEARS FOR SOURCE GROUP: ALL

Max: 4.7E-04 [ug/m^3] at (613249.75, 4793466.50)

COMMENTS:
PFOA - Annual

SOURCES:
3

COMPANY NAME:
Sterling Environmental Engineering, P.C.

RECEPTORS:
5165

MODELER:
AMM

OUTPUT TYPE:
Concentration

SCALE: 1:71,992
0 2 km

MAX:
4.7E-04 ug/m^3

DATE:
5/4/2023

PROJECT NO.:
2020-20

ATTACHMENT 6

SBS SMALL-SCALE THERMAL TREATMENT TEST PFAS ANALYTICAL DATA

eurofins
Lancaster Laboratories
Environmental

2425 New Holland Pike, Lancaster, PA 17601 • 717-656-2300 • Fax: 717-656-6766 • www.EurofinsUS.com/LancLabsEnv

ANALYSIS REPORT

Prepared by:	Prepared for:
Eurofins Lancaster Laboratories Environmental 2425 New Holland Pike Lancaster, PA 17601	Ultra Compost Inc. 256 Riviera Lane Sunrise Beach MT 65079

Report Date: June 11, 2019 16:48

Project: Biochar

Account #: 44334
Group Number: 2042698
PO Number: 242495
State of Sample Origin: KS

Electronic Copy To Ultra Compost Inc. Attn: Bryce Meeker

Respectfully Submitted,

Elizabeth M. Bauer

Elizabeth M. Bauer
Project Manager

(717) 556-7290

To view our laboratory's current scopes of accreditation please go to https://www.eurofinsus.com/environment-testing/laboratories/eurofins-lancaster-laboratories-environmental/certifications-and-accreditations-eurofins-lancaster-laboratories-environmental/ . Historical copies may be requested through your project manager.

SAMPLE INFORMATION

Client Sample Description	Sample Collection Date/Time	ELLE#
Biosolids Grab Sample	05/06/2019 10:20	1051834
Biochar Grab Sample	05/06/2019 10:20	1051835

The specific methodologies used in obtaining the enclosed analytical results are indicated on the Laboratory Sample Analysis Record.

Sample Description: **Biosolids Grab Sample**

Project Name: **Biochar**

Ultra Compost Inc.
ELLE Sample #: **SW 1051834**
ELLE Group #: **2042698**
Matrix: Solid Waste

Submittal Date/Time: 05/08/2019 08:30
Collection Date/Time: 05/06/2019 10:20

CAT No.	Analysis Name	CAS Number	Dry Result	Dry Limit of Quantitation*	Dry Method Detection Limit	Dilution Factor
LC/MS/MS Miscellaneous	**EPA 537 Version 1.1 Modified**		**ng/g**	**ng/g**	**ng/g**	
14027	6:2-Fluorotelomersulfonic acid	27619-97-2	< 2.1	2.1	0.64	1
14027	8:2-Fluorotelomersulfonic acid	39108-34-4	< 2.1	2.1	0.64	1
14027	NEtFOSAA	2991-50-6	2.8	2.1	0.53	1
	NEtFOSAA is the acronym for N-ethyl perfluorooctanesulfonamidoacetic Acid.					
14027	NMeFOSAA	2355-31-9	5.3	2.1	0.53	1
	NMeFOSAA is the acronym for N-methyl perfluorooctanesulfonamidoacetic Acid.					
14027	Perfluorobutanesulfonic acid	375-73-5	< 0.64	0.64	0.21	1
14027	Perfluorobutanoic acid	375-22-4	2.2	2.1	0.64	1
14027	Perfluorodecanesulfonic acid	335-77-3	1.1	1.1	0.32	1
14027	Perfluorodecanoic acid	335-76-2	11	0.64	0.21	1
14027	Perfluorododecanoic acid	307-55-1	6.6	0.64	0.21	1
14027	Perfluoroheptanesulfonic acid	375-92-8	< 0.64	0.64	0.21	1
14027	Perfluoroheptanoic acid	375-85-9	1.4	0.64	0.21	1
14027	Perfluorohexanesulfonic acid	355-46-4	< 0.64	0.64	0.21	1
14027	Perfluorohexanoic acid	307-24-4	16	0.64	0.21	1
14027	Perfluorononanoic acid	375-95-1	1.9	0.64	0.21	1
14027	Perfluorooctanesulfonamide	754-91-6	< 0.64	0.64	0.21	1
14027	Perfluorooctanesulfonic acid	1763-23-1	4.6	0.95	0.32	1
14027	Perfluorooctanoic acid	335-67-1	20	0.64	0.21	1
14027	Perfluoropentanoic acid	2706-90-3	2.2	0.64	0.21	1
14027	Perfluorotetradecanoic acid	376-06-7	2.0	0.64	0.21	1
14027	Perfluorotridecanoic acid	72629-94-8	2.4	0.64	0.21	1
14027	Perfluoroundecanoic acid	2058-94-8	8.8	0.64	0.21	1
The recovery for injection standard 13C2-PFDA is outside of QC acceptance limits as noted on the QC Summary. The recovery for injection standard 13C2-PFDA is also outside of QC acceptance limits in the associated matrix spike and matrix spike duplicate samples, thus indicating a matrix effect.						
Wet Chemistry	**SM 2540 G-2011 %Moisture Calc**		**%**	**%**	**%**	
00111	Moisture	n.a.	5.6	0.50	0.50	1
	Moisture represents the loss in weight of the sample after oven drying at 103 - 105 degrees Celsius. The moisture result reported is on an as-received basis.					

Sample Comments

State of New York Certification No. 10670

*=This limit was used in the evaluation of the final result

Sample Description: **Biosolids Grab Sample**

Project Name: **Biochar**

Ultra Compost Inc.
ELLE Sample #: **SW 1051834**
ELLE Group #: **2042698**
Matrix: Solid Waste

Submittal Date/Time: 05/08/2019 08:30
Collection Date/Time: 05/06/2019 10:20

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
14027	Biosolid NY 21 PFAS	EPA 537 Version 1.1 Modified	1	19129012	05/15/2019 02:25	Christine E Dolman	1
14090	PFAS Solid Prep	EPA 537 Version 1.1 Modified	1	19129012	05/09/2019 16:00	Anthony C Polaski	1
00111	Moisture	SM 2540 G-2011 %Moisture Calc	1	19133820002A	05/13/2019 10:02	William C Schwebel	1

Sample Description: **Biochar Grab Sample**

Project Name: **Biochar**

Ultra Compost Inc.
ELLE Sample #: **SW 1051835**
ELLE Group #: **2042698**
Matrix: Solid Waste

Submittal Date/Time: 05/08/2019 08:30
Collection Date/Time: 05/06/2019 10:20

CAT No.	Analysis Name	CAS Number	Dry Result	Dry Limit of Quantitation*	Dry Method Detection Limit	Dilution Factor
LC/MS/MS Miscellaneous	**EPA 537 Version 1.1 Modified**		ng/g	ng/g	ng/g	
14027	6:2-Fluorotelomersulfonic acid	27619-97-2	< 2.0	2.0	0.59	1
14027	8:2-Fluorotelomersulfonic acid	39108-34-4	< 2.0	2.0	0.59	1
14027	NEtFOSAA	2991-50-6	< 2.0	2.0	0.49	1
	NEtFOSAA is the acronym for N-ethyl perfluorooctanesulfonamidoacetic Acid.					
14027	NMeFOSAA	2355-31-9	< 2.0	2.0	0.49	1
	NMeFOSAA is the acronym for N-methyl perfluorooctanesulfonamidoacetic Acid.					
14027	Perfluorobutanesulfonic acid	375-73-5	< 0.59	0.59	0.20	1
14027	Perfluorobutanoic acid	375-22-4	< 2.0	2.0	0.59	1
14027	Perfluorodecanesulfonic acid	335-77-3	< 0.98	0.98	0.29	1
14027	Perfluorodecanoic acid	335-76-2	< 0.59	0.59	0.20	1
14027	Perfluorododecanoic acid	307-55-1	< 0.59	0.59	0.20	1
14027	Perfluoroheptanesulfonic acid	375-92-8	< 0.59	0.59	0.20	1
14027	Perfluoroheptanoic acid	375-85-9	< 0.59	0.59	0.20	1
14027	Perfluorohexanesulfonic acid	355-46-4	< 0.59	0.59	0.20	1
14027	Perfluorohexanoic acid	307-24-4	< 0.59	0.59	0.20	1
14027	Perfluorononanoic acid	375-95-1	< 0.59	0.59	0.20	1
14027	Perfluorooctanesulfonamide	754-91-6	< 0.59	0.59	0.20	1
14027	Perfluorooctanesulfonic acid	1763-23-1	1.3	0.88	0.29	1
14027	Perfluorooctanoic acid	335-67-1	< 0.59	0.59	0.20	1
14027	Perfluoropentanoic acid	2706-90-3	< 0.59	0.59	0.20	1
14027	Perfluorotetradecanoic acid	376-06-7	< 0.59	0.59	0.20	1
14027	Perfluorotridecanoic acid	72629-94-8	< 0.59	0.59	0.20	1
14027	Perfluoroundecanoic acid	2058-94-8	< 0.59	0.59	0.20	1
Wet Chemistry	**SM 2540 G-2011 %Moisture Calc**		%	%	%	
00111	Moisture	n.a.	2.0	0.50	0.50	1
	Moisture represents the loss in weight of the sample after oven drying at 103 - 105 degrees Celsius. The moisture result reported is on an as-received basis.					

Sample Comments

State of New York Certification No. 10670

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
14027	Biosolid NY 21 PFAS	EPA 537 Version 1.1 Modified	1	19129012	05/18/2019 00:43	Jason W Knight	1
14090	PFAS Solid Prep	EPA 537 Version 1.1 Modified	1	19129012	05/09/2019 16:00	Anthony C Polaski	1

*=This limit was used in the evaluation of the final result

Sample Description: **Biochar Grab Sample**

Project Name: **Biochar**

Ultra Compost Inc.
ELLE Sample #: **SW 1051835**
ELLE Group #: **2042698**
Matrix: Solid Waste

Submittal Date/Time: 05/08/2019 08:30
Collection Date/Time: 05/06/2019 10:20

Laboratory Sample Analysis Record

CAT No.	Analysis Name	Method	Trial#	Batch#	Analysis Date and Time	Analyst	Dilution Factor
00111	Moisture	SM 2540 G-2011 %Moisture Calc	1	19140820001A	05/21/2019 11:09	William C Schwebel	1

Quality Control Summary

Client Name: Ultra Compost Inc. Group Number: 2042698
Reported: 06/11/2019 16:48

Matrix QC may not be reported if insufficient sample or site-specific QC samples were not submitted. In these situations, to demonstrate precision and accuracy at a batch level, a LCS/LCSD was performed, unless otherwise specified in the method.

All Inorganic Initial Calibration and Continuing Calibration Blanks met acceptable method criteria unless otherwise noted on the Analysis Report.

Method Blank

Analysis Name	**Result** **ng/g**	**LOQ**** **ng/g**	**MDL** **ng/g**
Batch number: 19129012	Sample number(s): 1051834-1051835		
6:2-Fluorotelomersulfonic acid	< 2.0	2.0	0.60
8:2-Fluorotelomersulfonic acid	< 2.0	2.0	0.60
NEtFOSAA	< 2.0	2.0	0.50
NMeFOSAA	< 2.0	2.0	0.50
Perfluorobutanesulfonic acid	< 0.60	0.60	0.20
Perfluorobutanoic acid	< 2.0	2.0	0.60
Perfluorodecanesulfonic acid	< 1.0	1.0	0.30
Perfluorodecanoic acid	< 0.60	0.60	0.20
Perfluorododecanoic acid	< 0.60	0.60	0.20
Perfluoroheptanesulfonic acid	< 0.60	0.60	0.20
Perfluoroheptanoic acid	< 0.60	0.60	0.20
Perfluorohexanesulfonic acid	< 0.60	0.60	0.20
Perfluorohexanoic acid	< 0.60	0.60	0.20
Perfluorononanoic acid	< 0.60	0.60	0.20
Perfluorooctanesulfonamide	< 0.60	0.60	0.20
Perfluorooctanesulfonic acid	< 0.90	0.90	0.30
Perfluorooctanoic acid	< 0.60	0.60	0.20
Perfluoropentanoic acid	< 0.60	0.60	0.20
Perfluorotetradecanoic acid	< 0.60	0.60	0.20
Perfluorotridecanoic acid	< 0.60	0.60	0.20
Perfluoroundecanoic acid	< 0.60	0.60	0.20

LCS/LCSD

Analysis Name	**LCS Spike Added** **ng/g**	**LCS Conc** **ng/g**	**LCSD Spike Added** **ng/g**	**LCSD Conc** **ng/g**	**LCS %REC**	**LCSD %REC**	**LCS/LCSD Limits**	**RPD**	**RPD Max**
Batch number: 19129012	Sample number(s): 1051834-1051835								
6:2-Fluorotelomersulfonic acid	3.79	4.19	3.79	4.52	111	119	58-148	8	30
8:2-Fluorotelomersulfonic acid	3.83	4.13	3.83	4.52	108	118	65-147	9	30
NEtFOSAA	1.36	1.65	1.36	1.67	121	122	54-143	1	30
NMeFOSAA	1.36	1.56	1.36	1.93	115	142	51-157	22	30
Perfluorobutanesulfonic acid	1.20	1.45	1.20	1.43	121	119	71-133	1	30
Perfluorobutanoic acid	1.36	1.92	1.36	1.92	141	141	75-148	0	30
Perfluorodecanesulfonic acid	1.31	1.74	1.31	1.53	133	116	63-153	13	30
Perfluorodecanoic acid	1.36	1.72	1.36	1.70	126	125	69-145	1	30

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.

Quality Control Summary

Client Name: Ultra Compost Inc. Group Number: 2042698
Reported: 06/11/2019 16:48

LCS/LCSD (continued)

Analysis Name	LCS Spike Added ng/g	LCS Conc ng/g	LCSD Spike Added ng/g	LCSD Conc ng/g	LCS %REC	LCSD %REC	LCS/LCSD Limits	RPD	RPD Max
Perfluorododecanoic acid	1.36	1.53	1.36	1.51	113	111	76-137	2	30
Perfluoroheptanesulfonic acid	1.29	1.56	1.29	1.52	120	117	68-135	2	30
Perfluoroheptanoic acid	1.36	1.84	1.36	1.87	135	138	76-143	2	30
Perfluorohexanesulfonic acid	1.29	1.56	1.29	1.55	121	121	68-132	0	30
Perfluorohexanoic acid	1.36	1.61	1.36	1.68	119	124	74-140	4	30
Perfluorononanoic acid	1.36	1.64	1.36	1.76	120	129	71-146	7	30
Perfluorooctanesulfonamide	1.36	1.53	1.36	1.53	112	113	70-131	0	30
Perfluorooctanesulfonic acid	1.30	1.44	1.30	1.56	111	120	69-137	8	30
Perfluorooctanoic acid	1.36	1.82	1.36	1.62	134	119	74-146	12	30
Perfluoropentanoic acid	1.36	1.68	1.36	1.64	124	120	74-142	3	30
Perfluorotetradecanoic acid	1.36	1.69	1.36	1.78	124	131	76-138	5	30
Perfluorotridecanoic acid	1.36	1.68	1.36	1.47	123	108	62-153	13	30
Perfluoroundecanoic acid	1.36	1.65	1.36	1.80	121	132	71-143	8	30
	%	%	%	%					
Batch number: 19133820002A	Sample number(s): 1051834								
Moisture	89.5	89.4			100		99-101		
Batch number: 19140820001A	Sample number(s): 1051835								
Moisture	89.5	89.46			100		99-101		

MS/MSD

Unspiked (UNSPK) = the sample used in conjunction with the matrix spike

Analysis Name	Unspiked Conc ng/g	MS Spike Added ng/g	MS Conc ng/g	MSD Spike Added ng/g	MSD Conc ng/g	MS %Rec	MSD %Rec	MS/MSD Limits	RPD	RPD Max
Batch number: 19129012	Sample number(s): 1051834-1051835 UNSPK: 1051834									
6:2-Fluorotelomersulfonic acid	0.640	3.75	4.97	3.79	5.18	115	120	59-154	4	30
8:2-Fluorotelomersulfonic acid	< 2.0	3.79	5.76	3.83	5.84	152	152	63-153	1	30
NEtFOSAA	2.61	1.35	4.43	1.36	4.99	135*	175*	70-130	12	30
NMeFOSAA	4.96	1.35	7.89	1.36	8.26	218*	243*	49-167	5	30
Perfluorobutanesulfonic acid	< 0.60	1.19	1.60	1.20	1.68	134	140	61-142	5	30
Perfluorobutanoic acid	2.10	1.35	3.83	1.36	4.01	128	141	64-145	5	30
Perfluorodecanesulfonic acid	1.04	1.30	1.83	1.31	1.86	61	63	42-148	2	30
Perfluorodecanoic acid	10.85	1.35	13.68	1.36	15.11	210 (2)	313 (2)	53-160	10	30
Perfluorododecanoic acid	6.28	1.35	8.05	1.36	8.25	131 (2)	145 (2)	64-152	3	30
Perfluoroheptanesulfonic acid	< 0.60	1.28	1.56	1.29	1.73	121	133	58-148	10	30
Perfluoroheptanoic acid	1.28	1.35	3.10	1.36	3.46	135	160*	66-154	11	30
Perfluorohexanesulfonic acid	< 0.60	1.27	1.79	1.29	2.33	140*	181*	70-132	26	30
Perfluorohexanoic acid	15.06	1.35	18.07	1.36	18.92	224 (2)	284 (2)	62-152	5	30

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.

Quality Control Summary

Client Name: Ultra Compost Inc.
Group Number: 2042698
Reported: 06/11/2019 16:48

MS/MSD (continued)

Unspiked (UNSPK) = the sample used in conjunction with the matrix spike

Analysis Name	**Unspiked Conc ng/g**	**MS Spike Added ng/g**	**MS Conc ng/g**	**MSD Spike Added ng/g**	**MSD Conc ng/g**	**MS %Rec**	**MSD %Rec**	**MS/MSD Limits**	**RPD**	**RPD Max**
Perfluorononanoic acid	1.76	1.35	3.54	1.36	3.91	132	158*	49-153	10	30
Perfluorooctanesulfonamide	0.493	1.35	1.97	1.36	2.03	110	113	76-127	3	30
Perfluorooctanesulfonic acid	4.37	1.29	5.47	1.30	5.24	85	67	52-160	4	30
Perfluorooctanoic acid	18.91	1.35	22.09	1.36	22.01	235 (2)	228 (2)	35-182	0	30
Perfluoropentanoic acid	2.12	1.35	4.03	1.36	4.10	142	145	37-169	2	30
Perfluorotetradecanoic acid	1.92	1.35	3.93	1.36	4.18	149	166*	67-153	6	30
Perfluorotridecanoic acid	2.23	1.35	3.83	1.36	4.40	119	160	46-169	14	30
Perfluoroundecanoic acid	8.30	1.35	9.56	1.36	11.35	93 (2)	224 (2)	50-152	17	30

Labeled Isotope Quality Control

Labeled isotope recoveries which are outside of the QC window are confirmed unless otherwise noted on the analysis report.

Analysis Name: Biosolid NY 21 PFAS
Batch number: 19129012

	13C4-PFBA	13C5-PFPeA	13C3-PFBS	13C5-PFHxA	13C3-PFHxS	13C4-PFHpA
1051834	71	79	106	70	94	79
1051835	50	44	58	53	72	56
Blank	83	86	76	80	78	85
LCS	91	90	86	91	87	90
LCSD	89	92	86	82	80	85
MS	71	77	100	68	89	74
MSD	73	82	106	73	97	80
Limits:	32-120	26-123	22-130	22-127	30-123	25-128

	13C2-6:2-FTS	13C8-PFOA	13C8-PFOS	13C9-PFNA	13C6-PFDA	13C2-8:2-FTS
1051834	102	75	109	52	86	67
1051835	77	55	53	42	54	84
Blank	82	87	85	84	86	91
LCS	99	90	91	98	90	98
LCSD	85	89	80	88	86	93
MS	96	71	112	55	79	52
MSD	112	82	119	53	75	54
Limits:	10-194	28-119	39-119	20-144	30-115	10-200

	d3-NMeFOSAA	13C7-PFUnDA	d5-NEtFOSAA	13C2-PFDoDA	13C2-PFTeDA	13C8-PFOSA
1051834	76	78	56	34	68	96

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.

Quality Control Summary

Client Name: Ultra Compost Inc.
Reported: 06/11/2019 16:48

Group Number: 2042698

Labeled Isotope Quality Control (continued)

Labeled isotope recoveries which are outside of the QC window are confirmed unless otherwise noted on the analysis report.

Analysis Name: Biosolid NY 21 PFAS
Batch number: 19129012

	d3-NMeFOSAA	13C7-PFUnDA	d5-NEtFOSAA	13C2-PFDoDA	13C2-PFTeDA	13C8-PFOSA
1051835	44	52	46	44	51	55
Blank	89	88	86	87	83	89
LCS	93	92	91	90	86	92
LCSD	80	82	85	94	82	89
MS	68	81	51	33	58	90
MSD	74	76	47	31	57	93
Limits:	10-140	24-124	10-150	17-124	11-123	16-113

*- Outside of specification
**-This limit was used in the evaluation of the final result for the blank
(1) The result for one or both determinations was less than five times the LOQ.
(2) The unspiked result was more than four times the spike added.

Environmental Analysis Request/Chain of Custody

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For Eurofins Lancaster Laboratories Environmental use only
Acct. # 44334 Group # 2042018 Sample # 1051834-35

COC #583549

Client Information

Client: Ultra Compost Inc	~~Acct. #:~~ Client # 44334
Project Name/#: Biochar	PWSID #:
Project Manager: Bryce Meeker	P.O. #:
Sampler: Bryce Meeker	~~Quote #:~~ Order #. 242495
State where samples were collected: Kansas [redacted]	For Compliance: Yes ☐ No ☒

Matrix: Soil ☐ Sediment ☐ Tissue ☐ Water: Potable ☐ Ground ☐ NPDES ☐ Surface ☐ Other: Biosolids/Biochar

For Lab Use Only
FSC:
SCR#: 242495

Preservation Codes

H=HCl	T=Thiosulfate
N=HNO_3	B=NaOH
S=H_2SO_4	P=H_3PO_4
F=Field Filtered	O=Other

Remarks: Process biosolids sample first, if positive, run biochar sample 2nd.

Sample Identification	Collected Date	Collected Time	Grab	Composite	Soil	Sediment	Tissue	Potable	Ground	NPDES	Surface	Other: Biosolids/Biochar	Total # of Containers	Analysis Requested: Moisture	PFAS in Soil by LC/MS/MS "SNY21"								Remarks
1) Biosolids 1	5/6/19	10:20am	X									X	1	X									Run first
2) Biosolids 2	5/6/19	10:20am	X									X	1		X								Run first
3) Biochar 1	5/6/19	10:20am	X									X	1	X									hold for analysis
4) Biochar 2	5/6/19	10:20am	X									X	1		X								hold for analysis

Turnaround Time (TAT) Requested (please circle)
[✓ Standard] Rush
(Rush TAT is subject to laboratory approval and surcharge.)

Requested TAT in business days: 10 / 20

E-mail address: bryceMeeker@gmail.com

Relinquished by	Date	Time	Received by	Date	Time
	4/30/19	10:35			
				5/8/19	0830

Data Package Options (circle if required)

Type I (EPA Level 3 Equivalent/non-CLP) Type VI (Raw Data Only)
Type III (Reduced non-CLP) NJ DKQP TX TRRP-13
NYSDEC Category A or B MA MCP CT RCP

EDD Required? Yes No
If yes, format:

Site-Specific QC (MS/MSD/Dup)? Yes No
(If yes, indicate QC sample and submit triplicate sample volume.)

Relinquished by Commercial Carrier:
UPS X FedEx Other

Temperature upon receipt 19.3 °C

Eurofins Lancaster Laboratories Environmental, LLC • 2425 New Holland Pike, Lancaster, PA 17601 • 717-656-2300 • FOR HELP COMPLETING FORM CHECK OUT https://www.eurofinsus.com/coc
The white copy should accompany samples to Eurofins Lancaster Laboratories Environmental. The yellow copy should be retained by the client.

7044 0718

Sample Administration Receipt Documentation Log

Doc Log ID: 248341

Group Number(s): 2042698

Client: Ulta Compost, Inc.

Brochar

Delivery and Receipt Information

Delivery Method:	UPS	Arrival Timestamp:	05/08/2019 8:30
Number of Packages:	1	Number of Projects:	1
State/Province of Origin:	KS		

Arrival Condition Summary

Shipping Container Sealed:	Yes	Sample IDs on COC match Containers:	Yes
Custody Seal Present:	Yes	Sample Date/Times match COC:	Yes
Custody Seal Intact:	Yes	VOA Vial Headspace ≥ 6mm:	N/A
Samples Chilled:	Yes	Total Trip Blank Qty:	0
Paperwork Enclosed:	Yes	Air Quality Samples Present:	No
Samples Intact:	Yes		
Missing Samples:	No		
Extra Samples:	No		
Discrepancy in Container Qty on COC:	No		

Unpacked by Nicole Reiff (25684) at 08:57 on 05/08/2019

Samples Chilled Details: Brochar

Thermometer Types: *DT = Digital (Temp. Bottle)* *IR = Infrared (Surface Temp)* *All Temperatures in °C.*

Cooler #	Thermometer ID	Corrected Temp	Therm. Type	Ice Type	Ice Present?	Ice Container	Elevated Temp?	Samples Collected Same Day as Receipt?
1	DT146	19.3	DT	Wet	N	Bagged	Y	N

Elevated Temperature Details: Brochar

All Temperatures in °C

Cooler #	Thermometer ID	Top Left Temp	Top Right Temp	Bottom Left Temp	Bottom Right Temp	Center Temp	Factors Contributing to Elevated Temp	Comments
1	32170023	19.2	19.1	18.8	19.4		Ice melted.	

Explanation of Symbols and Abbreviations

The following defines common symbols and abbreviations used in reporting technical data:

BMQL	Below Minimum Quantitation Level	**mL**	milliliter(s)
C	degrees Celsius	**MPN**	Most Probable Number
cfu	colony forming units	**N.D.**	non-detect
CP Units	cobalt-chloroplatinate units	**ng**	nanogram(s)
F	degrees Fahrenheit	**NTU**	nephelometric turbidity units
g	gram(s)	**pg/L**	picogram/liter
IU	International Units	**RL**	Reporting Limit
kg	kilogram(s)	**TNTC**	Too Numerous To Count
L	liter(s)	**µg**	microgram(s)
lb.	pound(s)	**µL**	microliter(s)
m3	cubic meter(s)	**umhos/cm**	micromhos/cm
meq	milliequivalents	**MCL**	Maximum Contamination Limit
mg	milligram(s)		

<	less than
>	greater than
ppm	parts per million - One ppm is equivalent to one milligram per kilogram (mg/kg) or one gram per million grams. For aqueous liquids, ppm is usually taken to be equivalent to milligrams per liter (mg/l), because one liter of water has a weight very close to a kilogram. For gases or vapors, one ppm is equivalent to one microliter per liter of gas.
ppb	parts per billion
Dry weight basis	Results printed under this heading have been adjusted for moisture content. This increases the analyte weight concentration to approximate the value present in a similar sample without moisture. All other results are reported on an as-received basis.

Analytical test results meet all requirements of the associated regulatory program (i.e., NELAC (TNI), DoD, and ISO 17025) unless otherwise noted under the individual analysis.

Measurement uncertainty values, as applicable, are available upon request.

Tests results relate only to the sample tested. Clients should be aware that a critical step in a chemical or microbiological analysis is the collection of the sample. Unless the sample analyzed is truly representative of the bulk of material involved, the test results will be meaningless. If you have questions regarding the proper techniques of collecting samples, please contact us. We cannot be held responsible for sample integrity, however, unless sampling has been performed by a member of our staff.

This report shall not be reproduced except in full, without the written approval of the laboratory.

Times are local to the area of activity. Parameters listed in the 40 CFR Part 136 Table II as “analyze immediately” are not performed within 15 minutes.

WARRANTY AND LIMITS OF LIABILITY - In accepting analytical work, we warrant the accuracy of test results for the sample as submitted. THE FOREGOING EXPRESS WARRANTY IS EXCLUSIVE AND IS GIVEN IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED. WE DISCLAIM ANY OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING A WARRANTY OF FITNESS FOR PARTICULAR PURPOSE AND WARRANTY OF MERCHANTABILITY. IN NO EVENT SHALL EUROFINS LANCASTER LABORATORIES ENVIRONMENTAL, LLC BE LIABLE FOR INDIRECT, SPECIAL, CONSEQUENTIAL, OR INCIDENTAL DAMAGES INCLUDING, BUT NOT LIMITED TO, DAMAGES FOR LOSS OF PROFIT OR GOODWILL REGARDLESS OF (A) THE NEGLIGENCE (EITHER SOLE OR CONCURRENT) OF EUROFINS LANCASTER LABORATORIES ENVIRONMENTAL AND (B) WHETHER EUROFINS LANCASTER LABORATORIES ENVIRONMENTAL HAS BEEN INFORMED OF THE POSSIBILITY OF SUCH DAMAGES. We accept no legal responsibility for the purposes for which the client uses the test results. No purchase order or other order for work shall be accepted by Eurofins Lancaster Laboratories Environmental which includes any conditions that vary from the Standard Terms and Conditions, and Eurofins Lancaster Laboratories Environmental hereby objects to any conflicting terms contained in any acceptance or order submitted by client.

Data Qualifiers

Qualifier	Definition
C	Result confirmed by reanalysis
D1	Indicates for dual column analyses that the result is reported from column 1
D2	Indicates for dual column analyses that the result is reported from column 2
E	Concentration exceeds the calibration range
K1	Initial Calibration Blank is above the QC limit and the sample result is ND
K2	Continuing Calibration Blank is above the QC limit and the sample result is ND
K3	Initial Calibration Verification is above the QC limit and the sample result is ND
K4	Continuing Calibration Verification is above the QC limit and the sample result is ND
J (or G, I, X)	Estimated value >= the Method Detection Limit (MDL or DL) and < the Limit of Quantitation (LOQ or RL)
P	Concentration difference between the primary and confirmation column >40%. The lower result is reported.
P^	Concentration difference between the primary and confirmation column > 40%. The higher result is reported.
U	Analyte was not detected at the value indicated
V	Concentration difference between the primary and confirmation column >100%. The reporting limit is raised due to this disparity and evident interference.
W	The dissolved oxygen uptake for the unseeded blank is greater than 0.20 mg/L.
Z	Laboratory Defined - see analysis report

Additional Organic and Inorganic CLP qualifiers may be used with Form 1 reports as defined by the CLP methods.

Qualifiers specific to Dioxin/Furans and PCB Congeners are detailed on the individual Analysis Report.

ATTACHMENT 7

CARBON INTENSITY ANALYSIS

February 21, 2023

Bryce Meeker
President
Saratoga Biochar Solutions, LLC
bryce@elementcarbonhv.com

RE: PRELIMINARY CARBON INTENSITY ANALYSIS OF A CARBON FERTILIZER PRODUCT PRODUCED VIA PYROLYSIS OF WWTP BIOSOLIDS AND WASTE WOOD

Dear Mr. Meeker,

This life cycle analysis (LCA) report, prepared for Saratoga Biochar Solutions, LLC (Saratoga), is a carbon intensity (CI) analysis of the “carbon fertilizer” product produced via pyrolysis of wastewater treatment plant (WWTP) biosolids and waste wood in Saratoga, NY. The CI was assessed using the standards and approach of life-cycle analysis (LCA) adopted under many carbon crediting programs, including the Low Carbon Fuel Standard (LCFS) program in California. This letter report represents the opinion of the EcoEngineers staff specializing in providing LCA services since 2009. The following sections provide background, procedures, analysis results, and conclusions.

1.0 Purpose of Analysis

This report is provided at the request of Saratoga to evaluate the CI of its carbon fertilizer product - a product produced via pyrolysis of WWTP biosolids and waste wood. Furthermore, potential strategies for lowering the CI of the carbon fertilizer are also evaluated and recommendations are provided.

2.0 Project Background

Saratoga plans to use a pyrolysis process to convert WWTP biosolids and waste wood into a carbon fertilizer product. The project is at a business planning/preliminary design stage with a goal of starting construction in 2023. Main feedstock of the project is WWTP biosolids with a 77% water content, of which current disposal methods are outlined below in Table 1. Minor feedstock is chipped waste wood (tree cuttings, etc.) from municipalities with a 40% water content that would otherwise be composted.

Table 1. Biosolids management methods in the State of New York.[1]

BIOSOLIDS MANAGEMENT METHOD	QUANTITY (DRY TONS)	% BY DRY WEIGHT	# OF POTWS	% OF POTWS
LANDFILLING*				
IN-STATE	230,303	61%	-	-
OUT-OF-STATE	27,160	7%	-	-
LANDFILLING TOTAL	**257,463**	**68%**	**310**	**53%**
BENEFICIAL USE				
LAND APPLICATION	12,888	3%	37	6%
COMPOSTING	45,012	12%	47	8%
HEAT DRYING/PELLETIZATION	897	<1%	3	<1%
MINE RECLAMATION**	2,202	<1%	3	<1%
BENEFICIAL USE TOTAL	**60,999**	**16%**	**90**	**16%**
INCINERATION	**58,031**	**16%**	**87**	**15%**
OTHER***	**1,170**	**<1%**	**93**	**16%**
TOTAL	**377,663**	**100%**	**580**	**100%**

Pyrolysis is the heating of organic compounds in the absence of oxygen. Pyrolysis is one of the technologies used to convert carbon rich feedstocks into multiple products that could be used for different purposes. A nutrient soil amendment called "carbon fertilizer" is the major product generated by the process which can be used in agriculture. The carbon fertilizer product is expected to replace chemical fertilizers because it will be marketed with a NPK value for direct use in soils. Additionally, the fixed carbon in the product is expected to stay in the soil for many years, in line with many existing literatures related to biochar soil application, effectively resulting in a carbon sequestration. Other than the carbon fertilizer product, the pyrolysis process also generates pyrogas, which is used to run feedstock dryers. In addition, grid electricity and natural gas are also used as process energy.

3.0 Procedures and Methodology Used to Evaluate CI and the CI Reduction Strategies

EcoEngineers performed the following work to estimate the CI of the carbon fertilizer in the proposed project, and to provide recommendations on CI reduction strategies:

- Gathered information on the proposed project from Saratoga staff and conducted calls to gain a general understanding of the project
- Reviewed data provided by Saratoga and resolved questions on the data for clarity
- Processed the data to create model inputs for the LCA model. The LCA model was developed based on the CA-GREET 3.0 Model[2] published by California Air Resources Board (CARB). In addition, current version of GREET model (GREET.net, version 2021)[3] was used to examine the reasonableness of the results obtained by using CA-GREET 3.0 model.
- Summarized the outputs from the LCA model, discussed the impacts of different CI components, and any additional considerations that Saratoga staff should be aware of

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[1] New York State Department of Environmental Conservation, Division of Materials Management. 2018. Biosolids Management in New York State. Accessed on 06/24/2022 at https://www.dec.ny.gov/chemical/97463.html

[2] California Air Resources Board. Released in 2018. Accessed on 06/24/2022 at https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation

[3] Argonne National Laboratory. Released in 2021. Accessed on 06/24/2022 at https://greet.es.anl.gov/index.php?content=greetdotnet

4.0 Data, Assumptions, and Scenarios for the Project

The system boundary for the evaluation starts from WWTP biosolids and waste wood transport and ends at carbon fertilizer soil application. Environmental impacts after soil application, such as increased or decreased greenhouse gas emissions due to the change of soil microbiological activities, crop yields, soil erosions, etc., are not included in the system boundary, mainly due to the high uncertainty related to these impacts and the lack of scientific data and consensus and/or actual field measurement data. The functional unit (FU) adopted is 1 ton carbon fertilizer on an as-is basis.

Saratoga provided the following documents for the project:

- General CI estimate data request for biochar from pyrolysis of biomass 31.10.2022
- Saratoga Biochar Solutions Equity Summary_30Mar2022
- 7031-2401 PFD Data Full HMB Cases - Rev 2 with Biosolids and Wood Split_EcoEngineers
- HPTP Proposal Element Carbon i131277 - Rev 3

Key parameters extracted/developed from the documents above are listed in Table 2. EcoEngineers reviewed and had no issues with the reasonableness of these parameters, but is not responsible for the accuracy of the data provided by Saratoga.

Whether, and how, to quantify the emissions in business-as-usual (BAU) scenarios (also called baseline scenarios), and the credits that may be assigned to the project due to the avoidance of such emissions, are questions that can have different answers when different carbon crediting platforms or methodologies are applied. In this analysis, the avoided emission credits from landfilling, composting and incineration were estimated based on the methodology adopted under CA LCFS for low carbon fuel production. However, it is not guaranteed that such avoided emission credits will be recognized by a carbon crediting platform.

Table 2. Key parameters for this analysis

Parameter	Value	Unit
Biosolids Feedstock		
Mass	75,120	Tons/yr
Transport Distance	70	Mile
Moisture Content	77	%
Waste Wood Feedstock		
Mass	2,504	Tons/yr
Transport Distance	35	Mile
Moisture Content	40	%
Electricity	5,134	MWh/yr
Natural Gas	56,536	MMBtu/yr
SO_2 Chemicals	822,588	lbs/yr
NH_3 Chemicals	315,068	lbs/yr
Carbon Fertilizer Product		
Mass	7,720	Tons/yr
Transport Distance	70	Mile
Moisture Content	10	%
N	4.9	% of TS
P2O5	10.14	% of TS
K2O	0.82	% of TS
Organic Carbon	35.96	% of TS
Fixed Carbon (FC) Content	28.09	% of TS
H	0.73	% of TS
H/C_{org}	0.24	Molar ratio
H/C_{FC}	0.31	Molar ratio

5.0 Results and Discussion

Table 3 shows the CI analysis results along with the contribution from the different inputs to the final CI score. All the impact are shown as per functional unit (FU), which is 1 ton carbon fertilizer as-is.

Table 3. CI analysis results and GHG reduction

	Per ton[1]	**P1, ton/a**
Carbon Fertilizer™ Produced, ton	**1.000**	**7,720**
Feedstock Transport	0.096	740
Natural Gas	0.544	4,197
Electricity	0.169	1,307
Chemicals	0.057	444
Carbon Fertilizer Transport	0.010	75
SBS Gross Carbon Intensity (CI)	**0.876**	**6,763**
Carbon Sequestration Value	(0.927)	(7,156)
CI with Carbon Sequestration	**(0.051)**	**(393)**
Fertilizer Mfg. Displaced, ton CO_2e	(0.315)	(2,432)
CI with Carbon Sequestration and Fertilizer Displacement	**(0.366)**	**(2,825)**
Disposal Avoided, ton CO_2e	(0.836)	(6,451)
CI with Carbon Sequestration, Fertilizer Displacement, and Avoided Disposal Credits	**(1.202)**	**(9,277)**

Several key findings and potential CI reduction strategies from the analysis include:

1. The total CI of carbon fertilizer, excluding the avoided emission credits from the baseline scenarios, was -0.051 ton CO_2e/ton carbon fertilizer. At 7,720 tons/year production rate, total GHG reduction in this scenario is 2,825 tons CO_2e per year when it is assumed the carbon fertilizer displace fossil fertilizers on a lb nutrient to lb nutrient basis. GREET.net model gave an almost identical GHG reduction value.
2. When considered, the avoided emission credits by diverting the feedstock from landfilling, composting, and incineration contribute -0.836 ton CO_2e/ton carbon fertilizer to the total CI, resulting in an additional 6,451 tons CO_2e GHG reduction per year.
3. The top contributors to the final total CI are carbon sequestration credits, avoided emission credits from baseline scenarios, and process energy including natural gas and electricity. And the CI result is more sensitive to these parameters than others.
4. Reduction of process energy use and/or the use of low CI process energy (such as waste heat, solar power, wind power etc.) has the potential to reduce the overall CI.
5. Another potential option to lower the CI is to use a combined heat and power (CHP) system powered by natural gas or by low-CI biogas for process energy.
6. Another potential way to reduce the CI is to capture and sequester the CO_2 generated during the pyrolysis process. By doing the carbon capture and sequestration (CCS), credits can be assigned back to the final carbon fertilizer product and therefore lower the overall CI.

6.0 Conclusions and Recommendations

Having reviewed the information provided by Saratoga and discussed with Saratoga staff over the period of this analysis, EcoEngineers evaluated the CI of the carbon fertilizer produced via pyrolysis of WWTP biosolids and waste wood. The calculated CI is -0.051 ton CO_2e/ton carbon fertilizer without avoided emission credits from baseline and fertilizer displacement. When factoring in the avoided emission credits from fertilizer displacement another -0.315 ton CO_2e/ton carbon fertilizer is added, hence yielding a -0.366 ton CO_2e/ton carbon fertilizer CI score. The disposal avoided emissions corresponds to -0.836 ton CO_2e/ton carbon fertilizer. When fertilizer the CI after the fertilizer displacement is integrated with the avoided disposal emissions, a total of -1.202 ton CO_2e/ton carbon fertilizer is reached. At the projected production rate of this project, over 2,800 tons of GHG emissions could be reduced without considering avoided emission credits from baseline, and over 9,200 tons while considering them. Furthermore, this report presented the key parameters that influence the CI and the potential ways to lower the CI of the carbon fertilizer product.

This report is based on the information provided by Saratoga, current regulations and general LCA methodologies, previous experience working with low carbon programs, and the opinion of EcoEngineers staff. This report is intended solely for Saratoga and is not intended for use by any other parties except with the express permission of Saratoga.

Sincerely,

Dr. Zhichao Wang, Ph.D, PE
Senior Engineer / LCA Director

Background & Qualifications of EcoEngineers

EcoEngineers is a leading renewable energy consulting firm and USEPA approved auditor with core services that include audit, compliance management, and consulting. Our consulting team is comprised of engineers, regulatory and compliance specialists, financial and life-cycle analysts - all of whom hold deep expertise in federal, state, and international energy regulations that set a price on carbon and create carbon markets. The low carbon value of renewable energy is represented by the economic value of fungible energy credits. EcoEngineers work improves regulatory compliance and quality of credits to protect the value of investments.

EcoEngineers provides LCFS services to renewable diesel, biodiesel, cellulosic ethanol, renewable natural gas and other renewable fuel producers and has extensive experience working with the California LCFS program and the CA-GREET models. EcoEngineers also provides LCA services under other carbon programs like BC RLCF. EcoEngineers has an LCA team dedicated to modeling fuel pathways using a variety of LCA tools and has submitted over 300 applications to California Air Resources Board (CARB) for registration under the LCFS. EcoEngineers has helped more than 100 pathways certified under the newly adopted LCFS regulation effective since January 2019, and is helping producers on an ongoing basis.

EcoEngineers provides RFS2 New Pathway Applications, Efficient Producer Petitions, 3rd Party Engineering Reviews, Part 80 Registrations and other services to producers of renewable diesel, ethanol, biodiesel, heating oil, renewable natural gas and other RFS participants. Additionally, as part of the suite of compliance services we offer, EcoEngineers is an EPA approved Q-RIN Quality Assurance Program (QAP) provider under the RFS program and conducts quarterly audits of over 160 domestic and international renewable fuel production facilities to ensure compliance under federal regulations. Our compliance management services provide RIN Academy Workshops, guidance on RIN generation protocol and compliance monitoring plans, and a proprietary RIN management platform.

ADDENDUM TO LCA REPORT

“RE: PRELIMINARY CARBON INTENSITY ANALYSIS OF A CARBON FERTILIZER PRODUCT PRODUCED VIA PYROLYSIS OF WWTP BIOSOLIDS AND WASTE WOOD”

This is an addendum to the life cycle analysis (LCA) report "**RE: PRELIMINARY CARBON INTENSITY ANALYSIS OF A CARBON FERTILIZER PRODUCT PRODUCED VIA PYROLYSIS OF WWTP BIOSOLIDS AND WASTE WOOD**" prepared for Saratoga Biochar Solutions, LLC (Saratoga), detailing the Emission Factors (EFs) and the calculations for the carbon intensity (CI) analysis of the "carbon fertilizer" product produced via pyrolysis of wastewater treatment plant (WWTP) biosolids and waste wood in Saratoga, NY.

In order to see the net impact of diverting organic waste from the current management processes, or business-as-usual (BAU) scenarios, to the alternative scenario (used for carbon fertilizer production), the lifecycle energy/material consumption and emissions from the current management, in addition to those in the alternative scenario, need to be investigated and compared.

Table 1 summarizes the BAU scenarios, the diversion fate percentages and the GHG emissions of each one of them that are avoided by the carbon fertilizer production and utilization.

Table 2 breaks down the alternative scenario and shows the net emissions of the carbon fertilizer production and utilization.

Tables 3 to 6 detail the calculations for the results presented on Table 1.

Emissions factors are listed and sources of these EFs are provided in the Tables.

Table 1. BAU avoided emissions summary.

Feedstock	BAU scenario	Diversion fate (%)	GHG Emissions, short Tons CO2e
Wood	Composting	100.0%	174
Biosolids	Landfill	68.0%	5,391
Biosolids	Composting	16.0%	759
Biosolids	Incineration	16.0%	133
GRAND TOTAL			**6,457**

Table 2. Alternate scenario – Carbon fertilizer emissions breakdown

Total Production & Consumption	**EF**	**EF Units**	**Data Source**	**miles**	**GHG Emissions, gCO2e**	**CI (ton CO2e/ton)**	**Fixed Carbon, short ton**	**GHG Emissions, gCO2e**	**gCO2e / short ton of Biochar**	**CI (ton CO2e/ ton)**
Biosolids, Tons/yr	125.70	g/ton-mile	CA-GREET 3.0	70	660,980,880	0.09				
Wood, Tons/a	125.70	g/ton-mile	CA-GREET 3.0	35	11,016,348	0.00				
Carbon Fertilizer, Tons/yr							1,951.63	(6,497,631,893)	(841,689)	**(0.93)**
Electricity, MWh/yr	231.08	g/kWh	CA-GREET 3.0		1,186,366,443	0.17				
Natural Gas, MMBtu/yr	74,654.76	g/mbtu	CA-GREET 3.0		3,811,285,117	0.54				
SO2 Chemicals, lbs/yr	0.05	g/g	CA-GREET 3.0		18,080,239	0.003				
NH3 Chemicals, lbs/yr	2.69	g/g	CA-GREET 3.0		384,779,725	0.05				
Biochar Transport	125.70	g/ton-mile	CA-GREET 3.0	70	67,926,133	0.01				
Total					6,140,434,885	0.88			795,418	**0.88**
Emissions Balance									(46,271)	**(0.05)**
N	3.95	g CO2e/g	CA-GREET 3.0		1,222,580,535				(158,370)	**(0.17)**
P2O5	1.49	g CO2e/g	CA-GREET 3.0		952,592,263				(123,397)	**(0.14)**
K2O	0.64	g CO2e/g	CA-GREET 3.0		32,879,353				(4,259)	**(0.005)**
BAU Baseline Avoided Emissions*			CA-GREET 3.0		5,857,871,070				(758,816)	**(0.84)**

* Value corresponds to the total GHG emissions in Table 1.

Table 3. Wood BAU emissions – Composting.

Composting BAU Emissions	MTCO2E /ton of compost	Conversion Factor	MTCO2E/ton of wood	Wet feedstock (Wood), ton	BAU (%) to Compost	BAU Composted Wet feedstock, ton	GHG Emissions, MT CO_2e	GHG Emissions, short Tons CO_2e
CO2e Emissions from Transportation Distances	NA	NA	0.020	2,504	100%	2,504	50.32	55.47
Fugitive CH4 + N2O from Composting	NA	NA	0.043 [1,2]				107.72	118.74
Total Wood Baseline Composting Emissions							**158.04**	**174.21**

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[1] CH_4: The Code of Federal Regulations, 40 CFR Part 98, Subpart HH & Subpart TT

[2] N_2O: The Code of Federal Regulations, 40 CFR Part 98, Subpart TT, Section 98.464

Table 4. Biosolids BAU emissions – Landfill.

Landfill BAU Emissions	EF	EF Units	Data Source	GHG Emissions, gCO_2e/ m.t wet feedstock	Wet feedstock (Biosolids), m.t	BAU (%) to Landfill	BAU Landfilled Wet feedstock, m.t	GHG Emissions, MT CO_2e	GHG Emissions, short Tons CO_2e
Fugitive CH4 from LF	3.75[3]	kg CH4/m.t. wet feedstock	CA-GREET 3.0	93,750	68,148	68%	46,340	4,344	4,789
Uncontrolled CH4 emissions from flaring	0.03	kg CH4/m.t. wet feedstock	CA-GREET 3.0	719				33	37
CO2e Emissions from Transportation Distances	138.42	gCO2e/metric ton-mile	CA-GREET 3.0	11,074				513	566
Total Biosolids Baseline Landfill Emissions								**4,891**	**5,391**

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[3] Based on below assumptions as provided by CA-GREET 3.0:
Degradable Organic Carbon (DOC) = 0.05
DOC_f = 0.5
CH_4 concentration in LFG (by volume) = 50%
Methane correction factor (MCF) for managed anaerobic landfill = 1
Non-captured CH4 from LF = 25%
Fugitive CH_4 Emissions (of Non-captured) = 90%
CH_4 emissions from flaring = 0.23%

Table 5. Biosolids BAU emissions – Composting.

Composting BAU Emissions	MTCO2E/ton of compost	Conversion Factor	MTCO2E/ ton of Biosolids	Wet feedstock (Biosolids), ton	BAU (%) to Compost	BAU Composted Wet feedstock, ton	GHG Emissions, MT CO_2e	GHG Emissions, short Tons CO_2e
CO2e Emissions from Transportation Distances	NA	NA	0.020	68,148	16%	10,904	219.14	241.56
Fugitive CH4 + N2O from Composting	NA	NA	0.043				469.05	517.04
Total Biosolids Baseline Composting Emissions							**688.19**	**758.60**

Table 6. Biosolids BAU emissions – Incinerating.

Incinerating BAU Emissions	GHG Emissions, gCO_2e/ m.t wet feedstock	Wet feedstock (Biosolids), m.t	BAU (%) to Incineration	BAU Incinerated Wet feedstock, m.t	GHG Emissions, MT CO_2e	GHG Emissions, short Tons CO_2e
Combustion Biosolids*	-	2,272	16%	10,904	-	-
CO2e Emissions from Transportation Distances	11,074				120.75	133.10
Total Biosolids Baseline Incinerating Emissions					**120.75**	**133.10**

* Combustion of waste biomass is conservatively considered zero.

ATTACHMENT 8

PILOT-SCALE THERMAL DESTRUCTION OF PER- AND POLYFLUOROALKYL SUBSTANCES IN A LEGACY AQUEOUS FILM FORMING FOAM

ACS ES&T Engineering

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Pilot-Scale Thermal Destruction of Per- and Polyfluoroalkyl Substances in a Legacy Aqueous Film Forming Foam

Erin P. Shields,* Jonathan D. Krug, William R. Roberson, Stephen R. Jackson, Marci G. Smeltz, Matthew R. Allen, R. Preston Burnette, John T. Nash, Larry Virtaranta, William Preston, Hannah K. Liberatore, M. Ariel Geer Wallace, Jeffrey V. Ryan, Peter H. Kariher, Paul M. Lemieux, and William P. Linak

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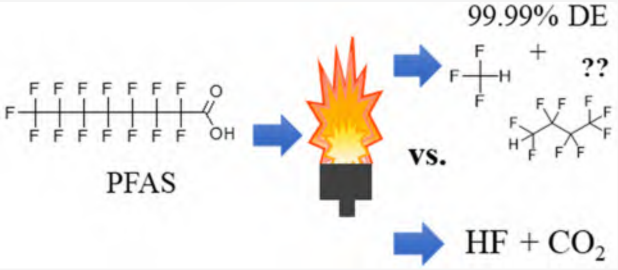

ABSTRACT: The destruction of per- and polyfluoroalkyl substances (PFAS) is critical to ensure effective remediation of PFAS contaminated matrices. The destruction of hazardous chemicals within incinerators and other thermal treatment processes has historically been determined by calculating the destruction efficiency (DE) or the destruction and removal efficiency (DRE). While high DEs, >99.99%, are deemed acceptable for most hazardous compounds, many PFAS can be converted to other PFAS at low temperatures resulting in high DEs without full mineralization and the potential release of the remaining fluorocarbon portions to the environment. Many of these products of incomplete combustion (PICs) are greenhouse gases, most have unknown toxicity, and some can react to create new perfluorocarboxylic acids. Experiments using aqueous film forming foam (AFFF) and a pilot-scale research combustor varied the combustion environment to determine if DEs indicate PFAS mineralization. Several operating conditions above 1090 °C resulted in high DEs and few detectable fluorinated PIC emissions. However, several conditions below 1000 °C produced DEs > 99.99% for the quantifiable PFAS and mg/m^3 emission concentrations of several nonpolar PFAS PICs. These results suggest that DE alone may not be the best indication of total PFAS destruction, and additional PIC characterization may be warranted.

KEYWORDS: *PFAS, AFFF, incineration, products of incomplete combustion, destruction efficiency*

■ INTRODUCTION

Per- and polyfluoroalkyl substances (PFAS) are a class of synthetic chemicals that possess strong carbon−fluorine bonds that give PFAS high stability and low surface energies.[1] These unique properties have made PFAS useful in heat resistant products, hydrophobic and oleophobic coatings, firefighting foams, and many other products and manufacturing processes.[1−3] The widespread use and stability of PFAS have led to the ubiquitous presence of PFAS in the environment and waste streams.[4−7] Even low levels of PFAS exposure can lead to bioaccumulation and has been associated with adverse health effects,[8−11] leading to low parts per trillion drinking water health advisory levels for several PFAS.[12] The current concentrations of PFAS in the environment have been determined to be near or over recent exposure guidelines,[13,14] indicating the need for PFAS emission reductions.[14]

Hazardous organic chemicals are often incinerated to destroy the compounds and prevent their release to the environment.[15,16] To ensure harmful emissions are not released into the atmosphere, the destruction efficiency (DE) or destruction and removal efficiency (DRE) of the parent organic molecule, or principle organic hazardous constituent (POHC), has been used to determine the destruction of the molecule.[15,17−19] Typically, a DE or DRE determined for a highly stable POHC (based on an incinerability index[20]) is used to ensure adequate destruction for all waste species.[15,18,20] The DE or DRE can be calculated using eq 1,

$$DE \text{ or } DRE = [1 - (W_{out}/W_{in})] \times 100\% \tag{1}$$

where W_{in} is the mass feed rate of the molecule in and W_{out} is the mass emission rate of the POHC coming out of the incinerator for DE or out of the stack and into the atmosphere for DRE. The distinction between DE and DRE is that DRE includes credit for POHC removal in facility air pollution control devices (e.g., particulate control, acid gas scrubbers,

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activated carbon beds) where DE does not. Although this results in some transference of the POHC to the liquid and solid discharges from air pollution control devices, these discharges are themselves treated as hazardous wastes. The regulation, 40 CFR Part 63.1203, states that a DRE of 99.99% indicates complete destruction of most chemicals.[19] For perspective, a requirement of 99.99% DRE indicates that for every 1 kg of POHC introduced, 100 mg of the POHC could be released in the air emissions. When applied to an aqueous film forming foam (AFFF) containing ~2% PFAS, ~200 mg of PFAS could be emitted for every 100 kg of the AFFF incinerated.

Many PFAS of industrial importance are composed of a fluoroalkyl chain and a polar functional group. PFAS can easily be altered from their original form by the removal of the functional group thermally at temperatures as low as 100 to 300 °C[21−23] and by other mechanisms at ambient temperatures.[24,25] The removal of the functional group creates volatile PFAS, from the carbon−fluorine backbone, that are greenhouse gases;[26,27] most have unknown toxicity, and some can transform to perfluorocarboxylic acids in the atmosphere.[28] The complete destruction of PFAS, the breaking of all the carbon−fluorine bonds and mineralization to form hydrofluoric acid (HF) and carbon dioxide (CO_2), is necessary to ensure PFAS are not released into the environment during the thermal treatment of PFAS contaminated media.

The primary objective of this study was to evaluate whether DEs indicate complete destruction of PFAS during thermal treatment. As an indicator of incomplete destruction, volatile products of incomplete combustion (PICs) were quantified along with the DEs of the quantifiable PFAS. The study was performed using a pilot-scale natural gas-fired refractory-lined combustor. The PFAS mixture used was an AFFF predominantly containing legacy perfluorooctanesulfonic acid (PFOS).

AFFF was injected into the combustor at various locations experiencing different peak temperatures. The AFFF was atomized through the flame, with exposure to flame generated radicals and near adiabatic flame temperatures, and at postflame locations with peak temperatures ranging from 1180 to 810 °C. These temperatures span realistic high temperatures achieved in hazardous waste incinerators (HWIs), as well as lower temperatures that may be more typical of other thermal destruction systems such as sewage sludge or municipal waste incinerators.[29] To our knowledge, this study is the first to use a pilot-scale incinerator to examine AFFF destruction over a wide range of temperatures and include PIC measurements as an indicator of performance.

■ MATERIALS AND METHODS

Experimental Furnace. Experiments were performed using a small pilot-scale U.S. Environmental Protection Agency (EPA) research combustor named the Rainbow furnace that has been described in previous studies.[30−32] Here the furnace load and flame stoichiometric ratio (SR) were varied between 30 and 45 kW and 1.3 and 2.0, respectively. To provide similar mass flows and thorough mixing of the effluent, high amounts of excess air were used to reduce and vary furnace temperatures to those more typical of HWIs and other incineration systems. Figure 1 presents a cutaway drawing of the Rainbow furnace with AFFF injection locations (burner, port 4, port 8) and stack sampling locations identified. In this configuration, the combustor most closely resembles a hazardous waste incinerator injecting a low heating value liquid waste. Hazardous waste incinerators often introduce aqueous waste through lances downstream of the flame.

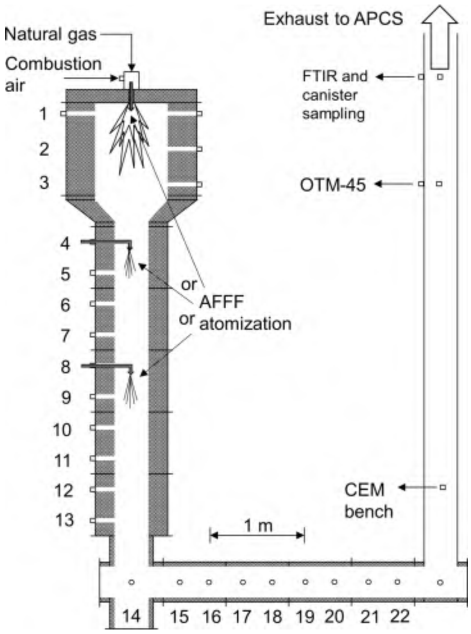

Figure 1. EPA refractory-lined natural gas-fired furnace showing the AFFF injection locations, through the flame with the natural gas and at ports 4 and 8 and the stack sampling locations indicated. Measurements are made prior to the facility air pollution control system (APCS).

AFFF Injection. One legacy AFFF formulation composed primarily of PFOS and perfluorohexanesulfonic acid (PFHxS) was used for these experiments. The AFFF was analyzed by a commercial laboratory for PFAS according to their liquid chromatography coupled to tandem mass spectrometry (LC/MS/MS) method derived from EPA Method 533.[33] The AFFF was added to a 19 L Cornelius keg placed on a scale to monitor mass loss and feed rate. The injection technique has been used previously[34] and is described here. AFFF was atomized through the burner or through one of two axial postflame access ports along the furnace centerline using twin fluid (air/AFFF) atomizers. The Cornelius keg was air pressurized (~584 kPa) to push the AFFF through a manually adjusted needle valve and 4−50 mL/min liquid rotameter (Brooks Instrument, Hatfield, PA) to the atomizer. Simultaneously, compressed air (584 kPa) was directed through a mass flow controller (Sierra Instruments, model Smart-Trak 50 L/min, Monterey, CA) to the atomizer. The AFFF and atomization air were combined at one end of a length of 0.1753 cm inside diameter, 0.3175 cm outside diameter stainless steel tubing. Within the tubing the atomizing air causes the liquid to form a thin film on the inner tube surface and shears the liquid film into droplets (~50 μm diameter for water) as it leaves the other end. The injector for the two postflame axial access ports included a 90-degree bend at the atomizer tip to direct the atomized AFFF downstream cocurrent with the combustion gases along the furnace centerline. In addition, to mitigate the potential for pyrolysis, the side port atomizer included two additional concentric outer tubes through which additional "sweep" air was introduced to keep the AFFF and atomizing air cool until the atomizer tip. The volumes of these two cooling flows were minor (~3%) compared to the combustion gas flow. The burner incorporated atomizer did not need cooling, and atomized AFFF into the natural gas at the center of the International Flame Research Foundation (IFRF) variable air swirl burner (using setting 4 of 0−8) where the combined natural gas AFFF mixture then burned as a diffusion flame with combustion air added annularly.

Figure S1 in the Supporting Information (SI) indicates Rainbow furnace temperature profiles, approximate residence times, and AFFF injection locations. One experiment introduced the AFFF through the flame where the AFFF would be exposed to near adiabatic flame temperatures (1963 °C for a methane−air diffusion flame at 101 kPa) and free radical chemistry characteristics of a natural gas diffusion flame. This was followed by five postflame experiments that varied the peak (injection) temperature from 1180 to 810 °C in approximate increments of 100 °C. The Rainbow furnace operating conditions for each injection experiment are listed in Table S1.

Real-Time Measurements. Figure 1 indicates stack locations where combustion exhaust samples were extracted for analysis. As previously described,[30] a Fourier transform infrared spectrometer (FTIR, Model 2030, MKS Instruments Inc., Andover, MA) and a continuous emission monitor (CEM, Model ZRE Analyzer, California Analytical, Orange, CA) measured furnace exhaust concentrations of oxygen (O_2), carbon monoxide (CO), and CO_2. These measurements are intended to verify combustion conditions and quantify small amounts of air in-leakage caused by the facility's induced draft blower and operation at a ∼1.27 cm H_2O draft. FTIR was also used to measure moisture (H_2O), HF, sulfur dioxide (SO_2), and nitric oxide (NO). Note that CEM measurements are dry (moisture removed), and FTIR measurements are wet. Where available, the CEM and FTIR values were compared, taking into account the water, to verify the FTIR's measurements.

Volatile Nonpolar PFAS. The volatile PFAS and fluorochemicals (vPFAS) were sampled using evacuated 6 L Silonite coated stainless steel canisters (Entech, Simi Valley, CA). The emissions were sampled with a heated probe, filter, and perfluoroalkoxy alkane (PFA) heated sample line at 120 °C and ∼3 L/min. A 1.0 L/min slip stream of the emissions was passed through three 0.1 M sodium hydroxide (NaOH) filled mini (∼30 mL) impingers and one empty impinger in an ice bath to remove acid gases and reduce the water content in the samples. The evacuated canisters (−101 kPa) collected stack gases after the impingers and were filled to ∼−34 kPa, resulting in an ∼4 L sample volume. Subambient pressure was maintained to minimize condensation inside the canister. For analysis, the canisters were pressurized with dry nitrogen to 207 kPa, and the injections were spiked with internal standards, d5-chlorobenzene, and 1,4-difluorobenzene.

The canisters were analyzed using a Markes International Unity-xr TD system and Markes BenchTOF-Select MS system (Bridgend, U.K.) integrated with an Agilent 7890B gas chromatograph (GC, Santa Clara, CA). Tetrafluoromethane was concentrated from 15 mL of sample to avoid trap breakthrough. Aliquots of 200 mL of the samples were trapped for other PFAS. Samples were concentrated using a Markes Greenhouse Gas trap at −30 °C and desorbed at 40 °C/s to 280 °C and held for 0.5 min. Analytes were separated using an Agilent GS-GasPro column (60 m × 0.32 mm inside diameter) starting at 50 °C, held for 1 min, increased at 5 °C/min to 130 °C, and then ramped at 10 °C/min to 240 °C and held for 37 min. Quantitation of 30 vPFAS were performed using a seven-point (0.5 to 20 ppbv, 50 to 200 ppbv for CF_4) calibration curve for each analyte.

Semi- and Nonvolatile Polar PFAS. The semivolatile and nonvolatile polar PFAS were sampled and analyzed according to the U.S. EPA's Other Test Method 45 (OTM-45).[35] Briefly, ∼ 3.0 m^3 was sampled over 3 h at a constant rate from the furnace exhaust. Due to the low pressure drop in the ductwork, isokinetic sampling could not be performed. OTM-45 creates four fractions (probe rinsate and filter, an XAD sorbent trap, impinger water, and a breakthrough XAD sorbent trap) for analysis using LC/MS/MS with a method based on Method 533 to quantify 49 polar PFAS, see Table S2 in the SI. The PFAS mass from each fraction was summed to give the total mass for each sample. A proof blank train was created by setting up and recovering an OTM-45 train with clean glassware near the sampling location. The sample extraction and analyses were performed by a commercial environmental laboratory, Eurofins TestAmerica (Knoxville, TN), according to OTM-45 and their standard operating procedures.

Calculation of Destruction Efficiency. To account for variable excess combustion air and any additional dilution caused by in leakage into the furnace, the DEs for the targeted PFAS in the AFFF were calculated using Method 19[36] as done previously.[30] The DE, or percent removal, was calculated using eq 1, but W_{out} was replaced with Method 19's E_{ao}, the mass emissions rate, and W_{in} was replaced with E_{ai}, the mass input rate. The mass emission rates are further defined in the SI.

Nontargeted PFAS. Nontargeted analysis (NTA) was performed with additional mass spectrometry analysis of the OTM-45 extracts using LC coupled to a high-resolution Thermo Orbitrap Fusion mass spectrometer (Thermo Fisher Scientific, Waltham, MA, U.S.A.) described elsewhere.[37,38] Extracts were diluted 1:3 with water and then analyzed with the LC/MS using a heated electrospray ionization source operated in negative mode. Data was generated using data dependent MS/MS acquisition with a scan range of 150−1500 *m/z* and Orbitrap resolutions of 60,000 and 15,000 for MS1 and MS2 acquisition, respectively. Instrument settings are detailed in the SI.

Raw instrument files were then processed with Thermo Compound Discoverer 3.3 to extract chemical features and tentatively matched against several databases (the USEPA's Distributed Structure-Searchable Toxicity (DSSTox), Thermo mzCloud, and Mass Bank of North America (MONA) mzvault library). The compounds' formula and potential names were generated by Compound Discoverer based on the MS1 molecular ion's mass. Some formulas and chemical names do not show fluorine, but the MS2 spectra possessed PFAS-like features. The PFAS-like features were manually identified based on a negative mass defect or predicted formula containing multiple fluorine atoms and fragmentation consistent with the fluorinated moieties listed in Table S3. Determining the presence of fluorinated molecules was the focus of this study; subsequent studies may focus on identification of unidentified compounds.

RESULTS AND DISCUSSION

Targeted PFAS Destruction. The AFFF was found to contain 10 PFAS from the targeted analyte list; see Table S4 in the SI. The quantitated PFAS consisted of C4 to C8 perfluoroalkyl carboxylic acids (PFCAs) and perfluoroalkyl sulfonic acids (PFSAs), and concentrations of the 10 PFAS were used to calculate the DEs for the PFAS in the AFFF. The

Table 1. OTM-45 Results

Temperature (°C)	MB[a]	PBT[a]	Flame	1180	1090	970	870	810
Sample volume (dscm)[b]	-	-	3.12	3.71	3.71	3.72	3.74	3.74
Injection Port	-	-	burner	4	4	8	4	8
PFAS[a]	ng/sample	ng/sample	ng/sample	ng/sample	ng/sample	ng/sample	ng/sample	ng/sample
PFBA	ND	5.57	22.3	108	9.10[c]	628[c]	3950	116000
PFPeA	ND	3.32	17.6	56.0	7.42[c]	249[c]	741	63400
PFHxA	ND	6.59	26.1	100	13.8	490	1240	151000
PFHpA	0.40	1.55	6.32	29.8	5.23	65.5	475	36300
PFOA	ND	2.30	36.8	156	144[d]	452[d]	1430	78400
PFBS	0.11	0.41	0.61	6.66	0.57	0.67	28.8	1860
PFPeS	ND	ND	ND	4.58	0.14	0.54	23.4	1680
PFHxS	ND	1.25	0.92	21.6	1.36[d]	2.33[d]	118	8520
PFHpS	ND	ND	ND	1.84	ND	0.34	17.1	989
PFOS	ND	9.30[d]	3.08[d]	116	42.2[d]	18.6[d]	819	62200

[a] MB is laboratory method blank, PBT is the proof blank train, abbreviations are in Table S2 [b] Dry standard cubic meter. [c] Pre-extraction internal standards were above of acceptance criteria, >150% [d] Pre-extraction internal standards were below acceptance criteria, <20%

Table 2. DEs for Measured PFAS in AFFF with Gray Shading Indicating Less than Four Nines DE

Temperature, (°C)	Flame	1180	1090	970	870	810
PFAS	(%)	(%)	(%)	(%)	(%)	(%)
PFBA	99.9958	99.9725	99.9978	98.3336[b]	98.3336[b]	45.7362
PFPeA	99.9993	99.9971	99.9996	99.9372[b]	99.9372[b]	94.0300
PFHxA	99.9997	99.9984	99.9998	99.9678	99.9678	95.6188
PFHpA[a]	99.9997	99.9984	99.9997	99.9566	99.9566	96.3086
PFOA	99.9996	99.9978	99.9981	99.9663[b]	99.9663[b]	97.9522
PFBS[a]	>99.9999	>99.9999	>99.9999	>99.9999	99.9996	99.9704
PFPeS	>99.9999	>99.9999	>99.9999	>99.9999	99.9996	99.9671
PFHxS	>99.9999	>99.9999	>99.9999[b]	>99.9999[b]	99.9997	99.9768
PFHpS	>99.9999	>99.9999	>99.9999	>99.9999	99.9996	99.9766
PFOS	>99.9999[b]	>99.9999	>99.9999[b]	>99.9999[b]	99.9997	99.9751

[a] PFBS and PFHpA were detected in the analytical method blanks. [b] Pre-extraction internal standards were outside of acceptance criteria; DEs used estimated maximum concentrations.

PFAS found in the stack emissions from the OTM-45 sampling for all six AFFF injections are shown in Table 1, with compound abbreviations defined in Table S2. No other PFAS from the OTM-45 target list above method blank (MB) and reporting levels were detected in any of the sampling trains besides the original 10, with just perfluorononanoic acid (PFNA) being detected near blank levels in two samples and perfluorooctanesulfonamide (FOSA) being just above the detection limit in one sample. This is not surprising, as the 49 PFAS from OTM-45 are from methods for water analysis and are complex polar structures of industrial relevance that are more likely to be found in industrial discharges than to be formed via de novo synthesis during combustion processes. An exception to this may be the PFCAs which may form from fluoroalkyl fragments in the presence of water at postflame and stack conditions.

For these experiments, the train's glassware was cleaned according to OTM-45 for each test, so a field blank train was not run since the proof blank train (PBT) was the same as a field blank train. The PBT showed some near detection limit levels of contamination, mainly due to the XAD fractions of the train. The PFCAs, perfluorobutanesulfonic acid (PFBS), perfluorohexanesulfonic acid (PFHxS), and PFOS were all measured at trace levels in the proof blank train. The results are reported according to OTM-45, without any blank correction. The samples with low levels of PFAS are reported as near blank levels to indicate that the result may be biased high and the PFAS may be below the detection limit. The OTM-45 data were also impacted by the low recovery of the isotopically labeled extraction internal standard for some longer chain PFAS. This is likely due to the water that collects in the XAD decreasing the solubility of the long chain PFAS. The impacted PFAS are noted in the tables, and the values are the highest estimated value provided by the commercial laboratory.

The experimental sequence was flame, 1090, 970, 870, 810, and 1180 °C. It appears that there may have been some hysteresis due to contamination of internal furnace surfaces after the test at the lowest temperature. Experiments were performed on separate days with at least 18 h of operation at new combustion conditions without AFFF injection to achieve equilibrium. The experiment at 1180 °C was performed the

Table 3. Volatile PFAS and Other Gases Quantified in the Emissions from AFFF Incineration

	Temperature (°C)					
	Flame	**1180**	**1090**	**970**	**870**	**810**
Canister Analytes (μg/m^3)						
tetrafluoromethane	ND	ND	ND	ND	ND	ND
hexafluoroethane	ND	ND	ND	11.4	9.36	6.51
chlorotrifluoromethane	ND	ND	ND	ND	ND	ND
fluoroform	ND	ND	ND	5.47	601	7530
octafluoropropane	ND	ND	ND	267	903	795
difluoromethane	ND	ND	ND	2.87	8.51	94.4
pentafluoroethane	0.70	1.35	0.65	3.99	276	8950
octafluorocyclobutane	ND	ND	ND	ND	ND	14.1
fluoromethane	ND	ND	ND	ND	ND	1.30
tetrafluoroethylene	ND	ND	ND	ND	1.16	149
hexafluoropropylene	ND	0.19	ND	0.31	4.96	567
1,1,1-trifluoroethane	ND	ND	ND	ND	ND	ND
hexafluoropropene oxide	ND	ND	ND	ND	ND	ND
chlorodifluoromethane	ND	ND	ND	ND	ND	ND
1,1,1,2-tetrafluoroethane	ND	ND	ND	3.39	1.84	64.2
perfluorobutane	ND	0.30	ND	ND	434	620
1*H*-heptafluoropropane	ND	0.99	ND	ND	86.8	2480
octafluourocyclopentene	ND	ND	ND	ND	5.15	235
trichlorofluoromethane	0.40	0.17	0.57	0.57	0.40	0.57
dodecafluoro-*n*-pentane	ND	ND	ND	ND	51.2	503
1*H*-nonafluorobutane	ND	0.64	ND	ND	59.8	1230
tetradecafluorohexane	ND	ND	ND	ND	1.41	307
1*H*-perflluoropentane	ND	ND	ND	ND	12.1	1000
E1[a]	ND	ND	ND	ND	ND	ND
hexadecaflluroheptane	ND	ND	ND	ND	ND	85.81
1*H*-perfluorohexane	ND	ND	ND	ND	6.65	1090
perfluorooctane	ND	ND	ND	ND	ND	291
1*H*-perfluoroheptane	ND	ND	ND	ND	ND	316
1*H*-Perfluorooctane	ND	ND	ND	ND	ND	203
E2[b]	ND	ND	ND	ND	ND	ND
FTIR Analytes						
CO (ppm)	7.2	3.6	4.5	5.7	109	1730
CO_2 (%)	6.2	6.3	5.2	5.0	4.4	4.0
HF (ppm)[c]	427	340	278	266	260	227
NO (ppm)[c]	86.7	91	63.5	38.1	4.9	0.4
SO_2 (ppm)[c]	60.9	41.7	34	31.4	35.2	35.4
Other Gas						
Oxygen, O_2 (dry, %)	7.9	7.2	9.0	9.2	11.8	12.0

[a] Heptafluoropropyl 1,2,2,2-tetrafluoroethyl ether. [b] 2*H*-Pefluoro-5-methyl-3,6-dioxanonane. [c] Values not verified with CEM data or certified transfer standard.

day after the lowest temperature injection experiment at 810 °C; Table 1 indicates slightly higher concentrations of some PFCAs than the experiment at 1090 °C, and the PFSAs had higher concentrations than the experiment at 970 °C. Even so, the concentrations were not far above the detection limits and still show very high DEs, but the potential for hysteresis is something to note. The apparent carryover could be due to the quartz probe not going through as extensive of a cleaning process as the other glassware and only being rinsed and brushed, or the furnace may not have fully desorbed PFAS deposited on refractory and ductwork surfaces during the previous 810 °C experiment. The 1180 °C experiment was not repeated due to the time to receive the analytical results and the high cost for each run. The possible contamination was relatively low, and the 1180 °C experiment measured most of the targeted compounds near the detection limit. As a result, the possible contamination did not impact the aim of these experiments to determine if DEs are an effective metric to verify treatment of PFAS. Future tests will involve more rigorous cleaning of the probe and a combustion blank to look for contamination in the system, and more time will pass between low temperature tests to allow more complete surface desorption.

The DEs for the 10 PFAS quantified in the AFFF as determined using Method 19 are shown in Table 2, with the values below four nines, <99.99%, emphasized using gray shading. The original PFAS concentrations (Table S4), AFFF feed rates and combustion parameters (Table S1), and AFFF stack emissions (Table 1) were used in the calculations. When reported PFAS emissions were not detected (ND), the detection limit was used as a conservative value for DE calculation. The lack of corrections for blank contamination as well as corrections for recoveries (including low recoveries) also serve to reduce DE values and provide more conservative values.

The DEs for all five PFSAs are >99.9999% for the four PFAS injection locations >970 °C. Even at 870 and 810 °C, DEs for all five PFSAs were >99.999% and >99.9%, respectively. DEs for the five PFCAs were also high (mostly >99.99%) for injection temperatures >1090 °C and mostly >99.9% for injection temperatures >870 °C. Even at the lowest AFFF injection temperature, 810 °C, DEs > 94% were measured for four PFCAs, except for perfluorobutanoic acid (PFBA). PFBA exhibited the lowest DEs, both with respect to AFFF injection temperatures and PFCA chain length. Lower than expected DEs for PFBA and PFCAs have been reported previously with various destruction technologies[25,39,40] and may suggest either that shorter PFCAs are relatively more stable species or shorter chained PFCAs are formed via hydrolysis of fluoroalkyl fragments in the postflame. Note that PFSAs do not indicate this same trend with calculated DEs for PFBS and PFOS approximately similar at corresponding temperatures. This trend for PFCAs might also suggest a pathway or intermediate through which PFAS transition during thermal destruction. PFAS might be affected by high concentrations of hydroxyl radicals (OH), H_2O, and CO_2 in the combustion gases that promote reformation of PFCAs from fluoroalkyl fragments. This has been reported to occur in the atmosphere[28] and experimentally,[41,42] and the formation of aldehydes and acyl fluorides that can react to create carboxylic acids has been predicted by several computational mechanisms.[43−46] If true, the conversion of PFSAs to PFCAs would reduce apparent DEs for PFCAs while the PFSAs would have higher DEs. These experiments, using a complex mixture of PFAS and other unknown components in the AFFF, do not represent the best approach for addressing mechanistic questions. Further experiments using neat solutions of specific PFAS in coordination with ongoing kinetic modeling efforts are needed to better address mechanisms.

Volatile Emissions. The generally high DEs (>99.99%) presented in Table 2 suggest PFAS are relatively fragile, at least with respect to losing their molecular identity even at temperatures <900 °C. High DEs, however, do not necessarily ensure the absence of emissions of fluoroorganic PICs. Evacuated canisters were used to look for some known[21−23] and suspected PICs. The current method under development at the EPA can measure the 30 vPFAS listed in Table 3. The reporting limits for 29 of these compounds is 0.5 ppbv, while tetrafluoromethane (CF_4) is limited to 50 ppbv. These are high values with respect to OTM-45 (∼pptv concentrations), and current efforts are focused on lowering these limits of quantitation. This method was used during the AFFF incineration experiments, and the results, presented in $\mu g/m^3$, are shown in Table 3. At AFFF injection locations >1090 °C, the PIC data show very little vPFAS at the current detection limits, but as the AFFF injection temperatures fall below 1000 °C, the vPFAS increase considerably to mg/m^3 levels. The increase in vPFAS also coincides with elevated CO concentrations rising from single digit levels up to ∼1700 ppmv (see Table 3). Increases in CO were the result of incomplete PFAS oxidation and not associated with the natural gas combustion, as the AFFF experiments with high CO were injected postflame long after natural gas combustion was complete.

An important finding from Table 3 is the notable emissions of relatively high concentrations (∼mg/m^3) of all eight 1*H*-perfluoroalkanes (C1−C8) during the 810 °C injection experiment. These vPFAS are expected to be formed during the thermolysis of the PFCAs or PFSAs under both pyrolytic and oxidative conditions.[21−23,43,45,47] The fluorocarbon concentrations increase with decreasing fluoroalkyl chain length, with fluoroform (CHF_3) and pentafluoroethane (C_2HF_5) present at 810 °C, at concentrations of 7.5 and 9.0 mg/m^3, respectively. 1*H*-Perfluorooctane (C_8HF_{17}) and 1*H*-perfluoroheptane (C_7HF_{15}) concentrations were significantly lower (0.2 and 0.3 mg/m^3, respectively), possibly indicating a mechanistic pathway of incremental α or β carbon removal. Tetrafluoroethylene (C_2F_4) concentrations are relatively low (∼0.15 mg/m^3), perhaps suggesting that a mechanism where C_2F_4 is formed[48,49] by β carbon scission is less important under oxidative conditions.

Note that similar results have been both experimentally and computationally derived under pyrolytic and oxidative conditions. Thermolysis often yields 1*H*-perfluorocarbons and 1-perfluoroalkenes with PFCAs,[21−23,47,50,51] with PFSAs forming the same compounds[52] as well as perfluorocarbons.[47,53] Computational studies predict similar products[43−46,48] using various computational methods. All the referenced models have a lactone or sulfone intermediate with HF elimination as the first step to the loss of the functional group. After the removal of the functional group, the steps to formations of nonpolar intermediates, including the breaking of carbon−carbon and carbon−fluorine bonds, are all relatively low energy steps. These steps involve unimolecular decomposition, hydrofluorination, hydrolysis, and fragmentation of the alkyl chain. A prominent and potentially important intermediate are acyl fluorides since these can readily be hydrolyzed to carboxylic acids, as suspected in this study. Altarawneh[43] examined the temperature sensitivity of PFBS destruction from 500 to 2000 K and indicated that PFBS is destroyed at low temperatures but can create fluorinated PICs at temperatures up to 1127 °C. These studies examined different conditions than the present study, but still the similarities are remarkable and provide further support that high DEs are not necessarily indicative of the absence of PICs.

HF concentrations presented in Table 3 were not validated because no accompanying CEM measurement was available. Subsequent attempts at Method 320 validation were unsuccessful due to poor HF transport efficiencies and subsequent poor calibration gas recoveries. Additionally, the measured HF concentrations were typically observed to rise throughout the duration of an experiment indicating the HF was not yet at equilibrium with the reactive surfaces of the furnace. The HF values are included for perspective to indicate approximate HF concentrations based on the amounts of AFFF introduced. Note that NO values decrease with decreasing AFFF injection temperatures. This behavior is not fully understood but may be related to selective noncatalytic reduction (SNCR) technologies used for the control of nitrogen oxides.[54−56] SNCR decreases NO concentrations in combustion effluents by reactions with added ammonia, ammonia derivatives, or urea to the combustion gases at temperatures between 700 and 1000 °C. AFFF is known to contain percent levels of amines, sulfonamides, and amides, and these may be acting to reduce the NO concentrations as the AFFF injection temperatures fall below 1000 °C. Efforts to improve confidence in FTIR measurements including HF and NO are ongoing.

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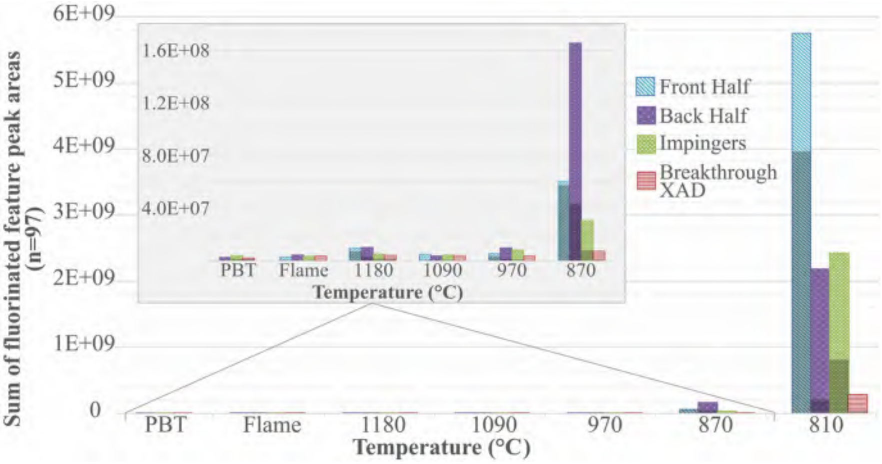

Figure 2. Sums of the peak areas of fluorinated features observed with nontargeted analyses of the OTM-45 extracts. Each fraction of the sampling train is shown for each temperature. The darkened portion of each bar is the sum of the targeted compounds' peak areas, included to show how well the targeted list covers the observed PFAS.

Nontargeted PFAS Emissions. Additional mass spectra analysis of the OTM-45 extracts revealed there were up to 92 features that indicated the presence of different semivolatile polar PFAS. Figure 2 presents the sum of the peak areas for these 92 fluorinated species for the six combustion experiments and the PBT. Where the peak area of a feature was very low, an arbitrary value was given to the peak to allow for statistical analysis by the software. This artificially makes the peak areas for fluorinated features in the blanks and some low detection samples higher than what they may actually be. Figure 2 does not correct for this, and again near blank levels may indicate the nontargeted peak areas are below detection limits. Figure 2 presents separate analysis for four OTM-45 sample fractions: front half (filter and probe rinse), back half (XAD-2 sorbent), impinger solutions, and a second volume of XAD-2 sorbent to quantify the potential for sample breakthrough. The NTA peak areas in Figure 2 are separated between those corresponding to 36 targeted PFAS (lightly shaded) and 56 nontargeted (unidentified) PFAS found. The tentative formulas and chemical names for the nontargeted PFAS are listed in Table S5. These formulas and names are based on the MS1 molecular ion; the software occasionally picked compounds that do not contain fluorine. The MS2 spectra did show PFAS-like features and are included in Table S5. The 36 targeted PFAS are part of the other OTM-45 targeted list of PFAS shown in Table S2, and Figure 2 shows how much the total PFAS present are made up of these targeted compounds. It is apparent many of the compounds sampled during these experiments are not found in the OTM-45 list. As the temperature decreases the peak area of the OTM-45 fractions shift from the back half XAD having the most area to the front half, or filter, fraction having the most area at 810 °C. This is due to the large increase of sulfonates in the emissions, see Table 1, that preferentially adsorbed on the filter, and to a lesser extent an increase of PFCAs on the filter too.

Figure 2 presents these data on two linear scales. The larger plot includes the 810 °C experiment, and the inset excludes these data to allow better comparison of the other experimental results. NTA indicates additional unidentified semivolatile polar PFAS mass in addition to the 36 targeted PFAS in all sample fractions. However, like the volatile nonpolar PIC measurements, injection temperatures > 1000 °C do not result in NTA PFAS mass significantly above blank levels. Note that the NTA also shows the suspected hysteresis effect of performing the 1180 °C experiment after the 810 °C experiment. The NTA indicates increasing PFAS emissions at AFFF injection temperatures < 1000 °C and that unidentified PFAS comprise a portion of these emissions.

■ CONCLUSIONS

The functional groups of many PFAS, and perhaps many PFAS of industrial importance, can be removed at temperatures which do not fully mineralize the fluorinated chain. This would classify many industrial PFAS as Class 3 to Class 5 compounds on the U.S. EPA's Thermal Stability Index, where Class 1 is the most stable and Class 7 compounds are the least stable.[45] Despite the ranking of parent PFAS, subsequent fluorinated PICs formed are stable,[57] and the simple use of DEs as the sole indicator of complete PFAS destruction may be misleading. For some PFAS, relatively low energies are needed to remove the polar functional group, with the first step being the loss of the terminal C or S likely through a lactone or sulfone intermediate, leaving a nonpolar fluoroalkyl chain. If conditions prevent continuation of the destruction mechanisms, this may result in high DEs, >99.99%, but not necessarily the mineralization of the PFAS molecule. Here, complete destruction is defined as mineralization, which for a C, F, O, H system results in CO_2, HF, and H_2O. In these experiments, combustion conditions were examined that produced high DEs and measurable PICs. However, when AFFF was exposed to temperatures ≥1090 °C (including exposure to flames and near adiabatic flame temperatures), high DEs and near detection limit concentrations of relatively few vPFAS PICs were observed. Based on these experiments, high destruction of PFAS can be shown only by considering both high DEs and the absence of PICs.

Finally, note that these experiments focused on steady-state combustor operations. This was done to simplify the fluid dynamics and mixing behavior and allow a focus on the kinetic aspects. However, except for thermal oxidizers and some other steady-state liquid injection applications, HWIs (often rotary kilns) introduce wastes in multiple ways, including batch solids and contained liquids. These cause transient release of organics to the vapor phase that may temporarily overwhelm available oxygen and depress temperatures. For most HWIs, the afterburner is intended to dampen and smooth this transient behavior, but it is likely that the time dependent behavior of PFAS in HWIs and other batch fed systems will depend on the system's ability to smooth these transients and maintain high temperatures. More research into rotary kiln systems and full-scale incinerators is needed.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsestengg.3c00098.

> Additional combustor conditions, sampling setup, method information, analytical data, destruction efficiency calculation method, and analytical methods for nontargeted analysis (PDF)

■ AUTHOR INFORMATION

Corresponding Author

Erin P. Shields − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States;* orcid.org/0000-0002-9335-1074; Phone: 919-541-3521; Email: shields.erin@epa.gov

Authors

Jonathan D. Krug − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States;* orcid.org/0000-0002-7045-7650

William R. Roberson − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Stephen R. Jackson − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Marci G. Smeltz − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Matthew R. Allen − *Jacobs Technology Inc., Cary, North Carolina 27518, United States*

R. Preston Burnette − *Jacobs Technology Inc., Cary, North Carolina 27518, United States*

John T. Nash − *Jacobs Technology Inc., Cary, North Carolina 27518, United States*

Larry Virtaranta − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

William Preston − *CSS Inc., Durham, North Carolina 27713, United States*

Hannah K. Liberatore − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States;* orcid.org/0000-0001-7423-3251

M. Ariel Geer Wallace − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Jeffrey V. Ryan − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Peter H. Kariher − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Paul M. Lemieux − *Homeland Security and Materials Management Division, Center for Environmental Solutions and Emergency Response, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

William P. Linak − *Air Methods and Characterization Division, Center for Environmental Measurement and Modeling, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, United States*

Complete contact information is available at: https://pubs.acs.org/10.1021/acsestengg.3c00098

Author Contributions

CRediT: **Erin P Shields** conceptualization, data curation, formal analysis, methodology, writing-original draft, writing-review & editing; **William R Roberson** conceptualization, data curation, formal analysis, methodology, writing-review & editing; **Matthew R Allen** data curation, formal analysis, validation; **R. Preston Burnette** data curation, methodology; **John T Nash** data curation; **Larry Virtaranta** data curation, formal analysis; **M. Ariel Geer Wallace** formal analysis, writing-review & editing; **Jeffrey V. Ryan** conceptualization, formal analysis, methodology, validation; **Peter H. Kariher** data curation, formal analysis; **William P. Linak** conceptualization, writing-original draft, writing-review & editing.

Notes

The research described in this article has been reviewed by the U.S. EPA Center for Environmental Measurement and Modeling and approved for publication. The contents of this article should not be construed to represent Agency policy nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The authors declare no competing financial interest.

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Supporting Information:

Pilot-Scale Thermal Destruction of Per- and Polyfluoroalkyl Substances in a Legacy Aqueous Film Forming Foam

Erin P. Shields[1], Jonathan D. Krug[1], William R. Roberson[1], Stephen R. Jackson[1], Marci G. Smeltz[1], Matthew R. Allen[2], R. Preston Burnette[2], John T. Nash[2], Larry Virtaranta[1], William Preston[3], Hannah K. Liberatore[1], M. Ariel Geer Wallace[1], Jeffrey V. Ryan[1], Peter H. Kariher[1], Paul M. Lemieux[4], William P. Linak[1]

[1]U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Measurement and Modeling, Air Methods and Characterization Division, 109 T.W. Alexander Dr., Research Triangle Park, NC, 27711, USA

[2]Jacobs Technology Inc., Cary, NC, 27518, USA

[3]CSS Inc., Durham, NC, 27713, USA

[4]U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Solutions and Emergency Response, Homeland Security and Materials Management Division, 109 T.W. Alexander Dr., Research Triangle Park, NC, 27711, USA

S1. Pilot-scale furnace description

The refractory-lined natural gas-fired combustor, Rainbow furnace, is rated for a peak load of 85 kW but is typically operated at reduced loads. However, even at 64 kW and a stoichiometric ratio (SR) of 1.2, post flame temperatures exceed 1400 °C (~2560 °F) and gas temperatures over 1000 °C (>1800 °F) are maintained for ~3 s[1-3]. Typically, commercial hazardous waste incinerators (HWIs) are required to maintain gas-phase temperatures between 980-1200 °C (1800-2200 °F) for a minimum of 2 s.

Figure S1 shows the temperature distributions measured by a combination of suction pyrometer and ceramic shielded thermocouples along the length of the furnace. This length scale has been converted to a calculated gas residence time using input flow rates, discretizing the Rainbow furnace volume between ports, and calculating temperature-corrected volumetric flow rates and incremental residence times for each section. Incremental residence times were then summed along the length of the furnace. The peak temperatures at the injection locations and the furnace conditions measured by the emission monitoring instrumentation are shown in Table S1.

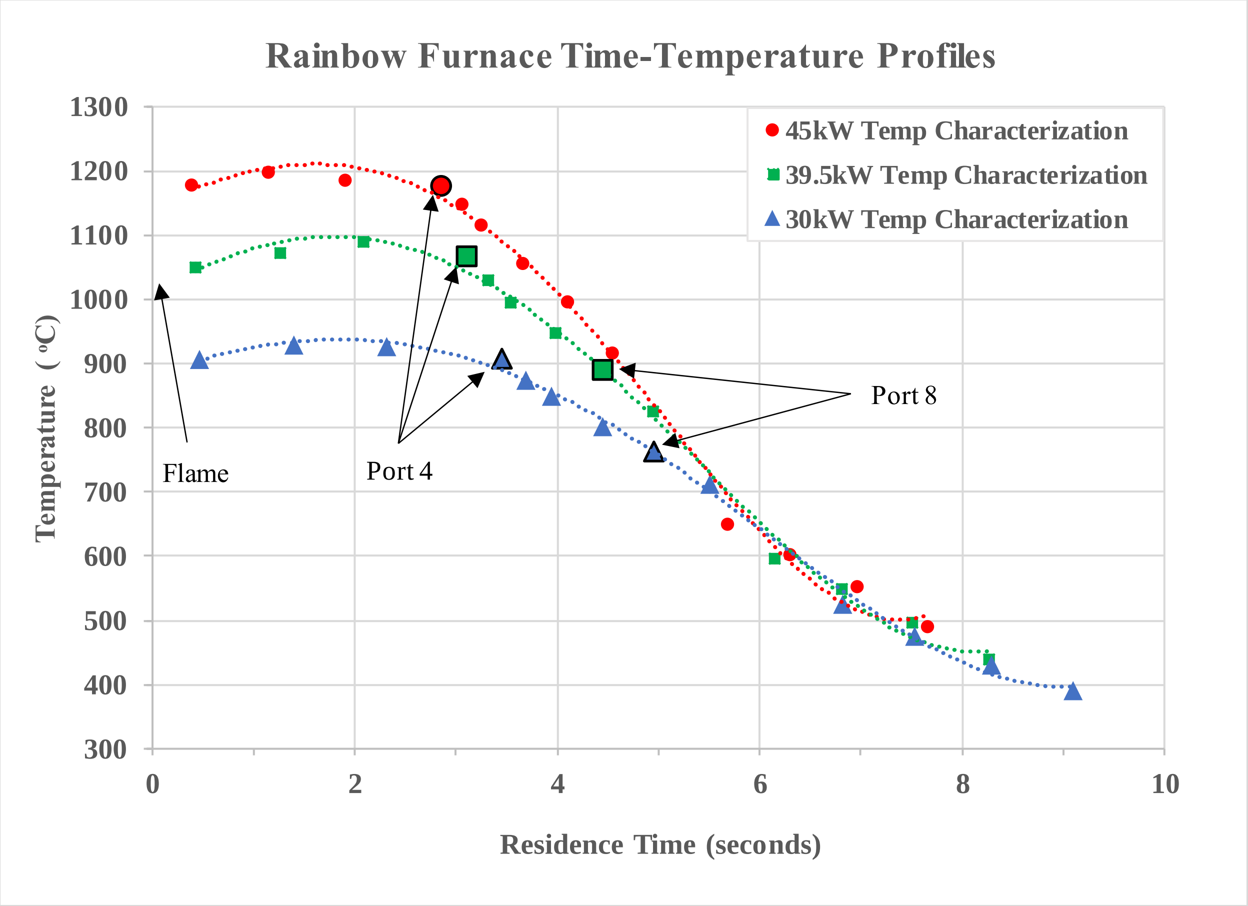

Figure S1: Temperature/residence time profiles for three experimental conditions: (▲) 30 kW natural gas, SR=2.0, (■) 39.5 kW natural gas, SR=1.5, (●) 45 kW natural gas, SR=1.3. The markers indicate the measured temperatures.

Table S1: Furnace conditions for each temperature condition

Furnace setting, firing rate, FR	Thermal load, kW	Stoich. ratio, SR	NG flow rate, L/min	Air flow rate, L/min	Injection location	Port temperature[1], °C	AFFF feed rate, mL/min	Atomizing air flow rate, L/min	Injector sweep air 1 flow rate[2], L/min	Injector sweep air 2 flow rate[2], L/min	AFFF feed rate, g/min
1	30	2.0	48.7	920.3	Port 4	870	13.3	10.0	20	10	13.5
1	30	2.0	48.7	920.3	Port 8	810	13.3	10.0	20	10	13.5
2	39.5	1.5	64.0	906.1	Flame	1963[3]	16.2	10.0	20	10	16.4
2	39.5	1.5	64.0	906.1	Port 4	1090	13.2	10.0	20	10	13.5
2	39.5	1.5	64.0	906.1	Port 8	970	13.2	10.0	20	10	13.5
3	45	1.3	72.5	900.5	Port 4	1180	13.3	10.0	20	10	13.5

[1] Port temperatures were measured before atomization injector insertion, and do not include any localized temperature depression caused by the AFFF, atomizing air and the two injector sweep airs. These additional volumes add ~4% to the total combustion gas volumetric flow.

[2] Injector sweep air (1&2) are introduced co-centrically around the AFFF and atomizing air to minimize heating and thermal degradation of the AFFF within the atomizing injector.

[3] Calculated methane-air adiabatic flame temperature.

S2. AFFF/emissions characterization

Table S2: OTM-45 PFAS target list[4]

Common Name[a]	**Abbreviated Name**	**CAS[b] Registry Number**
Perfluorobutanoic acid[1,3,4,6]	PFBA	375-22-4
Perfluoropentanoic acid[1,3,4,6]	PFPeA	2706-90-3
Perfluorohexanoic acid[1,2,3,4,6]	PFHxA	307-24-4
Perfluoroheptanoic acid[1,2,3,4,6]	PFHpA	375-85-9
Perfluorooctanoic acid[1,2,3,4,6]	PFOA	335-67-1
Perfluorononanoic acid[1,2,3,4,6]	PFNA	375-95-1
Perfluorodecanoic acid[1,2,3,4,6]	PFDA	335-76-2
Perfluoroundecanoic acid[1,2,3,4,6]	PFUnDA	2058-94-8
Perfluorododecanoic acid[1,2,3,4,6]	PFDoA	307-55-1
Perfluorotridecanoic acid[2,3,4,6]	PFTrDA	72629-94-8
Perfluorotetradecanoic acid[2,3,4]	PFTeDA	376-06-7
Perfluoro-n-hexadecanoic acid	PFHxDA	67905-19-5
Perfluoro-n-octadecanoic acid	PFODA	16517-11-6
Perfluoro-1-butanesulfonic acid[1,2,3,4,6]	PFBS	375-73-5
Perfluoro-1-pentanesulfonic acid[1,3,6]	PFPeS	2706-91-4
Perfluoro-1 -hexanesulfonic acid[1,2,3,4,6]	PFHxS	355-46-4
Perfluoro-1-heptanesulfonic acid[1,3,6]	PFHpS	375-92-8
Perfluoro-1-octanesulfonic acid[1,2,3,4,6]	PFOS	1763-23-1

Perfluoro-1-nonanesulfonic acid[3,6]	PFNS	68259-12-1
Perfluoro-1-decanesulfonic acid[3,6]	PFDS	335-77-3
Perfluorododecane sulfonate	PFDoS	79780-39-5
Perfluoro-1-octanesulfonamide[3,5,6]	FOSA	754-91-6
N-Methylperfluorooctanesulfonamide [5]	MeFOSA	31506-32-8
N-ethylperfluorooctanesulfonamide [5]	EtFOSA	4151-50-2
2-(N-methylperfluoro-1-octanesulfonamido)-ethanol [5]	N-MeFOSE	24448-09-7
2-(N-ethylperfluoro-1-octanesulfonamido)-ethanol [5]	N-EtFOSE	1691-99-2
N-methyl perfluorooctanesulfonamidoacetic acid[2,3,6]	MeFOSAA	2355-31-9
N-ethyl perfluorooctanesulfonamidoacetic acid[2,3,6]	EtFOSAA	2991-50-6
1H,1H,2H,2H-Perfluorohexane sulfonic acid[1,3,6]	4:2 FTS	757124-72-4
1H,1H,2H,2H -Perfluorooctane sulfonic acid[1,3,6]	6:2 FTS	27619-97-2
1H,1H,2H,2H -Perfluorodecane sulfonic acid[1,3,6]	8:2 FTS	39108-34-4
1H,1H,2H,2H-perfluorododecane sulfonate (10:2)	10:2 FTS	120226-60-0
4,8-Dioxa-3H-perfluorononanoic acid[6]	ADONA[1]	919005-14-4
Hexafluoropropylene Oxide Dimer Acid[6]	HFPO-DA (GenX)[1]	13252-13-6
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid[6]	9Cl-PF3ONS (F-53B Major)[1]	756426-58-1
11-Chloroeicosafluoro-3-oxaundecane-1-sulfonic acid[6]	11Cl-PF3OUdS	763051-92-9
Nonafluoro-3,6-dioxaheptanoic acid[1,5]	NFDHA	151772-58-6
Perfluoro(2-ethoxyethane)sulfonic acid[1,5]	PFEESA	113507-82-7
Perfluoro-4-methoxybutanoic acid[1,5]	PFMBA	863090-89-5
Perfluoro-3-methoxypropanoic acid[1,5]	PFMPA	377-73-1
Decafluoro-4-(pentafluoroethyl)cyclohexanesulfonate[4]	PFecHS	67584-42-3
2H-perfluoro-2-decenoic acid[4]	8:2 FTUCA or FOUEA	70887-84-2
2-perfluorodecyl ethanoic acid[4]	10:2 FDEA	53826-13-4
2-perfluorooctyl ethanoic acid[4]	8:2 FTA or FOEA	27854-31-5
2H-perfluoro-2-octenoic acid[4]	6:2 FHUEA	70887-88-6
2-perfluorohexyl ethanoic acid[4]	6:2FTCA or 6:2 FHEA	53826-12-3
3:3 Fluorotelomer carboxylic acid [5]	3:3 FTCA	356-02-5
5:3 Fluorotelomer carboxylic acid [5]	5:3 FTCA	914637-49-3
7:3 Fluorotelomer carboxylic acid or 3-perfluoropheptyl propanoic acid[4, 5]	7:3 FTCA or FHpPA	812-70-4

a This method measures all forms of the analytes as anions while the identity of the counterion is inconsequential. Analytes may be purchased as acids or as any of the corresponding salts

b Chemical Abstract Service.

1 Compound targeted in EPA Method 533

2 Compound targeted in EPA Method 537.1

3 Compound targeted in EPA Method 8327

4 Compound targeted in ASTM Method D7968
5 Compound targeted in DoD Isotope Dilution Method
6 Compound targeted in AFFF analysis used for this study

Table S3: PFAS-like MS2 fragments used to identify likely PFAS compounds\

m/z	Formula	m/z	Formula
62.98878	C F O2	186.9824	C5 F5 O2
68.99576	C F3	192.9894	C5 F7
70.99387	C3 F O	198.9494	C2 F5 O3 S
82.96085	F O2 S	216.9894	C7 F7
84.99067	C F3 O	218.9862	C4 F9
92.99576	C3 F3	220.9843	C6 F7 O
96.99067	C2 F3 O	229.9472	C3 F6 O3 S
98.95577	F O3 S	234.9811	C4 F9 O
104.9958	C4 F3	242.9862	C6 F9
112.9856	C2 F3 O2	254.9862	C7 F9
116.9969	C2 H F4 O	262.976	C5 F9 O2
118.9926	C2 F5	268.983	C5 F11
120.9907	C4 F3 O	282.9811	C8 F9 O
130.9926	C3 F5	284.9779	C5 F11 O
134.9875	C2 F5 O	292.983	C7 F11
142.9926	C4 F5	302.9873	C8 H F10 O
146.9875	C3 F5 O	314.9379	C4 F9 O4 S
154.9926	C5 F5	322.9936	C8 H2 F11 O
166.9926	C6 F5	328.9677	C6 F11 O3
168.9894	C3 F7	376.9525	C6 F11 O6
178.9773	C3 F5 O3	442.9264	C7 F13 O5 S
180.9894	C4 F7	442.9442	C7 F13 O7
184.9843	C3 F7 O	499.9375	C8 H F17 O3 S

The targeted PFAS found in the legacy AFFF used in this study are shown in Table S4. The concentrations were determined by a commercial laboratory according to methods derived from EPA Method 533[5]. This AFFF is a concentrate containing approximately 70% water, 20% diethylene glycol monobutyl ether, 0.5-1.5% triethanolamine, 1-5% PFAS, and the rest mainly being alkyl-based surfactants[6]. The sample was analyzed for the PFAS denoted by the superscript 6 in Table S2, of which these 10 were found that were in previous analyses and were quantified sufficiently above detection limits to allow destruction efficiencies (DEs) to be calculated. Evident from Table S4 is the presence of five perfluorinated carboxylic acids (C4 to C8) and five perfluorinated sulfonic acids (C4 to C8) with PFHxS and PFOS comprising over 90% of the PFAS mass. The units were converted to ng/g to allow the mass injected calculations to be simplified. The amount of organic fluoride from the targeted PFAS is listed as the targeted organic fluorine. The likely total organic value is about twice this value due to the zwitterionic and other nontargeted PFAS, and is the value used for predicting HF concentrations.

Table S4: Results of targeted PFAS and total organic fluorine analyses of the AFFF

Compound	**ppb (ng/g)**	**weight %**
Perfluorobutanoic acid (PFBA)	6850	0.000685
Perfluorobutanesulfonic acid (PFBS)	202000	0.0202
Perfluoropentanoic acid (PFPeA)	34100	0.00341
Perfluoropentanesulfonic acid (PFPeS)	164000	0.0164
Perfluorohexanoic acid (PFHxA)	111000	0.0111
Perfluorohexanesulfonic acid (PFHxS)	1180000	0.118
Perfluoroheptanoic acid (PFHpA)	31600	0.00316
Perfluoroheptanesulfonic acid (PFHpS)	136000	0.0136
Perfluorooctanoic acid (PFOA)	123000	0.0123
Perfluorooctanesulfonic acid (PFOS)	8020000	0.802
Targeted Organic Fluorine	6410000	-

Table S5: Nontargeted molecular ions' m/z, tentative formulas, and tentative compound names

Name	**Formula**	**m/z**
1-Pentafluorophenyl-pyrrole-2,5-dione	C10 H2 F5 N O2	261.99441
2,2,3,3,4,4,5,5,6,6,7,7-Dodecafluoro-1,8-diisocyanatooctane	C10 H4 F12 N2 O2	411.00041
Disodium 2-oxo-4-(trifluoromethyl)-2H-1-benzopyran-7-yl phosphate	C10 H6 F3 O6 P	308.9775
	C12 H F13 N9 O5 P	627.95581
[1-2,2-2,2-5,3-2-Terthiophene]-2-3-,2-4-diamine	C12 H10 N2 S3	276.99387
1-[4-Bromo-3-(trifluoromethyl)benzene-1-sulfonyl]piperidine	C12 H13 Br F3 N O2 S	369.97336
6-(3-Bromophenyl)-4-(ethylsulfanyl)-4,5-dihydropyridazin-3(2H)-one	C12 H13 Br N2 O S	310.98689
10:2 Fluorotelomer sulfonic acid	C12 H5 F21 O3 S	626.95259
Harmine	C13 H12 N2 O	211.08688
Peroxide, bis[(undecafluorocyclohexyl)carbonyl]	C14 F22 O4	648.93475
3-(4-Bromophenyl)-7-chloroquinazoline-2,4(1H,3H)-dione	C14 H8 Br Cl N2 O2	348.93907
	C14 H9 F20 O10 P	746.9535
Bisphenol AF	C15 H10 F6 O2	335.0507
carbamazepine-d10	C15 H2 [2]H10 N2 O	244.98545
3-(4-Bromophenyl)-1-[4-(methanesulfonyl)phenyl]prop-2-en-1-one	C16 H13 Br O3 S	318.97922
Dimethyl (2-iodoethenyl)(3-phenylprop-2-en-1-yl)propanedioate	C16 H17 I O4	399.0092
Pentafluoroethanesulfonate	C2 H F5 O3 S	198.94941
Thallium, chlorodimethyl-	C2 H6 Cl Tl	268.98284
Tris[3,5-bis(trifluoromethyl)phenyl](oxo)-lambda~5~-phosphane	C24 H9 F18 O P	685.00612
1,1,1,3,3,3-Hexafluoropropan-2-one, oxime	C3 H F6 N O	179.98895

perfluoropropane sulfonate;perfluoropropane sulfonate	C3 H F7 O3 S	248.94613
1,1,1,3,3,3-Hexafluoropropane-2,2-diol	C3 H2 F6 O2	366.98368
2,2,3-Trifluoro-3-(1,1,2,2-tetrafluoroethyl)oxirane	C4 H F7 O	196.98428
Copper(1+) 1,1,2,2,3,3,4,4,4-nonafluorobutan-1-ide	C4 H F9	218.98613
O-Propan-2-yl methylphosphonodithioate	C4 H11 O P S2	168.99181
1,1,1,3,3,4,4,4-Octafluoro-2-(trifluoromethyl)-2-butanol	C5 H F11 O	284.97719
2,2-Difluoro-5-(trifluoromethyl)furan-3(2H)-one	C5 H F5 O2	186.98239
2-coumarate	C9 H8 O3	163.03999
Cyclopentene, 1,3,3,4,4,5,5-heptafluoro-	C5 H F7	192.98934
2,2,3,3,4,4,5,5,6-Nonafluorooxane	C5 H F9 O	246.98104
1-(Difluoromethyl)-3-methyl-1,3-dihydro-2H-imidazole-2-thione	C5 H6 F2 N2 S	163.01417
	C5 H9 N7 O15 P2 S	499.92984
Perfluorohexane dienoic acid	C6 H F7 O2	236.97909
3,3,4,4,5,5,6,6,6-Nonafluorohex-1-yne	C6 H F9	242.98606
Unsatudared Perfluoro-n-butyloxy methanoic acid	C6 H F9 O3	246.98104
Acethion acid	C6 H13 O4 P S2	242.99215
2-hydroxybutane-1,4-diyl dimethanesulfonate	C6 H14 O7 S2	261.01032
4,4,5,5,6,6-Hexafluorohex-2-ynoic acid	C6 H2 F6 O2	218.98854
2,6-Dioxo-1,2,3,6-tetrahydro-9H-purine-9-carbonyl chloride	C6 H3 Cl N4 O3	212.98146
5-Fluoro-1-methyl-3-(trifluoromethyl)-1H-pyrazole-4-carboxylic acid	C6 H4 F4 N2 O2	211.01365
3-Nitrophenyl azide	C6 H4 N4 O2	163.02615
3-bromo-5-methylthiophene-2-carboxylic acid	C6 H5 Br O2 S	218.91197
Perfluoroheptanesulfonate	C7 H F15 O3 S	448.9332
Perfluoroheptane dienoic acid	C7 H F9 O2	286.97577
2,2-Dichloro-3-[(propan-2-yl)oxy]cyclopropane-1-carboxylic acid	C7 H10 Cl2 O3	210.99364
2,2,3,3,4,4,5,5,6,6,7,7,7-Tridecafluoroheptanimidamide	C7 H3 F13 N2	361.00329
Perfluorooctane dienoic acid	C8 H F11 O2	336.97218
1-Iodo-3-[2-(2-methoxyethoxy)ethoxy]prop-1-yne	C8 H13 I O3	282.98454
(6E)-1,1,2,2,3,3,4,4,5,6,7,8,8,8-tetradecafluorooct-6-ene-1-sulfonic acid	C8 H2 F14 O3 S	442.94246
2,2,3,3,4,4,5,5-Octafluoro-1,6-diisocyanatohexane	C8 H4 F8 N2 O2	311.00683
N,N-Dimethylselenobenzamide	C9 H11 N Se	211.99765
Pseudouridine	C9 H12 N2 O6	243.06239
Epinine 4-O-sulfate	C9 H13 N O5 S	246.0441
Xestostreptin	C9 H14 N2 O3	197.09312
Azelaicacid	C9 H16 O4	187.09755
2-(2,4-Dichloro-5-nitrophenyl)-5-methyl-1,2-dihydro-3H-1,2,4-triazol-3-one	C9 H6 Cl2 N4 O3	286.97585

S3. AFFF injection considerations

HWIs use a variety of methods to introduce wastes, and not all include flame contact and possible interaction with flame generated radicals that exist near flames. Wastes are commonly injected through lances post-flame or introduced as solids or in containers away from a flame. On the pilot-scale incinerator, Port 4 and Port 8 injection locations are intended to explore this behavior where unimolecular thermal decomposition mechanisms likely control PFAS destruction. Table S1 includes the measured temperatures corresponding to these ports and furnace operating conditions. These temperatures were measured before AFFF atomization using the same port, and do not include any localized temperature reduction caused by the AFFF, atomization air, and two sweep air flows. However, including the atomization air, the added air flow is a relatively small (~4%) percentage of the total combustion gas flow, and unlikely to reduce temperatures greatly. In fact, temperature measurements taken one port below the injection port while atomizing AFFF indicated small temperature increases (~20 °C) presumably from the oxidation of surfactants and other organic constituents in the AFFF. While flame temperature measurements in this experimental system are not possible, adiabatic flame temperatures can be calculated. In diffusion flames, peak temperatures exist at the flame front where stoichiometric quantities of fuel and oxygen diffuse together and react. Assuming no heat loss (adiabatic), a temperature can be calculated within this localized stoichiometric reaction volume. For methane-air, the adiabatic flame temperature is 1963 °C. In practical systems, this localized heat is quickly transferred to the surroundings reducing bulk gas temperatures, but for PFAS introduced with the fuel through a diffusion flame, very high localized temperatures associated with the flame may be encountered. Also presented in Table S1 are the AFFF feed rates and flow rates for the atomizing air and two sweep air streams. AFFF feed rates were determined based on the PFAS composition (see Table S4), combustion and sampling volumetric flows, reasonable sampling times (3 hr), and analytical detection limits (DLs). We wanted to feed sufficient AFFF over the course of a 3 hr sample collection period to allow calculation of six 9s (99.9999%) DEs for all 10 PFAS at concentrations greater than the DLs. Note we specify DEs and not destruction and removal efficiencies (DREs) as our experimental system does not include particle or acid gas control systems. We wanted to characterize PFAS destruction without the complications of including possible transference from one media (air emissions) to solid (ash) or liquid (scrubber) discharges. However, exhausts from the Rainbow furnace and other research combustors are directed to a facility air pollution control system (APCS) that include an afterburner, water quench, baghouse, and sodium hydroxide (NaOH) wet scrubber. AFFF feed rates were also constrained by the desire to limit the stack concentration of HF below 300 ppm_v to limit potential damage to the furnace refractory and metal ducts.

S4. Destruction efficiency calculations

EPA Method 19[7] was used to calculate the DEs of the PFAS found in the AFFF. The DE was calculated using Method 19's equation 19-24 for the percent removal by thermal destruction (here the combustor), $\%R_g$, shown here as equation 1. The average pollutant rate at the inlet, E_{ai}, was calculated using Method 19's equation 19-7, shown as equation 2. The average pollutant rate at the outlet, E_{ao}, was calculated using Method 19's equation 19-9, shown as equation 3. Where C_w is the wet basis pollutant concentration (lb/scf), C_d is the dry basis pollutant concentration (lb/scf), F_c (equation 4) is the volume of combustion components per unit of heat content (992.07

scf/million Btu for FR1 and FR2, and 991.79 scf/million Btu for FR3), $\%CO_{2w}$ is the wet basis percent carbon dioxide, and B_{ws} is the percent moisture of the effluent gas. For these experiments the influent concentration of the PFAS was on a wet basis, while the effluent concentrations were on a dry basis since the water is removed from the samples during sampling and analyses.

$$\%R_g = 100\ [1.0 - (E_{ao}/E_{ai})] \qquad (1)$$

$$E_{ai} = C_w\ X\ F_c\ X\ 100/(\%CO_{2w}) \qquad (2)$$

$$E_{ao} = C_d\ X\ F_c(1\text{-}Bws)\ X\ 100/(\%CO_{2w}) \qquad (3)$$

$$F_c = K(K_{cc}{*}\%C)/GCV \qquad (4)$$

The variables for F_c are K, the conversion factor to million Btu, K_{cc} is (0.321 scf/lb)/%, $\%C$ is the percent carbon of the fuel, and GCV is gross calorific value of the fuel consistent with the ultimate analysis (Btu/lb).

S5. Non-targeted PFAS Instrumental Details

Chromatographic separation was performed using a Vanquish UPLC system (Thermo Fisher Scientific, Waltham, MA) and heated ACQQUITY BEH C18 column (2.1 mm x 50 mm x 1.7 um particles) at a flow rate of 300 uL/min, column temperature of 55 °C, injection volumes of 25 uL, and a binary mobile phase gradient composed of Solvent A (95:5 water:methanol with 2.5 mM ammonium acetate) and Solvent B (5:95 water:methanol with 2.5 mM ammonium acetate). A Restek PFAS delay column (50mm x 2.1mm x 5um particles) was installed between the mixing chamber and the analytical column to suppress background PFAS contaminants from the LC system. The separation gradient consisted as follows: 3 min pre-equilibration at 10% B, 0-15 min linear gradient from 10% - 100% B, and 15-20 min hold at 100% B.

Mass spectrometry analysis was conducted on Thermo Orbitrap Fusion mass spectrometer (Thermo Fisher Scientific, Waltham, MA) with a heated electrospray ionization (HESI) source operated in negative mode.

Ion source settings were as follows: Ion Source Type: H-ESI, Spray Voltage: Static, Negative Ion (V): 2000, Sheath Gas (Arb): 25, Aux Gas (Arb): 8, Sweep Gas (Arb): 2, Ion Transfer Tube Temp (°C): 325, Vaporizer Temp (°C): 300.

MS1 Orbitrap scan settings were as follows: Detector Type: Orbitrap, Orbitrap Resolution: 60,000, Mass Range: Normal, Use Quadrupole Isolation: True, Scan Range (m/z): 150-1500, RF Lens (%): 60, AGC Target: 4.0e5, Maximum Injection Time (ms): 50, Microscans: 1, Data Type: Profile, Polarity: Negative, Source Fragmentation: Disabled, Use EASY-IC™: True.

Data Dependent MS/MS acquisition filters were as follows: Dynamic Exclusion: Exclude after n times: 2, Exclusion duration (s): 5, Mass Tolerance: ppm, Low: 5, High: 5, Exclude Isotopes:

True; Apex Detection: Expected peak width (FWHM, s): 8, Desired Apex Window (%): 40; Intensity: Filter Type: Intensity Threshold, Minimum Intensity: 1.0e5.

MS2 Scans were conducted using the following settings: Isolation Mode: Quadrupole, Isolation Window (m/z): 1.5, Isolation Offset: Off, Activation Type: HCD, Collision Energy Mode: Assisted, HCD Collision Energies (%): 10,20,40, Detector Type: Orbitrap, Scan Range Mode: Auto: m/z Normal, Orbitrap Resolution: 15,000, AGC Target: 5.0e5, Inject Ions for All Available Parallelizable Time: False, Maximum Injection Time (ms): 22, Microscans: 1, Data Type: Profile, Use EASY-IC™: False.

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ATTACHMENT 9

TRACE ELEMENTS RELEASE AND PARTICULATE MATTER EMISSION DURING THE COMBUSTION OF CHAR AND VOLATILES FROM IN SITU BIOSOLID FAST PYROLYSIS

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Trace Elements Release and Particulate Matter Emission during the Combustion of Char and Volatiles from *In Situ* Biosolid Fast Pyrolysis

Sui Boon Liaw, Mohammad Usman Rahim, and Hongwei Wu*

Department of Chemical Engineering, Curtin University, GPO Box U1987, Perth Western Australia 6845, Australia

Supporting Information

ABSTRACT: This paper presents a systematic study on the emission of trace elements (e.g., As, Cu, Cr, Ni, V, Co, Cd, and Pb) during the combustion of char, volatiles, and biosolid at 1300 °C using a two-stage pyrolysis/combustion reactor system. Over 50% As, Cd, and Pb in biosolid are released with volatiles during fast pyrolysis at 800−1000 °C, while other elements are mostly retained in char. During biosolid combustion, PM_{10} consists of mainly major elements and the contribution of trace elements is <0.5 wt %. Particulate matter (PM) produced from the combustion of volatiles produced *in situ* from biosolid fast pyrolysis at 800−1000 °C is dominantly PM_1, contains only volatile elements (As, Cd, and Pb), and has a unimodal distribution with a fine mode diameter of 0.043 μm. Char combustion produces both PM_1 and PM_{1-10}, with the PM having a bimodal distribution (a fine mode at 0.043 μm and a course mode at 6.8 μm). It is also found that As, Cd, and Pb only contribute to PM_1 emission even during char combustion. While Ni, Co, Cu, and part of V are responsible for PM_{1-10} emission, most Cr and some V presented in char also contribute to PM_1 emission during char combustion. Significant differences are also observed in the PM between direct biosolid combustion and the sum of PM from char and volatile combustion. The results suggest that direct biosolid combustion may have produced substantially different char and volatiles, which may have experienced significant interactions during combustion.

1. INTRODUCTION

Combustion of biosolid from wastewater treatment plants is an important technical option for achieving large volume reduction, destruction of toxic organic compounds, and energy recovery from sludge.[1−3] Biosolids have high ash contents, and a large proportion of such inherent ash-forming species may be released with flue gas during combustion.[4,5] Particularly, the significant quantity of trace elements (e.g., As, Cu, Cr, Ni, V, Co, Cd, and Pb) in biosolids or sludge[6,7] can lead to the emissions of particulate matter that is known to be a health hazard.[8,9] Therefore, it is critical to understand the distribution of these trace elements in PM_{10} and also the fundamental mechanisms governing the emission of these trace elements in PM_{10}. As fuel particles (such as biosolids) are injected into a combustor, pyrolysis is the first step of the reactions that produce char and volatiles for combustion. The present understanding on the release of trace elements as part of PM_{10} emission from biosolid combustion is largely based on the results from the combustion of the whole biosolid. There have been no studies on the contribution of volatile combustion or char combustion alone to the emission of trace elements as part of PM_{10}. Recently, the same group first deployed a novel two-stage pyrolysis/combustion reactor for studying the combustion of biomass-derived products at 1300 °C, enabling the clarification of the release of major elements (including Na, K, Mg, Ca, S, and Cl) as PM during the combustion of biochar and also volatiles produced *in situ* from biomass pyrolysis.[10,11] This study continues the work using the novel two-stage pyrolysis/combustion reactor, with emphasis on the release of trace elements in PM_{10} during the combustion of char or volatiles produced from biosolids, which are rich in trace elements.

2. EXPERIMENTAL SECTION

2.1. Biosolid Sample. Biosolid was supplied by a local municipal wastewater treatment facility in Perth, Western Australia, Australia. The sample was dried at 105 °C for 24 h, ground in a mortar grinder (model Fritsch Pulverisette 2), and then sieved to the size fraction of 75−150 μm for use in subsequent experiments. The properties of the prepared biosolid sample are presented in Tables 1 and 2.

2.2. Combustion Experiments and Particulate Matter (PM) Sampling. The combustion of biosolid and its derived products (char or volatiles) was carried out in two different combustion reactor configurations (A and B) at 1300 °C, both of which were realized using a laboratory-scale drop-tube furnace (DTF). Schematic diagrams of the two reactor configurations are illustrated in Figure S1 of the Supporting Information. Configuration A (see Figure S1a of the Supporting Information) was used for the combustion of biosolid and char prepared from biosolid, similar to those used in previous studies.[10,12] In each experiment, fuel particles are fed into the reactor via a water-cooled feeding probe, using a stream of primary air (instrument grade, 1.0 L/min). An additional stream of secondary air (4.6 L/min) was also fed into the reactor for achieving complete combustion. A flow of helium (1 L/min) is introduced to the water-cooled sampling probe for rapid quenching of flue gas. The combustion flue gas was further diluted to a total flow rate of 10 L/min at 115 °C before the separation of coarse ash particles with an aerodynamic diameter of >10 μm using a cyclone (model Dekati Cyclone) and then separation and collection of PM_{10} into 14 size fractions using a Dekati low-pressure impactor (DLPI) coupled with a backup filter. The temperature of the sampling system is maintained at 115 °C to prevent condensation of acid gases.[12] Configuration B (see Figure S1b of the Supporting Information) enables the DTF system work as a two-stage pyrolysis/combustion reactor system that was

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Table 1. Fuel Properties of Biosolid Used in This Study

	proximate (wt %, db)			ultimate (wt %, daf[a])				
moisture[b] (wt %)	ash	VM[c]	FC[d]	C	H	N	S	O[e]
5.5	18.6	68.6	12.8	53.73	7.88	8.66	1.11	28.62

[a] daf = dry and ash free. [b] weight percent after air-dried. [c] VM = volatile matter. [d] FC = fixed carbon. [e] by difference.

Table 2. Contents of Major and Trace Elements in Biosolid, Expressed as mg/kg of Biosolid on a Dry Basis

major elements		trace elements	
Al	6811.6 ± 79.4	Cu	487.9 ± 3.2
Fe	3296.5 ± 53.8	As	2.933 ± 0.150
Na	1366.8 ± 6.7	Cr	33.421 ± 1.103
K	2181.5 ± 19.0	Ni	18.264 ± 0.134
Mg	4857.3 ± 57.8	V	6.688 ± 0.045
Ca	20434.3 ± 410.6	Co	3.266 ± 0.053
Cl	875.7 ± 4.8	Cd	2.473 ± 0.082
P	18105.1 ± 211.2	Pb	13.050 ± 1.322
S	8608.2 ± 82.2		
Si	19021.4 ± 629.4		

used for the combustion of volatiles produced *in situ* from the fast pyrolysis of biosolid. The reactor system was used in a previous study to investigate the transformation alkali and alkaline earth metallic species during the combustion of volatiles generated from mallee biomass.[11] Essentially, it cascades a novel quartz drop-tube/fixed-bed pyrolyser (see the zoom in subfigure in Figure S1b of the Supporting Information) as the first stage into a DTF as the second stage. Biosolid was fed into the quartz drop-tube/fixed-bed pyrolyser via a feeding tube using a stream of feeding gas (1.0 L/min of ultrahigh-purity argon), along with a second stream of pyrolysis gas (0.5 L/min of ultrahigh-purity argon) around the feeder. The volatiles produced *in situ* from biosolid rapid pyrolysis immediately passed through quartz frit and were injected into the second-stage DTF for combustion using a stream of air (instrument grade, 4.1 L/min). It should be noted that, as a result of the working temperature limit (~1100 °C) of the quartz reactor, this study considers the combustion of volatiles generated *in situ* from biosolid fast pyrolysis at 800, 900, and 1000 °C (denoted as "V-800 °C", "V-900 °C", and "V-1000 °C", respectively). The residence time of the biosolid particle in the DTF is estimated to be ~2 s.

A series of fast pyrolysis experiments were carried out separately with the same quartz reactor in a smaller vertical tube furnace, using the identical pyrolysis conditions used in the two-stage pyrolysis/combustion reactor system to obtain the char sample for the study of PM_{10} released from combustion of char in the DTF. The char samples obtained from pyrolysis of raw biosolid at 800, 900, and 1000 °C are denoted as "C-800 °C", "C-900 °C", and "C-1000 °C", respectively.

In all experiments, the sample feeding rate (biosolid or char) was adjusted to be an equivalent biosolid feeding rate of 0.05 g/min and the feeding continued for 30 min. Complete combustion was achieved because the thermogravimetric analysis (TGA) of PM samples suggests that the absence of unburned carbon and the leachates from the washing of PM samples using ultrapure water for 24 h contain negligible organic carbon. In this paper, PM with an aerodynamic diameter of less than 0.1 μm is referred to as $PM_{0.1}$, PM with an aerodynamic diameter between 0.1 and 1 μm is referred to as $PM_{0.1-1}$, PM with an aerodynamic diameter of less than 1 μm is referred to as PM_1, PM with an aerodynamic diameter between 1 and 10 μm is referred to as PM_{1-10}, and PM with an aerodynamic diameter of less than 10 μm is referred to as PM_{10}. All combustion experiments were conducted in at least duplicate to ensure the reproducibility.

2.3. Sample Analysis and Characterization. The proximate analysis of the biosolid sample was conducted using a thermogravimetric analyzer (model Mettler-Toledo Star 1) using the temperature specification detailed in ASTM E870-82. The C, H, and N contents of the biosolid sample was determined using an elemental analyzer (model PerkinElmer 2400 CHNS/O Series II). The Cl content of the biosolid and char samples was determined using an improved Eschka method.[13] For the quantification of major species in a sample (biosolid, char, or PM samples), the sample might be ashed, acid-digested, and then quantified by ion chromatography (IC, model Dionex ICS-3000) or inductively coupled plasma−atomic emission spectroscopy (ICP−OES, model PerkinElmer Optima 8300), following a procedure detailed elsewhere.[12] The trace elements (As, Cd, Pb, Cr, Co, Ni, Cu, and V) in the biosolid, char, or PM samples were quantified following another method detailed elsewhere[14] using inductively coupled plasma−mass spectroscopy (ICP−MS, model PerkinElmer NexION 350D).

3. RESULTS AND DISCUSSION

3.1. Partitioning of Trace Elements in Char and Volatiles during Biosolid Fast Pyrolysis. During the fast pyrolysis of biosolid at 800, 900, and 1000 °C, the char yields are insensitive to the pyrolysis temperature and remain relatively unchanged at 22 ± 1.5% [dry basis (db)]. The data suggest that biosolid pyrolysis have been completed under the reaction conditions. The partitioning of the major and trace elements into char and volatiles during biosolid fast pyrolysis under the conditions is presented in Figure 1. For the major elements, Figure 1a shows that ~20% Na and K in biosolid are released as part of the volatiles during pyrolysis at 800 °C and the release increases with pyrolysis temperature (e.g., ~30% at 1000 °C). The majorities (>90%) of other volatile elements (i.e., Cl and S) in biosolid are also released with volatiles. Especially, all Cl were released as part of volatiles, and there was

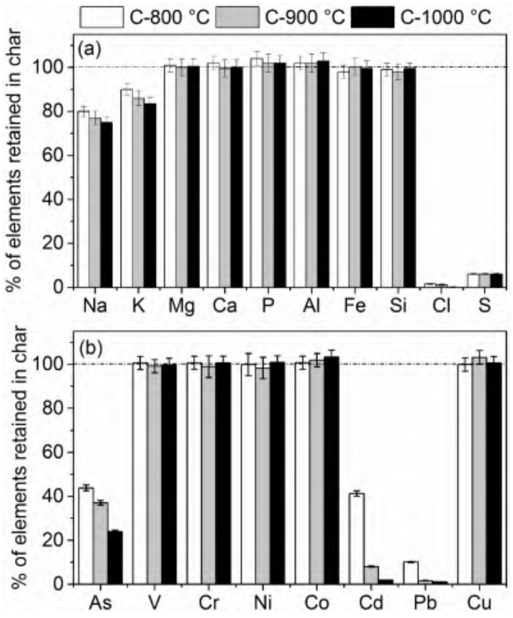

Figure 1. Retention of (a) major elements and (b) trace elements in char during the fast pyrolysis at 800−1000 °C, normalized to the total amount of the respective elements in the raw biosolid.

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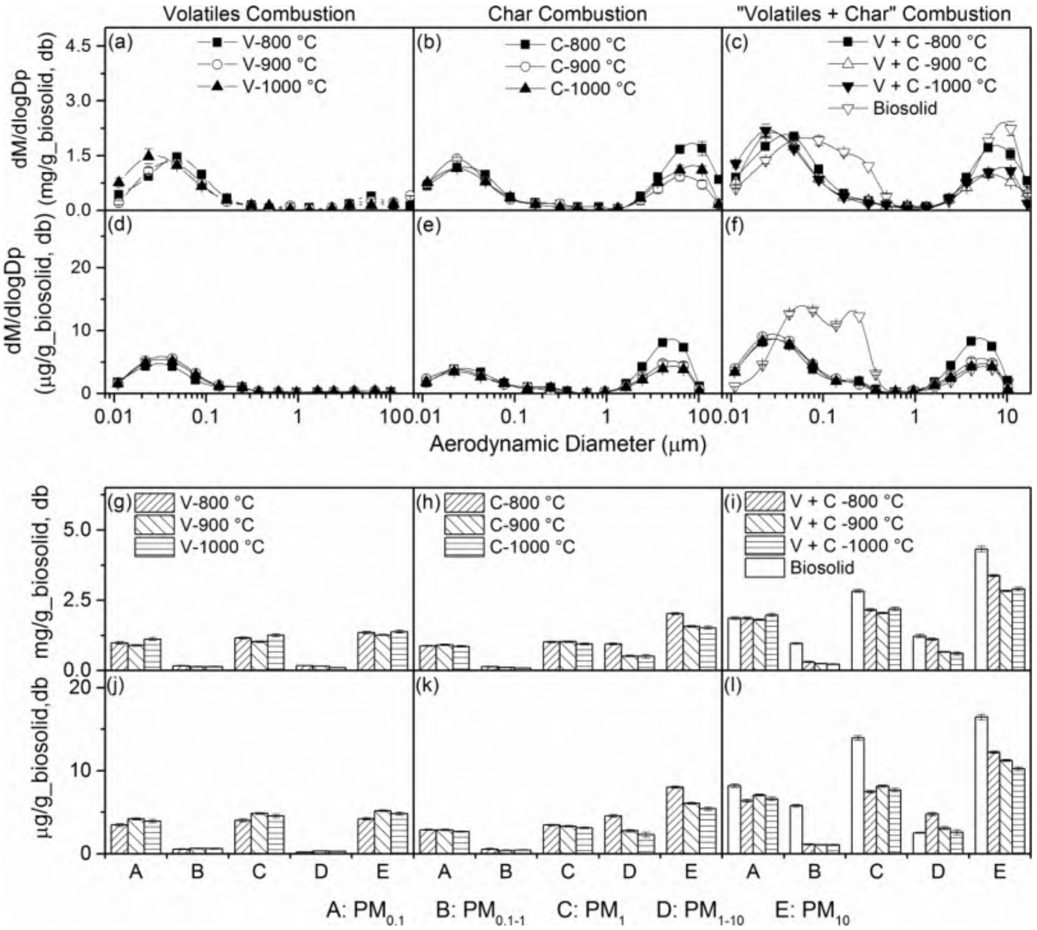

Figure 2. PSDs and yields of PM collected from the combustion of volatiles (first column), char (second column) and "volatiles + char" (third column, with comparison to those from the direct combustion of biosolid). Panels a−c, PSDs of total PM_{10} collected; panels d−f, PSDs of the total trace elements in PM_{10}; panels g−i, yield of the total $PM_{0.1}$, $PM_{0.1-1}$, PM_1, PM_{1-10}, and PM_{10} collected; and panels j−l, elemental yield of trace elements analyzed in $PM_{0.1}$, $PM_{0.1-1}$, PM_1, PM_{1-10}, and PM_{10} collected. The yield is normalized to those in the biosolid (db) input into the reactor.

virtually no Cl retained in char after biosolid pyrolysis at 1000 °C. However, the release of other major elements (P, Mg, Ca, Si, Fe, and Al that are less volatile[15]) are minimal during biosolid pyrolysis. As for the trace elements, substantial amounts of As, Cd, and Pb, which are known to be volatile,[16] are released during biosolid pyrolysis. The releases of these volatile elements also increase with the pyrolysis temperature. For example, ~56% of As is released at 800 °C, but the release increases to ~76% at 1000 °C. The releases of Cd and Pb are ~60 and 90% at 800 °C, respectively, but almost all Cd and Pb are released with volatiles at 900 °C or above. However, most other trace elements (V, Cr, Ni, Co, and Cu) are retained in the char, and the releases of these trace elements are minimal.

3.2. Yields and Particle Size Distributions (PSDs) of PM.

Figure 2 presents the PSDs of PM_{10} and the yields of $PM_{0.1}$, $PM_{0.1-1}$, PM_1, PM_{1-10}, and PM_{10} emitted during the combustion of char, volatiles, and biosolid, in terms of both total PM (panels a−c and g−i of Figure 2) and the PM contributed by the trace elements (panels d−f, and j−l of Figure 2). There are several important observations. First, the PSDs of the overall PM collected from the combustion of volatiles have a unimodal distribution with a fine mode diameter of ~0.043 μm (see Figure 2a). Almost all of the PM are PM_1 (actually $PM_{0.1}$), and little is in the form of PM_{1-10} (see Figure 2g). In contrast, the combustion of the biosolid char produces both PM_1 and PM_{1-10} (see Figure 2b) in the overall PM, resulting in a bimodal PSD of two distinct modes, i.e., a fine mode diameter of ~0.043 μm and a coarse mode diameter of ~6.8 μm. The results are consistent with our previous data on the overall PM emitted from the combustion of biochar and volatiles produced from the fast pyrolysis of mallee biomass.[10,11] Second, more interestingly, the PSDs of the PM contributed by trace elements during volatile combustion also only have a unimodal distribution at a fine mode diameter of ~0.043 μm (see Figure 2d), with almost all PM as PM_1 (actually $PM_{0.1}$) and little as PM_{1-10} (see Figure 2j). In comparison to those of the total PM, the PSDs of the PM contributed by trace elements during char combustions also have a bimodal distribution that has two distinct modes (i.e., a fine mode at ~0.043 μm and a coarse mode at ~6.8 μm). Third, a comparison between the yields of total PM (Figure 2g) and the PM contributed by trace elements (Figure 2j) suggests that the contribution of trace elements to the total PM is <0.5%.

Lastly, as shown in panels c, f, i, and l of Figure 2, it is important to note the significant differences in the PSDs and yields between the PM_{10} produced from the direct combustion of biosolid at 1300 °C and the PM_{10} calculated via summing those from the separate combustion of volatiles and char produced at different pyrolysis temperatures (800−1000 °C), i.e., the "v + c" cases in Figure 2. Notably, the direct combustion of raw biosolid produces substantially more PM_1

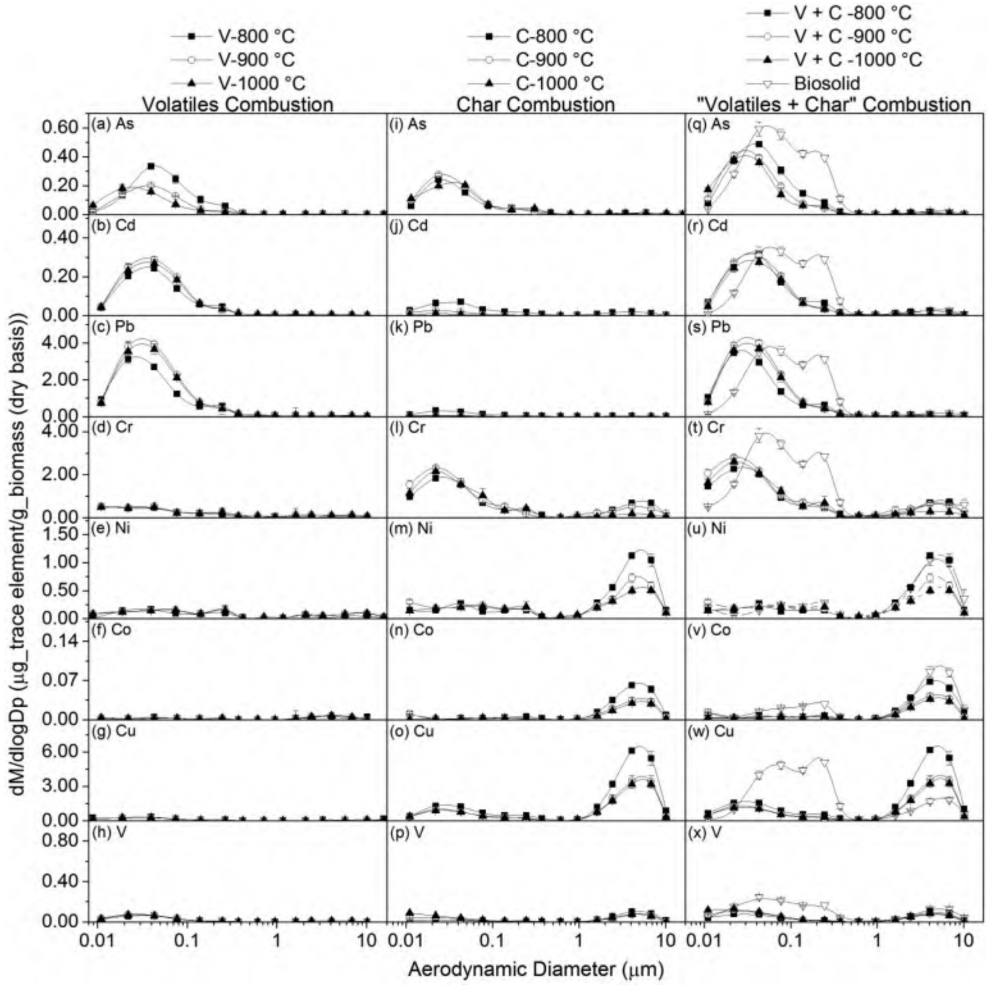

Figure 3. Distribution of trace elements in PM from combustion of (a−h) volatiles, (i−p) char, and (q−x) "volatiles + char" in comparison to direct combustion of biosolid.

compared to that in the "v + c" cases (see panels i and l of Figure 2) and also leads a shift of the fine mode to a larger mode diameter of ∼0.077 μm (see panels c and f of Figure 2). While the exact mechanisms are unknown at present, the higher PM_1 yields may be attributed to the considerably higher pyrolysis temperature (1300 °C) experienced by biosolid particles during its direct combustion than 800−1000 °C in the "v + c" cases. The shift in the fine mode diameter may be attributed to the mixed combustion of both volatiles and char during direct biosolid combustion. During the combustion of volatiles, PM_1 is formed mainly as a result of homogeneous nucleation and condensation, resulting in fine PM_1 (actually $PM_{0.1}$). However, during the direct combustion of biosolid, the presence of more fine particles as a result of char combustion would potentially lead to substantial heterogeneous condensations and, hence, the shift of PM_1 to a larger mode diameter. In addition, more intense char fragmentation would possibly take place during the direct combustion of biosolid compared to that during the combustion of char, which generally experiences a lower combustion temperature and, hence, less intense char fragmentation[17] than the direct combustion of biosolid. This would have contributed to more PM_{1-10} during the direct biosolid combustion than those from the "v + c" cases at pyrolysis temperatures of 900 and 1000 °C.

3.3. Elemental PSDs and Yields of Individual Trace Elements in PM_{10}.

Figure 3 presents the elemental PSDs and yields of individual trace elements in the PM emitted from the combustion of volatiles, char, and biosolid. The elemental yields of individual trace elements in $PM_{0.1}$, $PM_{0.1-1}$, PM_1, PM_{1-10}, and PM_{10} are presented in Figure 4. Several important observations can be made in Figures 3 and 4. First, as shown in panels a−h of Figures 3 and 4, during the combustion of volatiles produced *in situ* from biosolid pyrolysis, the trace elements in PM_1 are dominantly contributed by As, Pb, and Cd that are known to be volatile,[16] while the contributions of other trace elements (Cr, Ni, Co, Cu, and V) are minimal. This is consistent with the fact that only As, Pb, and Cd were released as part of volatiles during biosolid rapid pyrolysis under the conditions (see Figure 1b).

Second, as shown in panels i−p of Figures 3 and 4, the combustion of char contributes to both PM_1 and PM_{1-10}. Interestingly, the PM_1 emitted during char combustion also consists of dominantly As and Cr and a small amount of Pb and Cd. The contributions of other trace elements are minimal. Furthermore, panels b and c of Figure 4 show that the yield of Cd and Pb in PM_1 during volatile combustion increases with the pyrolysis temperature, coinciding with the opposite trends in the yield of Cd and Pb in PM_1 during char combustion. This is because a high pyrolysis temperature results in more Cd and Pb being released with volatiles but less retention of these trace elements in char (see Figure 1b). Figure 5 shows that ∼38% As in biosolid is water-soluble. The remaining As is like to be

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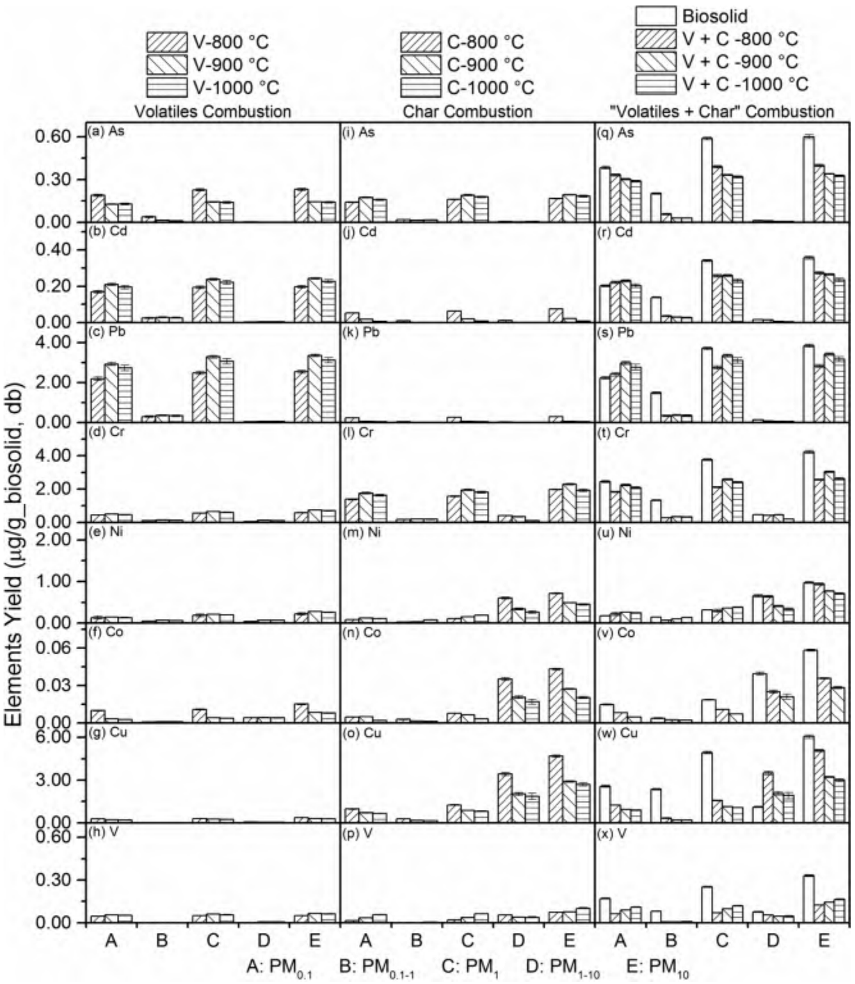

Figure 4. Yields of trace elements in $PM_{0.1}$, $PM_{0.1-1}$, PM_1, PM_{1-10}, and PM_{10} from the combustion of (a–h) volatiles, (i–p) char, and (q–x) "volatiles + char" in comparison to direct combustion of raw biosolid.

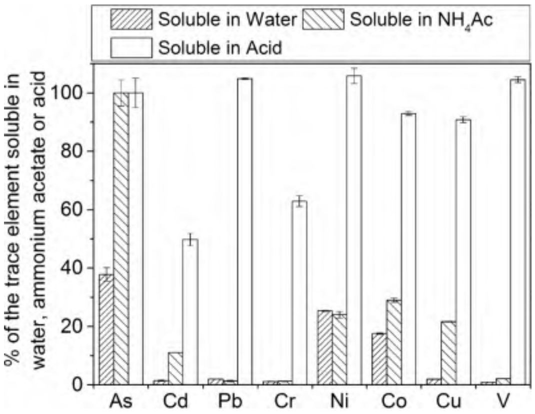

Figure 5. Percentage of trace elements in biosolid that are soluble in water, ammonium acetate, or acid.

bound to the organic structure of biosolid. Pyrolysis results in the release of water-soluble As (such as $AsCl_3$, which has a low boiling point) and part of the organic-bound As in volatile as AsO gas. It is also known that, with Ca (that is abundant in biosolid), As can form arsenate crystals that are stable at temperatures up to 1000 °C.[18] Therefore, As retained in char would be decomposed into AsO gas during char combustion at 1300 °C, contributing to PM_1 formation. On the other hand, Cd is mainly released in its elemental and/or chloride forms, while Pb is mainly released in the form of its oxides and chloride during pyrolysis.[18,19] Being mainly insoluble in biosolid (see Figure 5), Pb and Cd are unlikely present in the form of chlorides but released as chlorides after reacting with HCl in the gaseous phase during combustion.

Third, during char combustion, PM_{1-10} is mainly contributed by Cr, Ni, Co, Cu, and V (see panels i–p of Figure 3). However, there is some interesting behavior of these individual trace elements. For example, while also contributing to PM_{1-10}, Cr is mainly distributed in PM_1. Under oxidizing condition, Cr is mainly present in various forms of gaseous oxyhydroxides, such as CrO(OH), $CrO_2(OH)$, and $CrO(OH)_2$, at 1300 °C.[18,20] During pyrolysis under oxygen depletion conditions, Cr may be present in char as Cr_2O_5. Subsequent combustion leads to decomposition of Cr_2O_5 into gaseous oxyhydroxides and, hence, contribute to PM_1 emission. For Cu, panels g and o of Figure 3 show that it only contributes to PM_{1-10} emission during char combustion. However, this is completely different to the observation that Cu is dominantly distributed in PM_1 (~82%) during the direct combustion of biosolid. The shift of Cu distribution to PM_1 might be due to the release of Cu in its chloride form when reacting with HCl in volatiles during combustion because most Cu in biosolid is water-insoluble (see Figure 5). It is known that the presence of HCl may lead to the release of Cu as fine aerosol during combustion.[21] As Cl is depleted in char, Cu is likely to retain in ash in the form of oxides[19] and, hence, contributes to PM_{1-10} via char fragmentation during combustion. For Ni, panels e, m, and u of Figure 3 show that it only contributed to the formation of PM_{1-10}. Under oxidizing conditions and 1300 °C, Ni is expected to be present in the form of NiO, which remained as a crystal,[18] thus not volatilized during combustion. Similar to Ni, Co only contributed to PM_{1-10} formation and present in the form of a CoO crystal during combustion at 1300 °C. For V, it is mainly retained in char during pyrolysis (see Figure 1b), the combustion of volatiles leads to insignificant contribution of V to PM_1. However, the combustion of char lead to the formation of V in PM_1 and PM_{1-10}. Vanadium forms V_2O_5 during combustion, which starts to decompose to gaseous VO_2 at ∼1080 °C.[18] The condensation of VO_2 vapor in the flue gas contributes to PM_1, while the remaining V_2O_5 crystal contributes to PM_{1-10}. Figure 3x shows that V contributes more to PM_1 during the direct combustion of biosolid compared to the "v + c" cases, most likely as a result of its reaction with HCl in the volatile phase to form volatile chlorides during combustion.[19]

Lastly, similar to the discussion in section 3.2, the actual pyrolysis process that took place during direct combustion of biosolid is at 1300 °C, which is considerably higher than 800−1000 °C in the "v + c" cases. The direct combustion of biosolid also consists of the mixed combustion of char and volatiles. These may explain both the higher yields of the volatile trace elements (As, Pb, and Cd) and the shift of a fine mode of these elements in PM_1 to a larger mode diameter during direct biosolid combustion in comparison to those in the "v + c" cases and the shift of a fine mode to a larger mode diameter. It is also important to note that the yield of less volatile elements, such as Ni and Co, in PM_{1-10} in the "v + c" case is less compared to direct combustion of biosolid. It is likely due to less intense char fragmentation aforementioned, so that more ash particles with an aerodynamic diameter of >10 μm may be formed and captured by the cyclone.

4. CONCLUSION

The emission of trace elements during combustion of biosolid and its derived products (volatiles and char) at 1300 °C are studied. The majority of As, Cd, and Pb are volatilized and released as volatiles during pyrolysis at 800−1000 °C. However, trace elements, such as Cr, Ni Co, Cu, and V, are retained in char. While combustion of volatiles only leads to PM_1 emission, combustion of char results in emission of PM_{1-10} as well as PM_1. PM_{10} contains dominantly major elements, and trace elements accounted for <0.5 wt %. Volatile trace elements (As, Cd, and Pb) contributed to PM_1 emission from volatile combustion. Because arsenic, cadmium, and lead are not completely released during pyrolysis, those retained in char are also released as PM_1 during char combustion. During char combustion, non-volatile trace elements, such as Ni and Co, are only responsible for PM_{1-10} emission but Cr is found to be one of the dominant trace elements responsible for PM_1 emission because it volatilizes during char combustion. Vanadium contributes to both PM_1 and PM_{1-10} during char combustion because V_2O_5 can partially decompose during combustion to form VO_2 gas and contribute to PM_1 formation. While the majority of Cu is released as PM_{1-10} during char combustion, Cu is dominantly released as PM_1 during the direct combustion of biosolid. The results suggest that, during the interactions between char and volatile combustion, direct biosolid combustion leads to the formation of volatile Cu compounds (e.g., $CuCl_2$) that are released as PM_1.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.energy-fuels.6b00776.

> Schematic diagrams of the conventional laboratory-scale DTF system (configuration A) and the novel two-stage pyrolysis/combustion system (configuration B) (Figure S1) (PDF)

■ AUTHOR INFORMATION

Corresponding Author

*Telephone: +61-8-92667592. Fax: +61-8-92662681. E-mail: h.wu@curtin.edu.au.

Notes

The authors declare no competing financial interest.

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ATTACHMENT 10

REVIEW OF INFLUENCE OF CRITICAL OPERATION CONDITIONS ON BY-PRODUCT / INTERMEDIATE FORMATION DURING THE THERMAL DESTRUCTION OF PFAS IN SOLID/BIOSOLIDS

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Review

Review of influence of critical operation conditions on by-product/intermediate formation during thermal destruction of PFAS in solid/biosolids

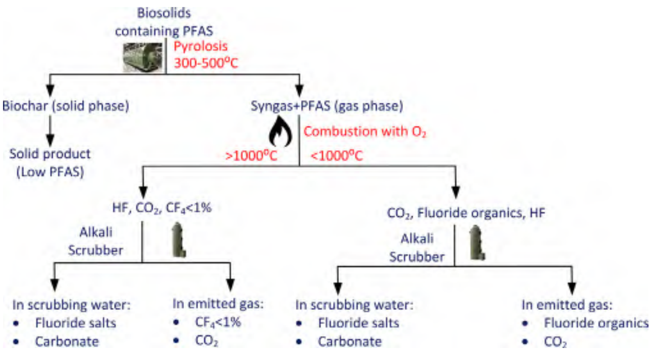
Jianhua Zhang [a,*], Li Gao [a,b,**], David Bergmann [b], Tamara Bulatovic [b], Aravind Surapaneni [b], Stephen Gray [a]

[a] *Institute for Sustainable Industries and Liveable Cities, Victoria University, Melbourne, VIC 8001, Australia*
[b] *South East Water Corporation, PO Box 2268, Seaford, Victoria 3198, Australia*

HIGHLIGHTS

- Thermal treatment of PFAS contaminated solid are reviewed.
- Short-chain PFAS and/or VOF is emitted via exhaust gas during the thermal treatment.
- Combustion achieves complete PFAS mineralisation at temperature > 1000 °C.
- HF concentration in the exhaust gas needs to be lowered by alkali scrubbing.

GRAPHICAL ABSTRACT



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ABSTRACT

Poly- and perfluoroalkyl substances (PFAS) are a large group of synthetic organofluorine compounds. Over 4700 PFAS compounds have been produced and used in our daily life since the 1940s. PFAS have received considerable interest because of their toxicity, environmental persistence, bioaccumulation and wide existence in the environment. Various treatment methods have been developed to overcome these issues. Thermal treatment such as combustion and pyrolysis/gasification have been employed to treat PFAS contaminated solids and soils. However, short-chain PFAS and/or volatile organic fluorine is produced and emitted via exhaust gas during the thermal treatment. Combustion can achieve complete mineralisation of PFAS at large scale operation using temperatures >1000 °C. Pyrolysis has been used in treatment of biosolids and has demonstrated that it could remove PFAS completely from the generated biochar by evaporation and degradation. Although pyrolysis partially degrades PFAS to short-chain fluorine containing organics in the syngas, it could not efficiently mineralise PFAS. Combustion of PFAS containing syngas at 1000 °C can achieve complete mineralisation of PFAS. Furthermore, the by-product of mineralisation, HF, should also be monitored due to its low regulated atmospheric discharge values. Alkali scrubbing is normally required to lower the HF concentration in the exhaust gas to acceptable discharge concentrations.

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* Corresponding author.
** Correspondence to: L. Gao, Institute for Sustainable Industries and Liveable Cities, Victoria University, Melbourne, VIC 8001, Australia.
E-mail address: Jianhua.zhang@vu.edu.au (J. Zhang).

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Contents

1. Introduction

1.1. Background

Since the 1940s, over 4700 poly- and perfluoroalkyl substances (PFAS) have been produced and used in our daily life (Zhang et al., 2021a). PFAS contain at least one perfluoroalkyl moiety (Wallington et al., 2021), in which the fully fluorinated aliphatic carbon chains are known as perfluoroalkyl substances and those with the incomplete replacement of hydrogen atoms by fluorine are referred to as polyfluoroalkyl substances (Sunderland et al., 2019). PFAS and their derivatives have unique physiochemical properties, such as excellent thermal, chemical, radiation and biological stabilities, and high surface-active characteristics widely used for decades in a variety of industrial and consumer products (Ahrens et al., 2019; Pang et al., 2022; Rizzo et al., 2019; Zhang et al., 2019a).

PFAS are environmentally persistent, and have received considerable attention because of their toxicity, environmental persistence, bioaccumulation and wide presence in the environment (Cousins et al., 2020a; Cousins et al., 2020b; McCarthy et al., 2021; Zhang et al., 2021b). It was reported that exposure to high level PFAS may compromise immune system, and lead to liver and kidney diseases (Fenton et al., 2021; Grandjean et al., 2017). In Fig. 1, schematic of PFAS circulation in environment is shown. It can be found that even if PFAS manufacturing is phasing out (Garnick et al., 2021), this circulation would be continuous, because PFAS are 'forever' chemicals.

PFAS have been found in various environments, including drinking water, groundwater, landfill leachate, effluents and sludge of wastewater treatment plants (WWTP), soil of firefighting training grounds, and soil impacted by firefighting events (Gomez-Ruiz et al., 2017; Hamid et al., 2018; Kothawala et al., 2017; Maimaiti et al., 2018; Yu et al., 2020). Currently, at least 90 sites across Australia are contaminated by PFAS due to fire service training (Srivastava et al., 2022). Such examples of PFAS contamination are replicated across the global due to the common use and persistence in the environment. It was reported that 98 % of Americans had PFAS in their blood (Brennan et al., 2021).

Two most commonly used and detected PFAS are perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA), and are of particular concern. PFOS was listed as a persistent organic pollutant listed in the Stockholm Convention on Persistent Organic Pollutants (POPs) for strict restriction in 2009 (Fiedler and Sadia, 2021). PFOA is being phased out according to the US EPA (Garnick et al., 2021).

1.2. Physical and chemical properties of PFAS

In Table A (see appendix), sub-classes of PFAS are listed, along with their chemical and physical properties, including molecular weight (MW), density, melting temperature (T_m), boiling temperature (T_b), vapour pressure (P^0) and solubility (S). Depending on their chemical structure, PFAS are classified into eight groups, with perfluorocarboxylic acids (PFCAs) and perfluorosulfonic acids (PFSAs) currently being those of most concern.

It can be found in Table A that many PFAS are in solid form at room temperature, often as a white powder or waxy substances, though some may be liquids (ITRC, 2020). The MW of PFAS are in range of 200 to 750 g/mol and the densities of PFAS are in range of 1.8 ± 0.4 g/m^3. It also can be found that PFAS are not volatile based on their vapour pressures. Depending on the form of PFAS (acid or salts), the solubilities vary greatly.

The stability of PFAS is determined by the specific functional group that is attached to the fluoroalkyl tail (Wang et al., 2022b). Hence, PFCAs and PFSAs are the most stable fluorinated surfactants, in which PFOA (belonging to PFCAs) and PFOS (belonging to PFSAs) are extremely stable, thermally and chemically, and resist degradation and oxidation. The acid forms of these PFAS decompose at temperatures >400 °C, but complete mineralisation occurs at temperatures >1000 °C (Mueller and Yingling, 2017). Since hydrogen containing substances are present in a practical situation such as a municipal incinerator, the mineralisation temperature of PFAS could be reduced, due to the formation of HF during incineration. The thermal stability is lower for the salts of PFAS acid and depends on which cation is the counter ion. For example, salts of PFSAs are more thermally stable than the corresponding salts of PFCAs, and the decomposition temperature of sodium perfluorooctanoate is lower than that of lithium perfluorooctanoate (Wang et al., 2022a).

1.3. PFAS in the biosolids of water treatment plants

Biosolids can be applied as fertilizer or soil conditioner to improve and maintain the characteristics of soils, stimulate plant growth, fertilise gardens and parks, and reclaim mining sites.

In Australia and New Zealand, biosolids have been used for (Oldfield, 2019):

- Agriculture – for biosolids applied to land for its fertilizer value without value added processing

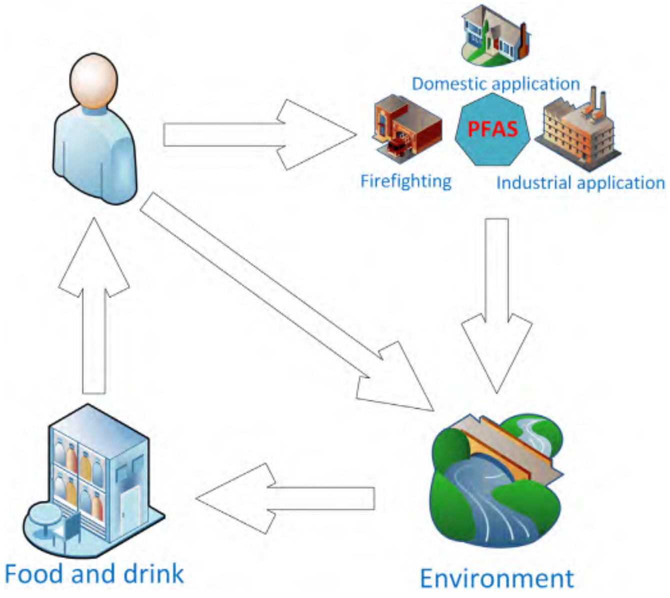

Fig. 1. Schematic of PFAS cycle.

- Landscaping (compost) – for biosolids processed through a composting facility and used for landscaping or other horticultural use
- Forestry – for biosolids applied to plantation forests to aid tree growth
- Landfill – for biosolids disposed to landfill, including mono-fill
- Ocean Discharge – for WWTP where solids are disposed of to the ocean. These solids are not defined as biosolids and no biosolids mass is associated with these WWTP.
- Stockpile – for biosolids stored, pending future planning, processing or use
- Land rehabilitation – for biosolids used in the rehabilitation of land including mine rehabilitation and landfill capping

Biosolids are graded according to chemical composition and the level of pathogens remaining after production. Not all biosolids can be used for all applications. Lower qualities are typically used for road base and mine site rehabilitation. Only the highest grade of biosolids can be used to grow crops for human consumption. Regulators, such as State Departments of Health and Environment, strictly control the application, production and quality of biosolids, since biosolids may also contain traces of synthetic organic compounds and metals, including arsenic, cadmium, chromium, lead, mercury, nickel and selenium (Moraes et al., 2022). These contaminants can impede the beneficial use of biosolids and limit the extent to which biosolids can be used.

PFAS are found ubiquitously in sludge and effluent from WWTPs, since they have been widely employed for both domestic and industrial applications (Tavasoli et al., 2021). In Table 1, the regulated PFAS detected globally in soil, biosolids and organic wastes are shown. It can be found that the concentration of PFAS seems related to the industrialisation of the countries. In the African countries, Kenya and Nigeria, the PFAS concentration in the solids are the lowest. In Germany, Hong Kong, and US, the highest PFAS concentrations are found.

Although PFAS have been phased out in many countries, substitutes for PFAS are being used, some of which could be precursors of PFAS. From 2012 and 2015, Eriksson et al. (2017) studied persistent PFAS, precursors, transformation intermediates, and newly identified PFAS in sludge from three municipal WWTPs in Sweden, and found that the levels of precursors, which can convert to PFAS in sludge, were more than those of PFCAs and PFSAs. Of those precursors in the sludge detected in 2015, the sums of polyfluoroalkyl phosphoric acid esters (PAPs), fluorotelomer sulfonic acids (FTSAs) and perfluorooctane sulfonamides and ethanols were respectively ranged from 15 to 20, 0.8 to 1.3 non-detected to 3.2 μg/kg dry weight (Eriksson et al., 2017). PFSAs and PFCAs as PFAS detected in the sludge were at 1.9–3.9 μg/kg and 2.4–7.3 μg/kg dry weight, respectively. The existing precursors in the sludge led to a net mass increase of persistent PFAS, such as perfluorohexanoic acid (PFHxA), PFOA, PFHxS, and PFOS in all effluents from WWTPs by mean values of 83 %, 28 %, 37 % and 58 %, respectively (Eriksson et al., 2017). It was also found from WWTPs in the USA that the mass flows of PFOS, PFOA, perfluorononanoate (PFNA), perfluorodecanoate (PFDA) and perfluoroundecanoate (PFUnDA) did not change in the effluent of primary treatment, but increased in the effluent of secondary treatment by activated sludge (Sinclair and Kannan, 2006). The loads of precursors in influent and sludge in the WWTPs produce a net mass increase of PFAS, which supports that degradation of precursor compounds is a key contributor to PFAS in the effluent from the WWTPs (Eriksson et al., 2017; Helmer et al., 2022; Thompson et al., 2022). The conversion of PFAS precursors into PFAS was likely due to bioactivity (3M, 2000), with larger perfluoroalkyl substances breaking down to PFOS and PFOA.

Moodie et al. analysed biosolids samples from 19 WWTPs with catchments from urban, rural and industrial waste discharges and different

Table 1
Globally reported PFAS in soil, biosolids and organic wastes (LOQ = limit of quantification).

Country	Matrix	PFOA (μg/kg)	PFHxS (μg/kg)	PFOS (μg/kg)
Australia	landfill leachate and biosolids (Gallen et al., 2016)	0–31	0–7	0–370
Belgium	soil (Groffen et al., 2019)	1.97–114	<LOQ-32	56–7800
Canada	biosolid (Letcher et al., 2020)	<0.07–11.5	<0.06–2.43	0.49–50.4
China	sewage sludge (Yan et al., 2012)	23–300	15–173	27.6–173
France	biosolids, composts, and other organic waste products (Munoz et al., 2021)	0.03–20.3	0.01–7.29	0.02–284
Germany	sewage sludge and bio-waste (Stahl et al., 2018)	<1–51	<1–95.3	<1–698
	sewage sludge (Ulrich et al., 2016)	0–20	0	0–2290
Greece	biosolid (Arvaniti et al., 2012)	0–19	0–18	2–17
Hong Kong	WWTP sludge (Ma and Shih, 2010)	1.3–16	n/a	3–7304
Kenya	WWTP sludge and wastewater samples (Chirikona et al., 2015)	0.033–0.29	0.007–0.832	<0.015–0.673
Korea	influent, effluent, and sludge in WWTPS (Kim et al., 2012)	5–190	<1.1–6.8	15–260
Nigeria	sewage sludge (Sindiku et al., 2013)	0.026–0.42	0.01–0.042	0.012–0.54
Norway	soil (Amundsen et al., 2008)	0.31–14	0.01–24.8	0.49–6.4
Spain	sewage sludge (Gómez-Canela et al., 2012)	0.08–0.69	0.05–0.1	0.54–5
Switzerland	sewage sludge (Alder and van der Voet, 2015)	0.9–87	0.1–6	197–324
Thailand	activated sludge (Kunacheva et al., 2011)	11–140	36–157	396–526
United States	biosolids and soil applied with biosolid (Johnson, 2022; Venkatesan and Halden, 2013)	11.8–70.3	5.3–6.6	308–618
	biosolid and organic non-biosolid-based products (Kim Lazcano et al., 2020)	8.6–26.0	0.45–1.9	3.5–37.5
	sediments and domestic sludge (Higgins et al., 2005)	0–29	n/a	14–2610
	sludge (Sinclair and Kannan, 2006)	69–240	10–18	26–65
	soil applied with municipal biosolids (Sepulvado et al., 2011)	8–68	n/a	80–219
	biosolids (Armstrong et al., 2016)	0.30–600	n/a	0.3–68.1

Table 2

PFAS concentrations detected in in biosolid samples from 19 wastewater treatment plants in Australia (Moodie et al., 2021) (Regulated PFAS are in red italics).

PFAS	Min (μg/kg)	Median (μg/kg)	Max (μg/kg)	PFAS	Min (μg/kg)	Median (μg/kg)	Max (μg/kg)
PFBA	ND	<MRL[a]	3.8	ADONA	ND[b]	ND	ND
PFPeA	<MRL	1.6	9.6	6:2 Cl-PFESA	ND	ND	ND
PFHxA	<MRL	2.1	17	8:2 Cl-PFESA	ND	ND	ND
PFHpA	<MRL	<MRL	8.5	FOSA	ND	ND	3
PFOA	*<MRL*	*4.9*	*45*	N-MeFOSA	ND	ND	0.4
PFNA	ND	0.8	4.9	N-EtFOSA	ND	ND	0.3
PFDA	<MRL	13.2	34	N-MeFOSE	ND	1.9	29
PFUDA	ND	<MRL	3	N-EtFOSE	ND	ND	57
PFDoA	<MRL	4	18	FOSAA	ND	0.3	4.6
PFTrA	ND	0.3	1.8	N-MeFOSAA	ND	1.6	56
PFTeA	<MRL	0.7	4.2	N-EtFOSAA	ND	1.6	50
PFBS	ND	0.7	15	diSAmPAP	ND	ND	9.5
PFPeS	ND	ND	2.5	3:3-Acid	ND	ND	ND
PFHxS	ND	<MRL	13	5:3-Acid	ND	4.6	61
PFHpS	ND	ND	3.9	7:3-Acid	ND	6.9	41
PFOS	*0.9*	*7.4*	*190*	4:2 FTSA	ND	ND	ND
PFNS	ND	ND	0.4	6:2 FTSA	ND	ND	3.5
PFDS	ND	ND	1.5	8:2 FTSA	ND	ND	4
PFDoS	ND	ND	5.6	10:2 FTSA	ND	0.3	1.9
6:6 PFPi	ND	ND	1.7	6:2 diPAP	ND	32	190
6:8 PFPi	ND	ND	1.3	6:2/8:2 diPAP	ND	26	300
8:8 PFPi	ND	<MRL	1.4	8:2 diPAP	ND	40	240
Total PFAS	**4.2**	**280**	**910**				

a. MRL = Method Reporting Limit, b. ND = Not Detectable.

treatment technologies in Australia during 2018, as shown in Table 2 (Moodie et al., 2021). The PFAS concentration varied between 4.2 and 910 μg/kg dry weight biosolids, and the median value was 280 μg/kg dry weight biosolids. PFAS precursors, PAPs were the dominant compound class, contributing 45 % of the total mean mass of PFAS after degradation in the WWTP. Persistent PFAS, PFCAs and PFSAs followed, respectively contributing 17 % and 16 % of the total mean PFAS mass. The average PFAS contribution per person into the biosolids annually varied between 0.6 mg and 15 mg, and was on an average of 6 mg per person per year, based on the population serviced by each WWTP. Domestic activities contributed to the baseline loading of PFAS in biosolids, and industrial waste was positively correlated to PFAS mass in biosolids (Moodie et al., 2021). Since PFAS precursors, diPAPs, transform during treatment into persistent PFAS and make the dominant contribution to total PFAS, it could be a potential issue for biosolids applied as a nutrient rich organic fertilizer in many agricultural applications as the translocation of PFAS from root to shoot has been observed (Awad et al., 2022; Costello and Lee, 2020; Zhang et al., 2021c).

The PFAS National Environmental Management Plan (Australia and New Zealand, 2020) (EPAs, 2020) established human health soil screening criteria for the sum of PFOS + PFHxS at 0.01 mg/kg (10 μg/kg) and PFOA at 0.3 mg/kg (300 μg/kg) for garden/accessible soil. PFOA in biosolids used for soil application would not cause immediate concern, since its maximum concentration (45 μg/kg) is much less than the regulated value, although it might accumulate in farmlands after long term application. However, PFOS + PFHxS in the biosolids could cause immediate concern, since the sum of the maximum values are in range of 190 to 203 μg/kg, which is about 20 times that of the regulated limit. Even when considering the PFOS median value of 7.4 μg/kg, it is only 26 % less than the regulated value (10 μg/kg), so variation in the concentration of PFOS + PFHxS from different sites, especially from sites treating wastewater from highly populated or industrial areas, may lead to a breach of the regulated values.

Another risk of applying PFOS containing biosolids to farmland is its persistence and accumulation following application. Taking account of the transformation of PFAS precursors into persistent PFAS, there is a possibility that farmland application of biosolids from Australian WWTPs could result in farmland soils exceeding the PFAS criteria for gardens/accessible soil.

However, risk studies by Bizkarguenaga et al. (2016) on application of sewage sludge from WWTPs as a nutrient rich organic fertilizer in agriculture found that the maximum intake values of PFOA and PFOS were only 1 % and 12 %, respectively, of acceptable and tolerable daily intake of PFOS (150 ng/kg) and PFOA (1500 ng/kg) established by the European Food Safety Authority (EFSA). This assumed vegetable consumption at the recommended minimal consumption of 400 g fresh fruit and vegetables per day by the World Health Organization (WHO) (Kalmpourtzidou et al., 2020; World Health Organization, 2019) and an average PFAS value of 10 mg/kg in sludge worldwide.

Based on the PFAS National Environmental Management Plan (Australia and New Zealand, 2020) (EPAs, 2020), the human health soil screening criteria for the sum of PFOS + PFHxS at 0.01 mg/kg (10,000 ng/kg) and PFOA at 0.3 mg/kg (300,000 ng/kg), and bioconcentration factors (PFOA (0.49) and PFOS (0.54) based on dry matter) from the study of Bizkarguenaga et al. (2016), and consumption of 400 g fresh vegetables (assuming 90 % water content), the intake of PFOA and PFOS are 5880 ng per day and 216 ng per day. Assuming a body weight of 60 kg, it translates to 98 ng/kg PFOA and 3.6 ng/kg PFOS per day per kg body weight, which is about 61 % and 18 % of the tolerable daily intake limits issued by Australian Government Department of Health (PFOS 20 ng/kg, PFOA 160 ng/kg) (Hobbs, 2017). Hence, the application of biosolids onto farmland needs to be considered cautiously based on Australian regulations.

2. Treatment of PFAS in solids

PFAS transport to the environment from contaminated solids is affected by PFAS adsorption and desorption behaviours. PFAS sorption to solids is governed by the interaction of organic matter with the PFAS hydrophobic fluorinated carbon tail, and electrostatic interactions of clay particles with the polar head group (Ateia et al., 2019; Mahinroosta and Senevirathna, 2020). PFAS are generally considered highly mobile chemicals (Kwiatkowski et al., 2020). Hence, it is necessary to treat contaminated solids to avoid spreading PFAS and its associated adverse effects throughout the receiving environment.

Immobilisation, soil washing and destruction technologies are widely researched in remediation of PFAS contaminated solids or soil (Horst et al., 2020; Sleep and Juhasz, 2021). However, except for destruction, the other two technologies just transfer PFAS to other media or temporarily halt PFAS transfer. PFAS destruction can be divided into non-thermal and thermal treatments, both of which convert organic fluorine to inorganic fluoride salts.

2.1. Non-thermal treatment

In 2020, a PFAS Innovative Treatment Team in USA, involving multi-disciplined research staff from EPA, universities, other research organizations and industry elected two most promising non-thermal technologies for commercial destruction of PFAS-contaminated solid media and waste, including (Berg et al., 2022):

- Mechanochemical destruction (ball milling)
- Supercritical water oxidation (SCWO)

Mechanochemical destruction employs a high-energy ball-milling device to degrade persistent organic pollutants to remediate solids (Vakili et al., 2021), and is considered a “greener” method in comparison to other methods (Bolan et al., 2021) due to there being no requirement for solvents or high temperatures. Some co-milling reagents such as silica, potassium hydroxide or calcium oxide were added to create highly reactive conditions. When crystalline structures of the co-milling reagents are crushed and sheared by high energy impacts by milling balls in the rotating vessel, the collisions create radicals, electrons, heat (localized high temperatures) and even plasma (Berg et al., 2022), which react with PFAS to produce inorganic fluoride compounds and graphite (Wang et al., 2019). Although one commercial company showed destruction >99 % of persistent organic pollutants in about 6 tons of soil in 1 h (Nakayama, 2010), mechanochemical destruction for PFAS treatment is still in its preliminary stages. Mechanochemical destruction could also be a unit operation coupled with other treatment technologies, processing ash from an incineration unit or treated biosolids from a pyrolysis/gasification unit.

Supercritical water oxidation utilizes supercritical water (temperature > 374 °C, pressure > 221 bar) to destroy hazardous waste compounds. Water in the “supercritical” state can accelerate certain chemical oxidation processes, and has been used to treat halogenated waste materials (containing fluorine, chlorine, bromine, or iodine) in the presence of an oxidizing agent (such as oxygen), including polychlorinated biphenyls (PCBs) since the 1980s (Anyasi and Atagana, 2022; Jiang et al., 2020; Zhang et al., 2019b). It has the potential to be used as an alternative to disposal of PFAS-laden material in landfill or combustion in an incinerator. Preliminary results achieved by Jama et al. (2020) showed >99 % destruction of 12 PFAS, from 3.6 μg/L to <0.036 μg/L, by supercritical water oxidation. However, more work is required to demonstrate high destruction efficiencies achievable for complex wastes.

2.2. Thermal treatments

Thermal treatment of PFAS includes combustion treatment where oxygen and high temperature are required, and non-combustion thermal treatment where low or no oxygen and relatively low temperature are used.

2.2.1. Combustion treatment

PFAS contaminated solids, including industrial and municipal solid wastes, spent activated carbon and anionic exchange resins, contaminated soils, and sewage sludge, are generally treated thermally within oxidizers, combustors, and incinerators designed for the purpose of organic waste destruction (Krug et al., 2022). Incineration has been used for destruction of halogenated organic chemicals, such as refrigerants and ozone depleting substances at high temperatures and long residence times by breaking carbon-halogen bonds, after which alkali scrubbing is used to remove halogen from flue gas (Oppelt, 1987). PFAS (including fluorinated refrigerants) are halogenated organic chemicals that are most difficult to incinerate, because the C—F bond is at least 50 % stronger than those of other carbon-halogen bonds (O'Hagan, 2008). Furthermore, the flame-sustaining free radical chain reactions can also be terminated by fluorine due to its electronegativity and reactivity. Hence, incomplete combustion of fluorinated product could be emitted from thermal oxidizers, combustors and incinerators.

In general, halogenated organic compounds are thermally decomposed via unimolecular and bimolecular reactions with flame radicals. Fluorinated organic compounds require much higher temperatures to achieve 99.99 % destruction than do their other halogenated counterparts under the same conditions. Carbon tetrafluoride (CF_4) might be generated in the incineration process and is the most difficult fluorinated organic compound to decompose based on calculated bond energies, requiring temperatures over 1400 °C with 1 s gas phase residence time to achieve 99.99 % destruction efficiency (Krug et al., 2022).

2.2.2. Non-combustion treatment

Pyrolysis/gasification as shown in Fig. 2, is one of the most promising non-combustion treatments for commercial destruction of PFAS, especially PFAS in biosolids, which was identified by the PFAS Innovative Treatment Team in the USA (Berg et al., 2022). Pyrolysis is a process that decomposes materials at moderately elevated temperatures in an oxygen-free or low oxygen environment. Gasification is similar to pyrolysis but uses small

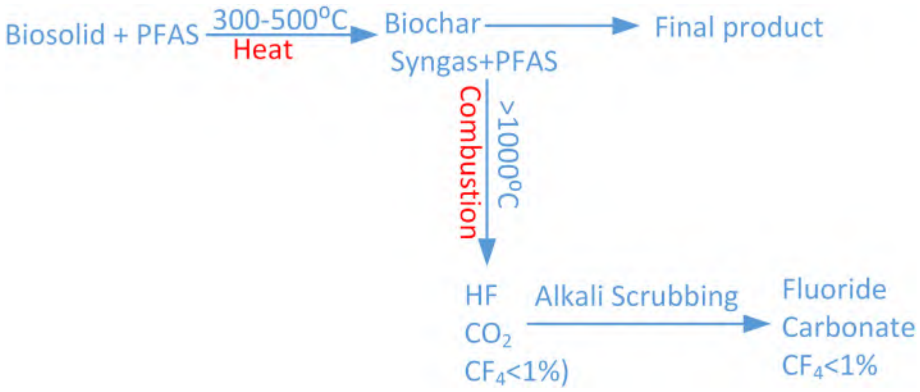

Fig. 2. Schematic of pyrolysis treatment to PFAS contaminated biosolid.

quantities of oxygen, taking advantage of the partial combustion process to provide the heat to operate the process. The oxygen-free environment in pyrolysis and the low oxygen environment of gasification distinguish these techniques from incineration.

Since PFAS have been widely detected in biosolids from wastewater treatment plants (WWTPs), there are concerns for land-application of biosolids. Pyrolysis and gasification might be used to treat PFAS-contaminated biosolids instead of combustion that is generally used for destruction of PFAS in sewage sludge incinerators.

Since organic wastewater contaminants (hydrocarbons) are dominant in biosolids (Hakeem et al., 2022; Rigby et al., 2021), pyrolysis and certain forms of gasification without oxygen are able to transform biosolids into a biochar and a hydrogen-rich synthetic gas (syngas) via thermal decomposition of C—H bonds of hydrocarbons, and the resultant solids for soil amendment and as a supplemental fuel for biosolids drying operations. It would also reduce energy cost and the emission of greenhouse gas (CO_2) compared to the combustion method, since it operates at low temperature and converts most of the carbon into biochar.

Both biochar and syngas can be valuable products. Biochar has many potential applications and is currently used to increase the soil's capacity to hold water and nutrients, requiring less irrigation and fertilizer on crops. Syngas can be used on-site, significantly lowering energy needs. As an additional advantage, pyrolysis and gasification require much lower air flows than incineration, which reduces the size and capital expense of air pollution control equipment.

Pyrolysis/gasification also show promise to reduce PFAS loadings from biosolids without compromising the benefits of the final products, and become an attractive alternative to sewage sludge incineration for reduction of WWTP solids to inert ash, with potential uses as input material in cement production and fine aggregate applications(Bernardin, 2022; Chang et al., 2020).

Pyrolysis or gasification can theoretically vaporise all PFAS and partially destroy some PFAS at its operating temperatures with extended residence times. Residence times vary from minutes to a couple of days as shown in Table 8. Since PFAS transfer into the hydrogen-rich syngas stream, subsequent combustion in a thermal oxidizer (or afterburner) could potentially destroy PFAS. However, the evaluation of potential products of incomplete destruction remains a subject for further investigation and research. The combination of pyrolysis and thermal oxidizer may be more effective at PFAS destruction than some lower temperature sewage sludge incineration processes.

High temperature destruction is usually achieved by combustion processes in the presence of oxygen, and no literature concerning high temperature destruction of PFAS in the absence of oxygen was found. Rather, oxygen has been used to assist combustion of the emitted pyrolysis gas and to raise the temperature above 1000 °C, at which complete mineralisation of PFAS and reaction of fluorine ion with hydrogen occurs. By using syngas combustion, external energy input could be reduced or is not required.

2.2.3. Cost of thermal treatment

Currently, there is no specific cost estimation for PFAS treatment, since it depends on the purpose of treatment. Compared to physical removal/adsorption, PFAS destruction would be significantly more capital and energy intensive. However, PFAS are considered as 'forever' chemicals, which only can be eliminated by destruction under critical conditions.

Thermal treatment is only treatment for PFAS destruction at commercial or pilot scale, and its operation cost can be estimated via existing facilities. For an incinerator with 98–99.99 % efficiency, treating halogenated VOC streams, with a combustion temperature of 1100 °C, residence time of 1.0 s, and use of an acid gas scrubber on the outlet, the cost could be as high as $3600 per metric ton (USEPA, 2006).

3. Thermal destruction of PFAS in solids and soils: fate and by-products/intermediates

3.1. By-products/intermediates of combustion treatment to PFAS

Multiple disposal techniques including incineration have been currently considered by USEPA to effectively treat wastes containing PFAS. For a combustion process to achieve complete PFAS thermal destruction (mineralisation), PFAS needs to degrade to CO_2, H_2O, HF, and/or sulphur compounds (Winchell et al., 2021). Despite the highly oxidized nature of PFOA and PFOS, these and other PFAS display a relatively high thermal reactivity, and the temperature used for thermal incineration of PFAS in carbon regeneration is usually higher than 1000 °C (Winchell et al., 2021). However, Stoiber et al. (2020) identified that incineration of PFAS-containing wastes can emit harmful air pollutants, such as fluorinated greenhouse gases and products of incomplete combustion, and some PFAS may remain in the incinerator ash. For example, during thermal destruction of PFAS, chloride, bromide or trivalent chromium could be converted to perchlorate, bromate and hexavalent chromium, which are strictly regulated (Horst et al., 2020).

The stability of perfluorinated radicals lead to high concentrations of radicals in the combustion process which highly incline to recombine and form larger molecules as products of incomplete combustion (PIC) distinctive from the original fluorinated organics. These reactions are caused by partial organic combustion due to insufficient temperature, residency time and/or mixing. The presence of metals or other catalytic surfaces, enhances these reactions and formation of PIC in post-combustion regions. Some PICs such as polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDDs/PCDFs) formed in the cool-down regions of waste incinerators have been widely studied (Xiong et al., 2022). However, studies of PFAS formation as PICs, have been incomplete due to lack of suitable analytical methods for comprehensive characterization of fluorinated and mixed halogenated organic compounds (Gullett and Gillespie, 2020).

A report published in 2003 by 3 M, a previous key PFAS manufacturer (Taylor and Yamada, 2003), studied a simulated incineration experiment

Table 3
Literature reported temperatures for mineralisation of PFAS in thermal oxidizing processes.

Source	Temperature	Note
Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams (Gullett and Gillespie, 2020)	1000 °C	Studies found PFOA is removed to nondetect levels using laboratory-scale combustion experiments
Environmental fate and effects of poly and perfluoroalkyl substances (PFAS) (Smith et al., 2016)	1000-1200 °C	Required incineration temperature for complete PFOS degradation in excavated soil
US Department of Defence-Funded Research on Treatment of Per- and Polyfluoroalkyl Substance-Laden Materials (Coyle et al., 2021)	1000 °C	Required temperature of secondary combustion chamber to completely destroy PFAS
A review of emerging technologies for remediation of PFASs (Ross et al., 2018)	1100 °C	Required for completely destruction of vaporised PFAS
Removal of Short Chain PFAS via GAC Adsorption (Forrester, 2018)	1000-1100 °C	Required for completely destruction of PFAS
Remediation of PFAS-Contaminated Soil and Granular Activated Carbon by Smoldering Combustion (Duchesne et al., 2020)	>1000 °C	Required for completely destruction of PFAS

under non-ideal combustion conditions. The temperatures of the primary combustion zone was set to 1250 °C to fully vaporise PFAS compounds, and the secondary combustion zone with the submitted gaseous chemicals was set at temperatures of 600 and 900 °C respectively using methane as the fuel source. Experiments showed that in the exhaust, <0.4 % PFOS (removal of 99.6 %) was detected at 600 °C and <0.05 % PFOS (removal of 99.95 %) was detected at 900 °C. Benzene was the most abundant product of incomplete combustion, and fluorobenzene was also observed. The highest concentration of degradation products from PFOS are C1 or C2 fluorocarbon alkane, most likely tri- or tetrafluoromethane or hexafluoroethane at 600 °C, and the concentration of those compounds at 900 °C were about 10 % of those at 600 °C. The nature of this by-product and its thermal stability show that perfluorinated alkanes are stable intermediates and require temperatures in the secondary combustion zone in excess of 900 °C for high levels of destruction. The formation of perfluoroalkanes and alkenes are expected and consistent with presentation of a saturated fluorocarbon chain. There was no evidence to suggest that fluorinated acids were significant combustion products in this study.

However, the efficiency of destruction to PFAS compounds and the tendency of forming fluorinated or mixed halogenated organic by-products are not well understood during incineration treatment (Winchell et al., 2021). Based on limited conceptual or laboratory-scale experiments and previous guidance for incineration of hazardous wastes, it is generally agreed that the combustion temperature for complete destruction of PFAS should be no <1000 °C, as shown in Table 3. In Europe, for hazardous waste with a content of >1 % of halogenated organic substances, a minimum 1100 °C is required to treat the resulting gas for at least 2 s (ToxicoWatch, 2020). A combustion temperature >1047 °C was also used in a pilot study treating PFAS containing materials (Focus Environmenta Inc., 2020).

Lower temperature of 750–900 °C was used in a biosolids gasification demonstration plant in Queensland, Australia in the absence of oxygen for biosolids containing PFOS + PFHxS between 9 and 38 μg/kg and PFOA no >5 μg/kg, reported 94 % PFAS destruction (Logan City Council, 2021). However, the resulting fluorine containing organics or total fluorine compounds, ozone depleting substances, other than regulated PFAS were not monitored. Furthermore, the emissions of HF (in Table 4) (Logan City Council, 2021) were 0.3, 0.5 and 0.02 mg/Nm^3 and well above the Australian regulated limits of 0.5 and 0.25 μg/Nm^3. The Total Oxidizable Precursor Assay (TOPA) method used by the report to report PFAS concentrations, predicts the PFAS concentrations following breakdown in the environment rather than the PFAS concentrations in the samples and is not a measure of general fluorinated organic compounds that may be produced during thermal treatment. It cannot be used to target exact PFAS precursors, as it is a semi-quantitative method (EPAs, 2020), which reveals the presence of PFAS that may, given time, weather to perfluorinated alkyl substances of concern, but is not a predictor of the endpoint of abiotic and biotic breakdown in the field (ALS, 2022). Hence, further research is required to identify the degradation products of PFAS and fluorinated organics from gasification and pyrolysis processes.

In Table 4, the by-products reported in literature from treatment of fluorinated chemicals at different temperature are shown. It can be found PFAS, especially short-chain PFAS, were detected in all laboratory and commercial trials. It should be noted that the works done in Moose Creek, Alaska were at commercial scale (National Research Council, 2019), where PFAS contaminated soil was treated under the operating conditions shown in Table 4. With 1 and 6 ton/h feed rates of PFAS contaminated soil ([PFOA] ≤ 0.0765 mg/kg, [PFOS] ≤ 7.24 mg/kg) at kiln temperatures of 425–815 °C and a secondary combustion temperature treating PFAS in gas phase of 980–1200 °C, the PFAS (PFOS 0.00023 mg/kg and 0.00028 mg/kg, and other regulated PFAS were not detectable) in the treated soil was well below the EPA standards of 0.0030 mg/kg PFOS and 0.0017 mg/kg PFOA. The total volume of PFAS emissions in the gas phase we calculated to be 0.0791 mg/h and 0.0831 mg/h respectively for the 1 and 6 ton/h feed rates, for which 71 % were PFCAs based on the 6 ton/h feed rate.

In a smoldering combustion treatment, PFAS contaminated granulated activated carbon (GAC) was used as fuel to treat PFAS contaminated soil or other materials (Major, 2019). There was no detectable PFAS in the

Table 4
Fluorine containing by-products (intermediates) in the exhaust gas from the treatment of fluorinated chemicals.

Source	Targeted material	Temperature	Fluorine containing by-products in the exhaust gas (% total detected PFAS presented only if data available)
Moose Creek facility thermal remediation of PFAS-contaminated soil (National Research Council, 2019)	PFOS and PFOA contaminated soil	425–815 °C (kiln) 980–1200 °C (secondary combustion for gaseous PFAS)	[a]PFBA (5.3 %), PFHxA (8.7 %), PFHpA (6.5 %), PFOA (52.5 %), PFNA (4.5 %), PFDA (3.0 %), PFDoA (3.5 %), PFUnA (3.4 %), PFHxS (1.9 %), PFOS (3.7 %), 6:2 FTS (2.2 %), NMeFOSAA (2.3 %), NEtFOSAA (2.6 %)
Demonstration of smoldering combustion treatment of PFAS-impacted investigation-derived waste (Major, 2019)	Synthetic PFOA, PFOS, PFHxS, PFNA, PFBS, and PFHpA contaminated solids	>900 °C	PFBA (0.2 %), PFBS (0.001 %), PFHxA (16.7 %), PFPeA (13.5 %), PFHxS (0.007 %), PFHpA (24.7 %), PFOA 31.0 %, PFOS (0.02 %), PFNA (13.9 %), PFDA (0.01 %), PFUnA (0.002 %), PFDoA (0.001 %)
Products obtained in the fuel-rich combustion of PTFE at high temperature (García et al., 2007)	PTFE	750 °C	CF_4 (20 %), C_2F_6 (80 %)
		850 °C	CF_4 (8 %), C_2F_6 (92 %)
		950 °C	CF_4 (4 %), C_2F_6 (9 %), C_3F_6 (1 %), benzenepentafluoro (86 %)
		1050 °C	CF_4 (1 %), C_2F_6 (2 %), benzenepentafluoro (97 %)
Thermal degradation of fluorotelomer treated articles and related materials (Yamada et al., 2005)	Fluorotelomer-based acrylic polymer $(C_{0.33}H_{0.40}{}^{O}{}_{0.04}{}^{F}{}_{0.19}{}^{Cl)}{}_{0.04}$ treated polyester fiber (2 % F by weight)	1000 °C	No fluorinated organic by-products were observed

[a] The percentage is based on data obtained in 2019.

solid phase after treatment with temperatures >900 °C. However, various types of PFAS were still detected in the emitted gas, in which PFCAs were >75 % of the total PFAS emitted from the treatment.

The complete degradation by-products from combustion of fluorine containing materials PTFE and fluorotelomer, at different temperatures are also shown in Table 4 (García et al., 2007; Yamada et al., 2005). For PTFE, as the treatment temperature increased, more fluorinated organic by-products with larger molecular weight were observed in the gas phase. However, the treatment of fluorotelomer showed no fluorinated organic by- products were detected in the gas phase when the temperature was great than 1000 °C.

Since the predicted destruction temperature (1200 to 1400 °C) of CF_4 is the highest of all PFAS, CF_4 could be used as a potential surrogate for monitoring emissions from fluorinated organics incineration. However, using CF_4 alone as the surrogate may underestimate PFAS destruction efficiency. Hence, multiple surrogates with different volatilities, polarities, and ionic charges should be considered as representatives of PFAS.

3.2. PFAS by-products/intermediates of pyrolysis/gasification treatment of PFAS

Pyrolysis is the thermal process that decomposes organic contaminants at a moderately elevated temperature in an oxygen-free condition. Pyrolysis can be used to treat PFAS in biosolids, and produce PFAS free biochar and syngas (Thoma et al., 2022). To achieve highest char yield, an optimum temperature of pyrolysis falls in the range of 300 to 500 °C (Manyà, 2012). The charcoal yield generally decreases as temperature increases (Antal and Grønli, 2003), but an increase of the peak temperature (highest temperature reached) results in an increase of the fixed-carbon content in biochar (Di Blasi et al., 1999; Thoma et al., 2022). Very low surface areas for charcoals were reported from a wide variety of biomass pyrolyzed at temperatures near 550 °C (Khalil, 1999). Setting peak temperatures higher than 700 °C does not seem appropriate for generation of charcoals with better adsorptive properties (Shim and Hurt, 2000), but the operation temperature can be extended to 800 °C for the purpose of generating incondensable gas as fuel (Thoma et al., 2022).

3.2.1. Theoretical modeling of by-products/intermediates from PFAS degradation by pyrolysis

Altarawneh et al. (2022) modelled perfluoropentanoic acid (PFPeA) degradation for temperatures >503 °C along with the formation of different by-products, and found full degradation of PFPeA occurred at 677 °C with a residence time of 25 s. In Fig. 3, the initiation reaction pathways are shown.

At low decomposition temperature (< 627 °C), a two-step reaction sequence dominates the decay of the PFPeA:

$$\begin{aligned}\text{PFPeA} &\rightarrow \text{HF} + \alpha - \text{lactone intermediate} \\ &\rightarrow \text{CO} + \text{heptafluorobutanoyl fluoride}\end{aligned}$$

Table 5

Percentage of final products at different temperatures.

Final products	Temperature (°C)		
	627	927	1127
CO_2 + 1H-pergluorobutane	2.4 %	7.8 %	11.5 %
CO_2 + HF + perluoro-1-butene	14.0 %	34.3 %	44.9 %
CO_2 + heptafluorobutanoyl fluoride	8.4 %	5.8 %	4.4 %
CO + pentafluoropropanoyl fluoride	75.2 %	52.2 %	39.2 %

In Table 5, the percentage of the final products are calculated based on Fig. 3. It can be found that CO + pentafluoropropanoyl + fluoride and CO_2 + HF + perluoro-1-butene are the dominant final products. Similar to the formation of a transitional α-sultone via elimination of HF during PFOS pyrolysis (Altarawneh, 2021; Weber et al., 2021), a α-lactone intermediate dominates the initial decomposition when the temperature is lower than 1127 °C. As the temperature increases, the direct formation (one step reaction) of perfluoro-1-butene and 1H-perfluorobutane increase, and the two step reaction declines. As results, percentage of CO_2 + HF + perluoro-1-butene becomes greater and CO + pentafluoropropanoyl fluoride become less respectively, which show reverse trends.

Altarawneh et al. (2022) predicted that under conditions of no gas-solid reaction, when temperature is >1227 °C, by-products of decomposition of PFAS are $:CF_2$ (biradical difluorocarbene, FTIR peak), HF, CO_2, CO, CF_4, C_2F_6, and C_2F_4, and when the temperature is lower than 1127 °C the by-products also include C_4HF_9, COF_2, C_3F_7COF, 1-C_4F_8, 2-C_4F_8 and C_3HF_7.

3.2.2. Fate of PFAS during pyrolysis treatment for biosolids/spent GAC

Pyrolysis could cause PFAS volatilization at temperatures <450 °C. The effectiveness of pyrolysis for PFAS removal and decomposition largely depends upon the concentration of PFAS, the physical and chemical environment, and reaction time. Over 90 % removal of PFOA and PFOS from sewage sludge was achieved in the pyrolysis process at 500-600 °C (Kundu et al., 2021). Several studies investigated the kinetics of pyrolysis thermal destruction of PFAS-containing salts (Na, Li, K, Mg, Ca, Sr, Ba, Pb, Cu, Al, Ag, NH_4), and concluded that the primary decomposition products are 1H-perfluoroalkane or perfluoroolefin (Krusic and Roe, 2004; LaZerte et al., 1953). During pyrolysis, the breaking of carbon-carbon bonds (418 kJ/mol) occurs before the breaking of carbon fluorine bonds (502 kJ/mol), producing fluoroalkyl radicals. Fluoroalkyl radicals contain an odd number of electrons, which make them electrophilic and unstable. Pyrolysis of long-chain perfluorochemicals is likely to produce tetrafluoroethene (C_2F_4), di-fluorocarbene (CF_2) and tri-fluoromethyl radicals (CF_3) as major short-chain products (Vecitis et al., 2009).

The pilot study conducted by Thoma et al. (2022) showed that after pyrolysis treatment of PFAS contaminated biosolids (25 different types of PFAS detected in the starting biosolids with concentration in range of 2 to 85 μg/kg), all the PFAS in the biochar were less than the detection limits

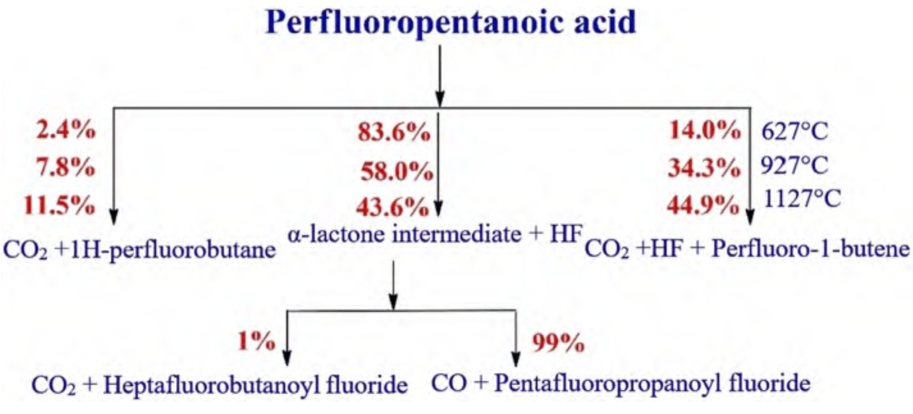

Fig. 3. Initiation reaction pathways at different temperatures.

for operating conditions of 19.1 ± 0.3 min residence time in the reactor and temperatures on the inner walls of the reactor at the front and end of the system of 649 ± 6 °C and 586 ± 32 °C, respectively. Moreside (2022) from Char Technologies also demonstrated that PFAS (28 compounds) were below the detection limit in biochar produced from biosolids following pyrolysis treatment at 700 °C, expect for PFHxA (0.15 mg/kg, biosolid from the tested Site 2). Hence, it is clearly demonstrated that pyrolysis is able to effectively produce low concentration PFAS char from processing of biosolids.

However, based on the properties of PFAS in Table A in the Appendix, all PFAS should have vaporised into the gas phase or have been degraded during the pyrolysis treatment. The syngas stream would contain vaporised PFAS and/or by-products from PFAS destruction. No data regarding PFAS and/or by-products of PFAS degradation in the gas phase directly after pyrolysis was found.

The regeneration of PFAS contaminated GAC for water treatment is conducted under very similar conditions (non-combustion in nitrogen ambient) to that of the pyrolysis process. However, the components, such as insoluble heavy metals or salts, in the biosolids are much more complex than that of the spent GAC, and their reactions with the PFAS components would be more unpredictable. Hence, the resulting by-products from the regeneration of GAC are only approximate outcomes for understanding what might be generated from pyrolysis.

Watanabe et al. (2016) studied thermal treatment of synthetised spent GAC by adsorbing PFOS, PFOA and PFHxA onto it. Some results are listed in Table 6. The degraded PFAS were monitored in a water trap directly receiving the exhaust gas from thermal treatment, and in off-gas out of the water trap. There was no PFAS detectable in the treated GAC. In the water trap, mineralised fluorine was dominant, and volatile organic fluorine (VOF) was the second major component at 800 °C and 900 °C, and became <0.1 % of the PFAS load for GAC treated at 1000 °C. Less than 0.1 % of short-chained PFAS were detected at 800 and 900 °C as shown in Table 6. There was no detected VOF escaping the water trap in this work. This study showed that 1000 °C was the preferred temperature to reduce organic fluorinated by-products in the vapour phase.

Xiao et al. (2020) researched thermal treatment of 10 PFAS components and three fluorine containing chemicals adsorbed to GAC. To achieve a significant mineralisation of PFOA/PFOS, heat treatment temperatures should be above 700–800 °C, based on the yield of fluoride ions.

Sonmez Baghirzade et al. (2021) also suggested that 1000 °C and 800 °C are necessary to achieve high de-fluorination for PFCAs (PFAS category including PFOA) and PFSAs (PFAS category including PFOS) respectively, although high decomposition rate was achieved at 700 °C for PFCA and 800 °C for PFSA.

As shown in Table 7, PFAS by-products were detected in the untreated syngas during pyrolysis treatment of biosolids conducted by Char Technologies at one of three sites for temperatures of 500 °C and 700 °C (Moreside, 2022). The degradation by-products of PFAS in the syngas were mostly PFCA, except for 6:2 FTS. Although short-chain PFAS were dominant and PFOA was also detected. As temperature increased from 500 to 700 °C, the PFAS by-product concentration declined almost exponentially, except for 6:2 FTS. However, further treatment was still required to remove PFAS by-products in the syngas to within the discharge standards. The total PFAS emissions were 29.14 ppm (408 mg/m^3) and 4.74 ppm (65 mg/m^3), respectively at 500 and 700 °C.

Table 6

By-products/intermediates (% of the total PFAS laden on GAC, extracted from charts) from regeneration of PFAS contaminated GAC (Watanabe et al., 2016).

Targeted PFAS	Temperature	By-products in the gas phase
PFOA, PFHxA, and PFOS	800 °C	PFPeA (<0.02 %), PFBA (<0.03 %), VOF (<6.3 %), HF (>50 %)
	900 °C	PFBA (<0.03 %), VOF (<6.3 %), HF (≈55 %)
	1000 °C	VOF (<0.6 %), HF (≈80 %)

Table 7

PFAS by-products/intermediates in syngas (Moreside, 2022) (BDL = below detection limit). The bold represents for the detectable PFAS.

PFAS	Biosolids (mg/kg)	Syngas (ppm)	
		500 °C	700 °C
8:2 FTS	BDL	BDL	BDL
6:2 FTS	BDL	**0.11**	**0.12**
4:2 FTS	BDL	BDL	BDL
10:2 F	**1.2**	BDL	BDL
PFBS	BDL	BDL	BDL
PFHxS	BDL	BDL	BDL
PFTrDA	BDL	BDL	BDL
PFOS	**26.6**	BDL	BDL
PFPeS	BDL	BDL	BDL
EtFOSA	BDL	BDL	BDL
EtFOSE	BDL	BDL	BDL
EtFOSAA	**5.3**	BDL	BDL
MeFOSA	BDL	BDL	BDL
MeFOSAA	**2.9**	BDL	BDL
MeFOSE	BDL	BDL	BDL
PFHpS	BDL	BDL	BDL
FOSA	BDL	BDL	BDL
PFDS	BDL	BDL	BDL
PFBA	BDL	BDL	BDL
PFDA	BDL	BDL	**0.042**
PFDoDA	BDL	BDL	BDL
PFHpA	BDL	BDL	BDL
PFHxS	**2.2**	**19.49**	**1.44**
PFNA	BDL	**1.68**	**1.21**
PFOA	BDL	**2.45**	**0.61**
PFPeA	BDL	**4.94**	**1.04**
PFTeDA	BDL	BDL	BDL
PFUnDA	**1.8**	**0.47**	**0.281**
Total PFAS	**39.6**	**29.14**	**4.71**

Thoma et al. (2022) combusted PFAS containing syngas at 1020 °C to drive the pyrolysis process and destroy PFAS. Since the exhaust gases sequentially passed through a packed-bed caustic wet scrubber and then through an activated carbon filter operating at 43.4 °C (±3.2 °C) after combustion, most of the short-chain PFAS from the thermal destruction should have been retained in the scrubbing water. In Table 8, the PFAS in the scrubber water are shown. It can be found PFOSA (in red in Table 8 and not detected in the biosolids) were the main PFAS by-products with the highest concentration in the scrubber water and PFOA concentration was the second highest. There was no PFAS observed in the exhaust gas after the water scrubber, and the only VOF consistently above the detection level was CF_4 (0.85 ppm, 3.9 mg/m^3).

3.3. Influence of duration of thermal treatment

For treatment of general solid wastes, thermal treatment should heat up the wastes to over 1000 °C for at least 2 s for chemical destruction (Vecitis et al., 2009). Incineration has been used for some organic contaminants, while thermal degradation of PFAS could have challenges due to the molecular stability and reactivity of fluorine (Olsavsky et al., 2020). In Table 9, the duration of thermal treatment being applied for various environmental media, including PFAS-contaminated sewage sludge, municipal solid wastes, and fluorotelomer-based polymers, are shown. It can be found the required time is much longer than 2 s to ensure destruction of PFAS. Furthermore, although those treatments conducted in the laboratory could decontaminate the treated solid through vaporisation of PFAS and achieved almost complete decomposition of PFAS in some cases, they could not mineralise PFAS into CO_2 and HF effectively. Pilot tests funded by the US Department of Defence suggests a thermal desorption unit operated at 650 °C with a residence time of 1 to 1.5 h for solids in combination with a thermal oxidizer operated at 1000 °C with a residence time of 2 s to mineralise PFAS in the gaseous phase (99 % HF mean recovery) (Coyle et al., 2021).

Table 8
PFAS in biosolids and scrubber water (Thoma et al., 2022) (41 analytes, combined results from two analytical laboratory, MDL = minimum detection limit; RL = report limit).

PFAS	Biosolids (µg/L)		Scrubber water (ng/L)	
	(Mean > MDL)	(Mean > RL)	(Mean > MDL)	(Mean > RL)
PFOA	85.7	85.7	9.1	13.2
5:3 FTCA	47.7	47.7	–	–
PFHxA	36.3	36.3	–	–
MeFOSAA	29.5	29.5	–	–
PFOS	23.7	23.7	–	–
EtFOSAA	21.7	21.7	–	–
MeFOSE	18.1	18.1	–	–
7:3 FTCA	16.6	16.6	–	–
PFDA	12.9	12.9	–	–
PFHpA	8.9	8.9	0.2	–
PFPeA	7.1	7.1	–	–
PFDoA	6.9	6.9	–	–
PFBA	6.7	6.7	0.6	–
EtFOSE	6.3	6.3	–	–
PFNA	5.4	5.4	–	–
PFUnA	4.2	4.2	–	–
PFBS	4.1	4.1	–	–
8:2 FTS	4.9	3.8	–	–
10:2 FTS	2.6	3.8	–	–
PFTeA	2.2	2.2	–	–
6:2 FTS	1.8	1.5	–	–
PFOSA	–	–	27.9	27.9
PFPrS	–	–	–	–
3:3 FTCA	–	–	–	–
4:2 FTS	–	–	–	–
PFPeS	–	–	–	–
HFPO-DA	–	–	–	–
ADONA	–	–	–	–
PFHxS	–	–	0.3	–
PFecHS	–	–	–	–
PFHpS	–	–	–	–
9Cl-PF3ONS	–	–	–	–
PFNS	–	–	–	–
PFDS	–	–	–	–
11Cl-PF3OUdS	–	–	–	–
MeFOSA	0.8	–	–	–
PFTrDA	1.0	–	–	–
PFDoS	–	–	–	–
EtFOSA	0.3	–	–	–
PFHxDA	–	–	–	–
PFODA	–	–	–	–

4. Regulations

Currently, there are no regulations directly addressing PFAS emissions in Australia, EU, Canada and US. However, both the USEPA and US Department of Defence suggest the temperature for thermal treatment to reduce PFAS residuals in gaseous emissions from the thermal treatment of PFAS contaminated solid materials should be >1000 °C (Berg et al., 2022; Coyle et al., 2021) to minimise the emission of PFAS by-products/intermediates. Many countries set emission regulations for HF, which is regulated to 0.2 kg/ton solid combusted by the USEPA. In Australia, the emission limit of total fluorine compounds is 50 mg/m^3 for new plants (IEA, 2017). The emission limits of HF 90-day average in Australia are 0.5 µg/m^3 (0.60 ppb, general purpose) and 0.25 µg/m^3 (0.30 ppb, land with vegetation sensitive to fluoride), which have been enforced by EPA, Victoria and DWER, WA (Australian and New Zealand Environment Council. Advisory Committee on Air, 1990; DWER, 2019; SEPP, 2001).

In two pyrolysis pilot trials, fluorine compounds emitted as PFAS from test Site 3 of Char Technologies were 409.97 mg/m^3 and 64.2 mg/m^3, both of which are above the Australian regulated value 50 mg/m^3 of total fluorine compounds (IEA, 2017). However, only CF_4 was constantly detected in pilot tests performed by Thoma et al. (2022) with a concentration of 3.9 mg/m^3.

5. Summary of thermal treatment of PFAS

Thermal treatment of solid materials will completely evaporate PFAS into the gas phase when the temperature is >700 °C, but can emit by-products/intermediates in the gas phase from incomplete destruction of PFAS that remain an environmental and health concern. By-products could be short-chain PFAS derived from long-chain PFAS, and would convert to PFOS with the assistance of bioactivity in the solid phase.

Furthermore, it was suggested for thermal treatment that:

- The temperature of thermal destruction (combustion and non-combustion) should be no <1000 °C to achieve complete mineralisation of PFAS, regardless of the reaction time
- Scrubbing of exhaust gas and/or syngas is also critical to meet the guideline value for fluorine compound emission (50 mg/ m^3) and HF emission (0.5 and 0.25 µg/m^3),
- With assistance of high temperature combustion/thermal oxidiser, and caustic water scrubbing, fluorine compound emission from pyrolysis pilot tests done by Thoma, et al. was 3.9 mg/m^3 below the current guideline values.

Table 9
Thermal treatment and duration for PFAS contaminated materials (Wang et al., 2022b).

Thermal treatment	Feed stocks	PFAS	Temperature (°C)	Duration	PFAS in solid phase	By products in gas phase (% of the total detected PFAS in gas phase, only if it is reported)
Incineration(Wang et al., 2013; Xiao et al., 2020)	Soil, water, granular activated carbon, sewage sludge, textiles, carpet, municipal waste, PFAS salts, polymers	PFOA, PFOS, PFBA, PFPeA, PFHpA, PFNA, PFDA, PFUnDA, PFHxA, PFHxS, potassium salts of PFBS	900	30 min 15 min	Not detectable	$\cdot CF_3$, $\cdot C_2F_3$, $\cdot C_3F_3$, $\cdot C_2F_4$, $\cdot C_2F_5$, $\cdot C_3F_5$, $\cdot C_4F_7$, $\cdot C_5F9$, 80 (mol)% (30 min, 900 °C) and 60 % (15 min + $Ca(OH)_2$) PFAS are mineralised
Thermal desorption (Crownover et al., 2019; Lind, 2018)	Soil	PFBA, PFPeA, PFBS, PFHxA, PFHpA, PFHxS, PFOA, PFNA, PFOS, PFDS, PFDA, PFUnDA, 6: 2 FTSA, 8:2 FOSA	150–550	15 min, 75 min or 10–14 days	Removal >99.91 % (>350 °C, 10–14 days) Removal>90 % (>450 °C, 75 min)	Not reported
Pyrolysis and gasification (Watanabe et al., 2018)	Sewage sludge, salts of PFCAs	PFOA, PFOS, PFHxA	150–700	15 min-65 h	Removal>99 % (700 °C, 10 min)	CF_4, C_2F_6, >74 % PFAS are mineralised (700 °C, 10 min, with NaOH)
Smoldering combustion (Duchesne et al., 2020)	Granular activated carbon, soil, sewage sludge	PFOA, PFOS, PFHxS, PFHpA, PFBS, PFNA	642, 900	10–61 min	Not detectable	642 ± 32 °C, PFBA (19 %), PFOS (81 %) >900 °C, PFHxA (44.7 %), PFOS (54.6 %), PFNA (0.7 %). In the emission, the total PFAS are <1 %, HF is about 16 %. No mineralisation data provided, >99 % degraded

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CRediT authorship contribution statement

Dr. Zhang drafted the manuscript and revised the manuscript based on all the comments from co-authors.

Dr. Gao was involved in the manuscript drafting and provided comments for the manuscript.

Dr. Bergmann was involved in manuscript revision and supervised the revision process.

Dr. Bulatovic was involved in manuscript revision and supervised the revision process.

Dr. Surapaneni was involved in manuscript revision and supervised the revision process.

Prof Stephen Gray was involved in the manuscript drafting, provided comments for the manuscript and supervised the revision process.

Data availability

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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