DRAFT REPORT

West Haven Biosolids Study

West Haven, Connecticut

June 1, 2023

CDM Smith

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Introduction

1.1 Background and Study Objectives

1.1.1 WPCF Background

The City of West Haven (City) owns and operates a Water Pollution Control Facility (WPCF) that serves residential, commercial, and industrial customers in the West Haven, Connecticut. The WPCF primary treatment facilities were originally constructed in the 1960s, with secondary treatment facilities constructed in the 1970s. The facility has undergone several upgrades since, most recently in the early 2010s. The most recent upgrade included improvements to influent screening/pumping (at Main Pump Station on Blohm Street), primary clarification, secondary treatment for biological nutrient removal (BNR), secondary clarification, and sludge pumping.

Currently, the WPCF liquid process train consists of fine screening, influent pumping, grit removal, primary clarification, secondary treatment for BNR via the integrated fixed film activated sludge (IFAS) process, secondary clarification, and disinfection via sodium hypochlorite, before discharge to the New Haven Harbor. The WPCF is designed to treat and discharge wastewater at a permitted annual average daily flow of 12.5 million gallons per day (MGD). The current average daily flow is approximately 6.55 MGD.

1.1.2 Sludge Treatment Operations

Primary sludge at approximately 0.5-0.7% total solids content is collected at the primary clarifiers and is pumped to a gravity thickener. Waste activated sludge (WAS) is collected at the secondary clarifiers and is conveyed to gravity belt thickeners and the resulting thickened WAS (TWAS) is blended with the thickened primary sludge (TPS) in blending tanks. The typical ratio of TPS:TWAS is 60:40 and according to plant staff, the total solids (TS) content of blended sludge is approximately 3.5%. Blended sludge is pumped to a belt filter press (Ashbrook-Simon-Hartley Type 85 Klampress, 2.0 meter) or a Flottweig Model C4E-4/454 centrifuge for dewatering. Sludge treatment operations are summarized in **Figure 1-1** below.

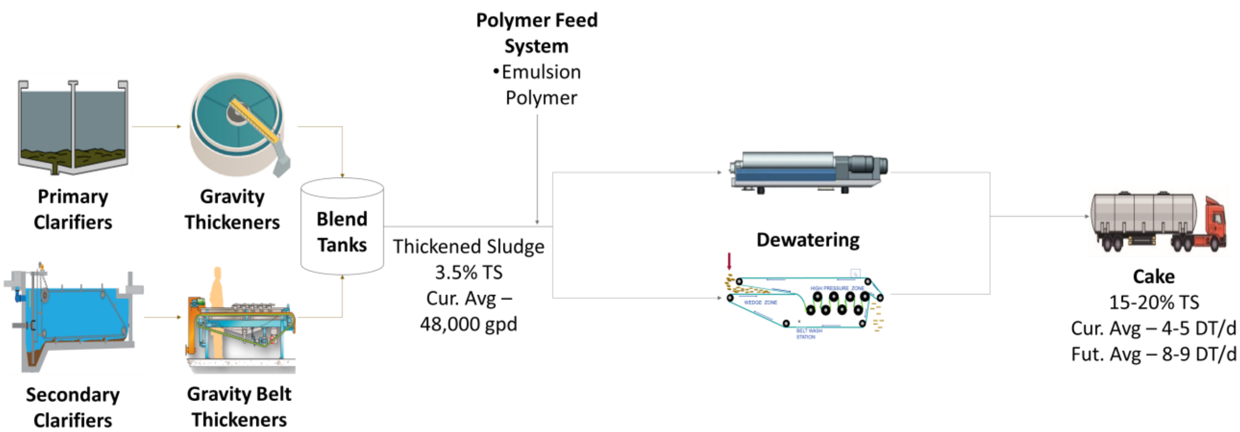

Figure 1-1
Existing Sludge Treatment Operations

1.1.3 Study Objectives

The City currently dewaters WPCF sludge to 15-20% solids and hauls the dewatered cake off-site for further processing and disposal. Approximately 1,900 dry tons (DT) of dewatered sludge (9,500 wet tons at 20% solids) is produced each year that requires management. The costs of hauling and disposal have increased significantly in recent years and are projected to continue to increase at a significant rate in coming years, due in part to reduced landfill/incineration capacity and anticipated regulations regarding contaminants of concern (e.g., PFAS). Additionally, issues such as odors, truck traffic in the City, and sustainability goals need to be considered.

This study aims to 1) evaluate existing sludge treatment operations and 2) evaluate alternative biosolids management strategies. The goal of this study is to provide the City with a plan to manage biosolids that is sustainable and cost effective for years to come.

1.2 Current and Future Sludge Production Data

1.2.1 Current Sludge Production Data

Currently, the City monitors data on liquid treatment processes such as daily flow, aeration tank parameters (mixed liquor suspended solids (MLSS), sludge volume index (SVI), dissolved oxygen (DO), temperature), and influent and effluent characteristics (BOD, TSS, nutrients). The only sludge data provided includes primary sludge TS (%), WAS mass (lbs/day), and sludge hauling data (liquid and cake mass).

Available sludge process data at West Haven WPCF is summarized in **Table 1-1**.

Table 1-1 Summary of Available Sludge Data at West Haven WPCF

Parameter	Value	Unit	Notes
Primary Sludge Total Solids	0.57%	%	Average from 2018-2020
Waste Activated Sludge Mass	4,336	Dry Lb/day	Average from 2018-2020
Hauled Sludge	805	Wet tons (WT)/mo	Average from 2017-2019

Note: Hauled sludge calculated based on estimated solids density and known quantities of dumpsters hauled away.

The data in Table 1-1 show that primary sludge TS was approximately 0.6% and WAS mass was approximately 4,300 lbs/day. The sludge hauling data is most useful to the objectives of this study and shows that 805 WT per month of sludge was disposed from 2017-2019.

Other data provided includes information from plant staff. WPCF staff report that the normal feed rate to the belt filter press (BFP) and/or centrifuge is between 39,000 to 43,000 gallons per day (gpd) of 3.5% blended sludge for 8-10 hours per day, 5 to 5-1/2 days per week. These data suggest the WPCF processes up to 14,000 lbs of dry solids per day. The reported total solids content of dewatered sludge cake ranges from 15 to 20%.

Given lack of historical sludge processing data, CDM Smith utilized "rule-of-thumb" solids production ratios based on plant flow (DT/MG). Several references from academic and industry literature were evaluated. Ultimately, rule of thumb solids production rates from Metcalf and Eddy (4th Edition) and WEF Manual of Practice 8 were considered in addition to the reported 39,000 to 43,000 gpd at 3.5% solids verbally reported by plant staff.

1.2.2 Future Sludge Production Data

Table 1-2 summarizes the estimated sludge quantities based on "rule-of-thumb" solids production factors. The results indicate that estimated total dry solids production (10,000 – 15,000 dry lbs/day) at existing flows is comparable to the measured values at the dewatering equipment (14,000 dry lbs/day). The results also show that sludge production could double at the annual average design flow of the WPCF (12.5 MGD).

Table 1-2 Estimated Sludge Loads at West Haven WPCF

	Current Flows (6.55 MGD)			Future Flows (12.50 MGD[3])		
	M&E Low Range	M&E High Range	WEF MOP 8	M&E Low Range	M&E High Range	WEF MOP 8
Primary Sludge Factor (DT/MG)	0.45	0.70	1.0[1]	0.45	0.70	1.0[1]
Waste Activated Sludge Factor (DT/MG)	0.30	0.40		0.30	0.40	
Estimated PS Production (dry lb/day)	5,900	9,200	N/A[1]	11,250	17,500	N/A[1]
Estimated WAS Production (dry lb/day)	3,900	5,200		7,500	10,000	
Total Sludge Load (dry lb/day)[2]	10,350	15,200	13,800	19,700	28,950	26,300

1. WEF MOP 8 does not use separate factors for primary sludge/WAS. Factor is for combined sludge production.
2. Sludge load increased by 5% to account for losses in dewatering process.
3. 12.5 MGD is permitted average monthly flow limit.

The conceptual design of the sludge management options were developed based on the sludge loads in Table 1-2, existing sludge properties, and industry standard design parameters. Sludge loads from the WEF MOP 8 estimates were used for the conceptual designs, as they provided median values among the methods considered, and were most comparable to existing sludge quantities.

1.3 Existing Solids Processing Equipment Condition Assessment

CDM Smith performed a site visit to the WPCF on September 24, 2021, to evaluate the condition of the existing sludge processing facilities. Generally, the condition of most equipment could be described as aging and in need of upgrade. The existing Sludge Disposal Building houses sludge incineration equipment that is currently not in use, due to the inability to meet Sewage Sludge Incinerator (SSI) air quality standards. A prior evaluation recommended upgrade to the air pollution control equipment to provide the ability to meet the new SSI regulations. Aside from the new centrifuge, much of the equipment in the Sludge Disposal Building has exceeded its anticipated useful life and the building itself is showing signs of deterioration. Based on space constraints onsite and the condition of the existing building and equipment, demolition or modification of this Sludge Processing Building was assumed. For the new processes considered below (anaerobic digestion, sludge drying, gasification), it was assumed that the cost to demolish the building and build a new building would be less than attempting to remove the incinerator and retrofit the existing building to make it accommodate the new processes considered above. However, since the existing Incinerator is located in the current building, it was assumed the existing building could be modified to accommodate equipment associated with the incinerator process.

1.4 Sludge Compositional Analysis

1.4.1 PFAS

Per- and Polyfluoroalkyl Substances (PFAS) describes a category of contaminants of emerging concern, that is representative of thousands of compounds used in everyday products. These compounds inevitably end up in municipal and industrial waste streams through consumer use and product manufacturing activities. PFAS are characterized by the carbon-fluorine bond, which is the strongest known chemical bond that is incredibly recalcitrant to degradation. This makes PFAS-laden wastewater and associated solids difficult to treat using conventional treatment technologies.

While PFAS are not generated by WPCFs, they enter the plant through municipal, commercial, and industrial wastewater streams. Common sources of PFAS are from industry that uses the compounds during manufacturing processes, and from landfill leachate. Numerous studies have concluded that conventional wastewater treatment and sludge processing do not efficiently remove or destroy PFAS. Additionally, PFAS are surfactant compounds, making them adhere readily to solids. Therefore, several studies have shown PFAS presence in sewage sludge and biosolids. For example, the state of Michigan completed a report in 2020 surveying PFAS in both municipal and industrially impacted wastewater treatment facilities[1]. The Michigan results show that PFOS (currently banned PFAS compound) concentrations in treatment plants with primarily municipal customers ranged from 2 to 100 µg/kg (ppb) while those impacted by industry ranged from 100 to 2,000 µg/kg (ppb). **Figure 1-2** provides PFAS concentrations in biosolids/sludge from Michigan wastewater treatment facilities (courtesy of Michigan EGLE).

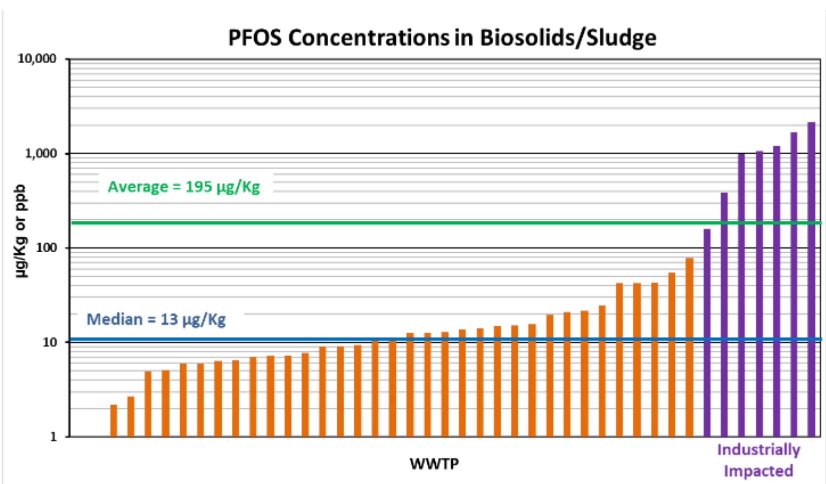

Figure 1-2
PFAS Concentrations in Biosolids/Sludge from Michigan Wastewater Treatment Facilities (courtesy of Michigan EGLE)[2].

[1] Michigan Department of Environment Great Lakes and Energy. Initiatives to Evaluate the Presence of PFAS in Munciipal Wastewater and Associated Residuals (Sludge/Biosolids) in Michigan. 2020. https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Programs/WRD/IPP/pfas-initiatives-wastewater-sludge.pdf?rev=2f47b34f32804b349dcf219fec460ec5

[2] Michigan Department of Environment, Great Lakes and Energy (EGLE). 2020. Initiatives to Evaluate the Presence of PFAS in Municipal Wastewater and Associated Residuals (Sludge/Biosolids) in Michigan. https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Programs/WRD/IPP/pfas-initiatives-wastewater-sludge.pdf?rev=2f47b34f32804b349dcf219fec460ec5&hash=7EA31041CBAA98EFB6B116FECDA4F918

CDM Smith also evaluated publicly available data from the states of Massachusetts and New Hampshire to provide a more geographically comparable data set for West Haven. PFAS concentrations from comparable plants to West Haven are shown in **Figure 1-3**. The results show that total PFAS concentrations ranged from less than 50 µg/kg to 200 µg/kg in Towns with a population ranging from less than 20,000 to 100,000. Town population does not appear to have a significant effect on PFAS concentrations, given that towns such as Somerset MA (<20,000) had higher PFAS concentration than Quincy, MA (>100,000). This suggests local industry, landfill leachate association, firefighting foam activity, etc. have a greater impact on PFAS concentration.

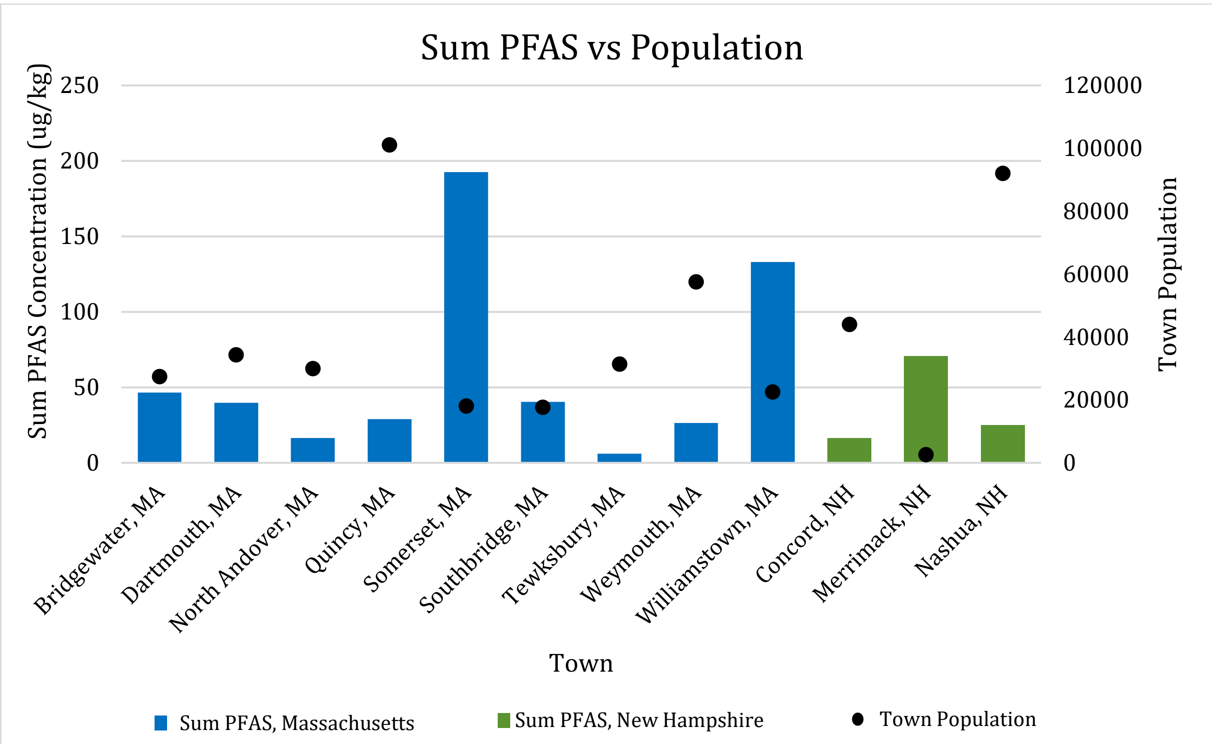

Figure 1-3
Sum of PFAS Concentrations in Select Towns, located in New Hampshire and Massachusetts

Overall, the data from existing studies and sludge surveys suggest that the PFAS concentrations in West Haven WPCF sludge could range from <10 to 200 ug/kg since West Haven is not impacted by many industrial users and landfill leachate. PFAS discharges could mostly be due to background levels in potable water and discharges from municipal and commercial customers.

However, every WPCF sludge has a unique PFAS profile. As seen in **Figure 1-4**, the PFAS compounds detected in WPCF biosolids can vary greatly, which is representative of the variety of waste streams across municipalities. For example, PFHxA and PFBS constituted a large fraction of the samples from Somerset, MA. However, just 20 miles southeast of Somerset is Dartmouth, MA. The Dartmouth sample constituted a lower sum of total PFAS, and detections were dominated by PFOS. Considering an evolving regulatory environment, it is advantageous to test WPCFs biosolids to evaluate the types of PFAS present, as well as the ranges in concentrations in which these compounds are present, both of which may impact future end use and disposal of the biosolids in question.

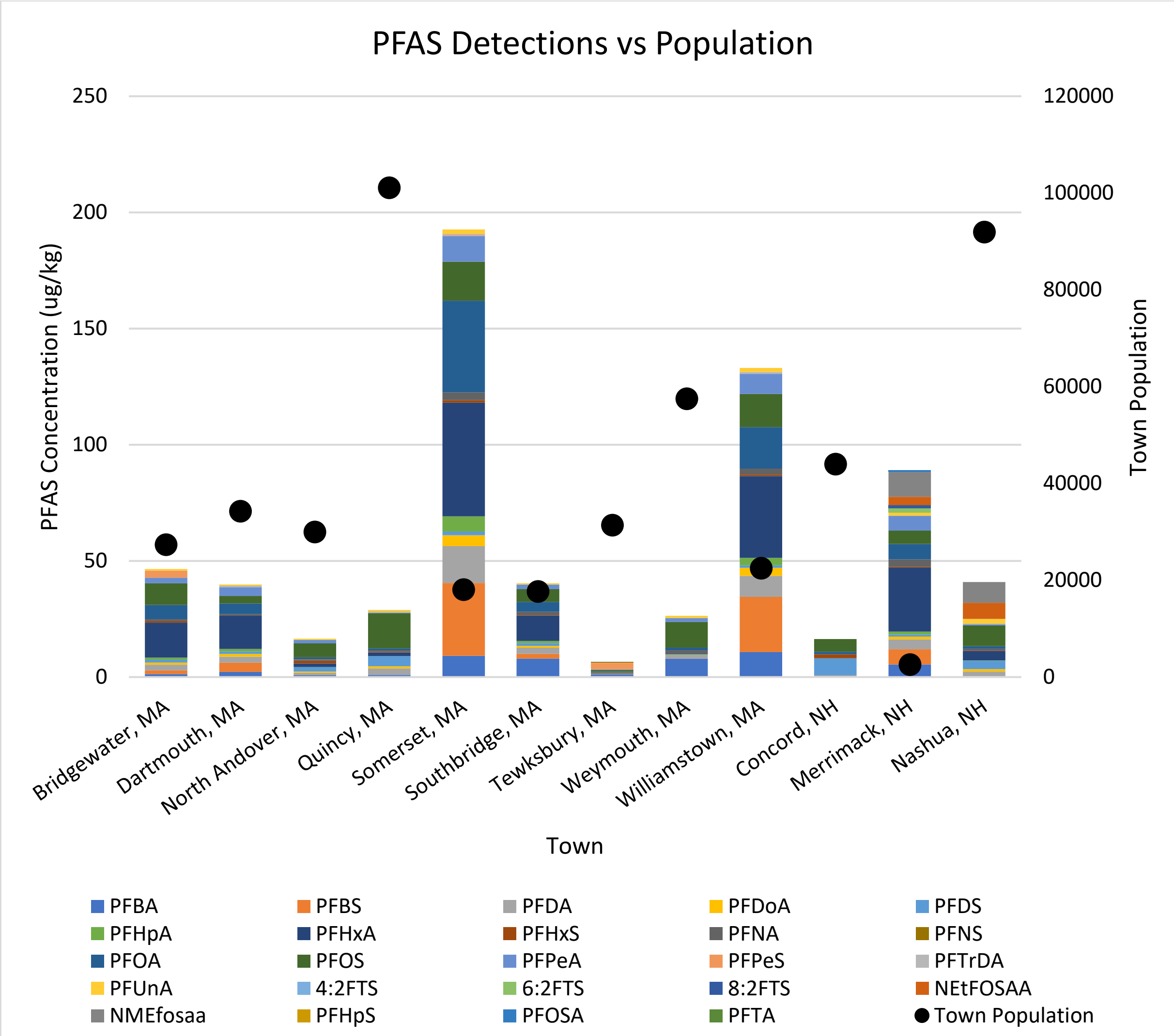

Figure 1-4
PFAS Concentrations Detected in Select Towns, located in New Hampshire and Massachusetts

To best understand potential PFAS impacts, it is recommended that the sludge be tested via analytical methods, which have been updated rapidly over the past decade. First, USEPA released analytical method 537 for 14 PFAS compounds in drinking water, then revised recently to Method 537.1 that includes 4 additional PFOS and PFOA replacement compounds. For analyzing PFAS in the environmental matrices other than drinking water, USEPA has not yet released any official analytical method. Recently, the USEPA provided guidance to WPCF's for analysis of PFAS in environmental matrices[3]. The recommendation is to use Draft Method 1633 to analyze for the presence of 40 PFAS chemicals in biosolids[4].

[3] Radhika Fox, Assistant Administrator, USEPA. Addressing PFAS Discharges in NPDES Permits and Through the Pretreatment Program and Monitoring Programs. EPA Regional Water Division Directors Region 1-10. December 5, 2022. https://www.epa.gov/system/files/documents/2022-12/NPDES_PFAS_State%20Memo_December_2022.pdf
[4] USEPA Office of Water. Draft Method 1633 – Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS. August 2021. https://www.epa.gov/system/files/documents/2021-09/method_1633_draft_aug-2021.pdf

1.4.2 Other Sludge Parameters to Consider

1.4.2.1 Metals

The composition of other important parameters in sludge (e.g., metals, nutrients) must be considered prior to establishing processes that generate higher value biosolids products (e.g., Class A material). The USEPA 40 CFR 503 establishes metal pollutants that must be below certain thresholds before sludge can be land applied or used for other beneficial purposes. States may follow federal levels or provide more stringent limits for biosolids land application. **Table 1-3** shows the federal and New York state for key pollutants. At the time of this report writing, recent toxicity characteristic leaching procedure (TCLP) analysis was unavailable to compare to federal and nearby state limits. It is recommended that TCLP analysis be conducted prior to selection of a technology for Class A biosolids recovery (e.g., drying, pyrolysis, gasification).

Table 1-3 Pollutant Concentration Limits for Sewage Sludge

Parameter	USEPA 40 CFR 503 Limits		NYSDEC 361-3.9 Limits	MASSDEP 310.32.12 Limits – Type 1 Sludge
	Pollutant Concentration	Ceiling Concentration	Maximum Limit	Maximum Limit
Arsenic	41	75	41	-
Cadmium	39	85	10	14
Chromium	No limit	No limit	1,000	1,000
Copper	1,500	4,300	1,500	1,000
Lead	300	840	300	300
Mercury	17	57	10	10
Molybdenum	No limit	75	40	40
Nickel	420	420	200	200
Selenium	100	100	100	-
Zinc	2,800	7,500	2,500	2,500
PCBs	-	-	-	1-2

1.5 Regulatory Review

1.5.1 Sludge Disposal Regulations

Connecticut does not currently allow the beneficial use of solids (e.g. land application) in-state. Most wastewater solids in the state are incinerated, which takes place at either SSI facilities at public or private facilities, within and outside of the state. In-state public SSI facilities are located in New Haven, Mattabasett, and Hartford, while private SSI facilities are found in Waterbury and Naugatuck. These facilities accept septage and wastewater solids from communities across Connecticut, as well as from some neighboring states.

Some communities send wastewater solids for disposal at landfills, however space limitations and increasing costs for solids disposal raise concern for the future of biosolids management in the state. Connecticut currently has no regulatory programs directing the recycling of biosolids and is heavily reliant on incineration for in-state management. Fairfield and Stamford WPCFs produce Class A biosolids, however the Connecticut Department of Energy and Environmental Protection (CT DEEP) does not allow in-state land application. Therefore, these Class A biosolids are commonly shipped out of state for land application or trucked to an incinerator. Therefore, the City must consider transportation and disposal costs for the desired biosolids product. Given these constraints, it is likely that high quality products will need to be hauled away at some cost.

For land applied biosolids, there are three different categories: Class A, Class B, and Class A EQ (Exceptional Quality). Class A EQ biosolids are those which exceed the requirements set forth for Class A biosolids and is considered comparable to standard fertilizer products. These biosolids must meet pollutant requirements for both Ceiling Concentrations (40 CFR 503.13(b)(1)) and Pollutant Concentrations (40 CFR 503.13(b)(3)), pathogen requirements for one of the Class A Pathogen Reduction Alternatives (40 CFR 503.32(a)) and Vector Attractiveness requirements for one of the Vector Attraction Reduction Options that are accomplished during sewage sludge processing/treatment (options 1-8) (40 CFR 503.33(b)(1)-(8)). The sewage sludge or material derived from sewage sludge is classified as non-EQ if it exceeds one or more of the requirements that define EQ sewage sludge as specified above and in the Rule. Other states may mirror federal regulations or have more stringent standards. For example, the state of New York has comparable pathogen requirements to federal regulations, but more stringent metals requirements.

1.5.2 PFAS Regulations

Since PFAS became an emerging contaminant of concern in the early 2000s, federal and state authorities have established several health-based regulatory values or advisory levels. The USEPA issued draft National Primary Drinking Water Regulation (NPDWR) for six PFAS including PFOA, PFOS, PFNA, GenX, PFHxS, and PFBS in March of 2023[5].

To date, the USEPA has not issued any advisory levels or regulations for PFAS in municipal wastewater, sludges, or biosolids. However, in August of 2022, the USEPA proposed the designation of PFOA and PFOS as hazardous substances under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also known as Superfund). If approved, this designation would directly impact wastewater utilities' sludge and biosolids programs and has the potential to restrict the use of biosolids in land application, thus limiting options available for end-use and disposal.

On April 20, 2022, the Governor of Maine signed into law, L.D. 1911 prohibiting the land application of biosolids due to PFAS contamination and the detection of PFAS in numerous farmlands[6]. Therefore, it is important to look ahead and plan for any future compliance issues that may arise from future legislation in CT and nearby states.

The USEPA continues to provide updates on their assessment of PFAS in biosolids and other environmental matrices. For example, the USEPA published the PFAS Strategic Roadmap that set a schedule for future regulatory action. The Biosolids plan is expected to be completed in Winter 2024[7], suggesting that regulatory action could be enforced by the end of the decade.

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[5] USEPA. Proposed PFAS National Primary Drinking Water Regulation. March 2023. https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas

[6] Brown, S. Connections: Unpacking Maine's New Ban On Biosolids Use Due to PFAS. Biocycle. August 9, 2022. https://www.biocycle.net/connections-biosolids-ban-pfas/#:~:text=The%20Maine%20legislature%20passed%20and,to%20concerns%20about%20PFAS%20contamination.

[7] USEPA. PFAS Strategic Roadmap. EPA's Commitments to Action 2021-2024. https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

Furthermore, the recent memorandum entitled "Addressing PFAS Discharges in NPDES Permits and Through the Pretreatment and Monitoring Program" provides guidance to WPCFs and state regulators to consider. Section C: Recommended Biosolids Assessment, suggested the following:

1. **Where appropriate states may work with their POTWs (Publicly Owned Treatment Works) to reduce the amount of PFAS chemicals in biosolids, in addition to the NPDES recommendations in Section B above, following these general steps**:

    a. USEPA recommends using draft method 1633 to analyze biosolids at POTWs for the presence of 40 PFAS chemicals

    b. Where monitoring and Industrial User (IU) inventory per section B.2 and B.3.a above indicate the presence of PFAS in biosolids from industrial sources, EPA recommends actions in B.3.b to reduce PFAS discharges from IUs[8].

    c. USEPA recommends validating PFAS reductions with regular monitoring of biosolids. States may also use their available authorities to conduct quarterly monitoring of the POTWs (see 40 CFR 403.10(f)(2)).

Section B includes updating IU inventory, updating IU permits to require quarterly monitoring, developing local limits, or issuing IU control mechanisms.

While the above recommendations are guidelines and not yet enforceable, they are indicative of potential future action with respect to PFAS in biosolids. States could require these recommendations in future NPDES permits.

[8] USEPA Office of Water. Draft Method 1633 – Analysis of Per- and Polyfluoroalkyl Substances (PFAS) in Aqueous, Solid, Biosolids, and Tissue Samples by LC-MS/MS. August 2021. https://www.epa.gov/system/files/documents/2021-09/method_1633_draft_aug-2021.pdf

Section 2

WPCF Biosolids Management Options

This section reviews available technologies, which may be incorporated to improve biosolids quality, decrease the volume of biosolids, generate potential products, and/or remove PFAS. The intent of this section is to evaluate biosolids alternatives which would not involve organic waste processing and is limited to solutions at the existing WPCF site.

The design criteria for evaluation of these biosolids management options is the sludge loads calculated in Table 1-2. The following criteria were used when soliciting information on the sludge management alternatives:

- Current Sludge Production – 14,000 lbs dry solids/day
- Future Sludge Production – 28,000 lbs dry solids/day
- Primary Sludge/Waste Activated Sludge – 60%/40%
- Sludge Thickening
  - Primary sludge – gravity thickening
  - WAS – gravity belt thickening
  - Combined Thickened Sludge Total Solids – 3.5%
- Dewatering
  - Belt Press or Centrifuge
  - Dewatered Sludge Cake Total Solids – 15% (belt press) to 20% (centrifuge)
- Volatile Solids – 74% of Total Solids

2.1 Sludge Hauling and Disposal

The North East Biosolids and Residuals Association (NEBRA) recently completed The National Biosolids Data Project in 2022[9]. The project includes detailed analysis of state-by-state data regarding biosolids production and available outlets. The project estimated that Connecticut WPCFs generated more than 140,000 dry tons of solids annually. Nearly all solids were incinerated (87%), with smaller quantities landfilled (8%) or delivered as Class A EQ biosolids (5%).

Incineration facilities currently operating in Connecticut include three publicly owned SSI facilities (Hartford, Mattabassett, New Haven) and two private SSI facilities (Naugatuck and Waterbury). According to NEBRA, only two WPCFs (Stamford, Fairfield) produce Class A EQ products via heat drying and composting, respectively, but most of those solids are shipped out of state due to CT land application restrictions or trucked to an incinerator. Due to limited capacity for incineration in the region, driven by out of state and in state demand, the price for solids disposal is frequently greater than $130 per wet ton ($650 per dry ton). According to NEBRA, most of the incinerators only accept thickened liquid sludge, not dewatered sludge.

[9] North East Biosolids and Residuals Association (NEBRA) National Biosolids Data Project. https://www.biosolidsdata.org/ https://www.biosolidsdata.org/connecticut

2.1.1 Local Market Research

CDM Smith evaluated the costs for sludge hauling and disposal at the WPCF over the past five years (**Figure 2-1**). The results show that monthly costs have increased significantly since late 2019 lows of $56,000 per month. From January 2020 to January 2023, the 12-month rolling average cost for sludge hauling and disposal has increased from approximately $56,000 to $85,000 per month, equivalent to a 52% increase.

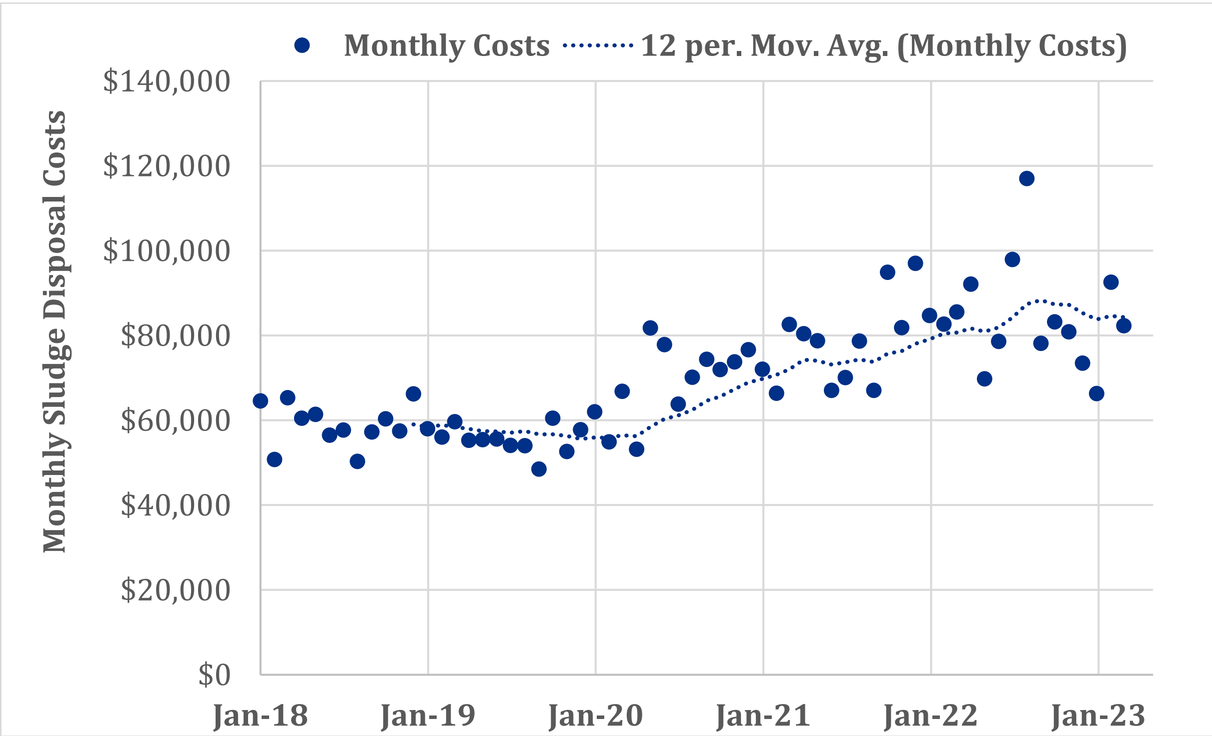


Figure 2-1
Monthly Sludge Disposal Costs at West Haven WPCF

Annual costs for sludge disposal alone have increased from approximately $670,000 per year in 2019 to $1,100,000 in 2022 (**Table 2-1**). The rate of cost increases appears to be accelerating since 2020. This is primarily due to reduced capacity for sludge outlets in the region. Assuming sludge production has not increased significantly since 2019, it appears that the current cost to dispose of sludge is approximately $100 per WT.

Table 2-1 Annual Sludge Disposal Costs at West Haven WPCF

Year	Annual Cost ($/yr)	Rate of Change from Prior Year (%)
2018	$708,050	-
2019	$667,165	-6%
2020	$826,949	+24%
2021	$936,650	+13%
2022	$1,095,157	+17%

Over the next several years, sludge hauling and disposal costs are expected to continue to increase. CDM Smith contacted third-party contractors, including Denali, Synagro, Casella, and Resource Management, Inc (RMI). The interviews with third party contractors suggested that the cost for wet cake sludge transportation and tipping fees could exceed $250 per wet ton (>$1,000 per dry ton, cake, 20-25% TS) in the next few years.

The primary cause for cost escalation is the concern for capacity and the future of current biosolids management practices. Some New England states are evaluating legislation surrounding land application, and there is talk of this becoming a permitted-only practice. This discussion has reportedly included Canada, which accepts a significant amount of U.S. biosolids. Some third-party contractors stated that while land application is a preferred use of wastewater biosolids, it would be risky to rely on this as the primary end-use for residuals in a quickly changing regulatory environment, primarily due to uncertainty with PFAS legislation. There are also concerns about increasingly high tipping fees and limited landfill capacity, causing many states in New England to question the next steps in wastewater residuals management.

According to local waste haulers, alternative products such as Class A biosolids or incinerator ash would likely have lower disposal rates at approximately $90-100 per wet ton ($111 per dry ton at 90% solids). However, this will be highly dependent on the hauling distance from West Haven to find a suitable site.

Table 2-2 below shows the opinion of operational costs for the sludge dewatering and disposal option at current and future flows.

Table 2-2 Operational Costs of Dewatering and Disposal

O&M Costs	Unit Costs	Current Sludge Flows		Future Sludge Flows	
		Quantity	Annual Costs	Quantity	Annual Costs
Labor	$95,000/FTE/yr	0.5 FTE	$42,500	1 FTE	$95,000
Dewatering Chemicals	$1.8/gal[a]	15,000 gal/yr	$28,000	30,000 gal/yr	$55,000
Electricity for Dewatering	$0.20/kWh	230,000 kWh/yr	$45,000	320,000 kWh/yr	$63,000
Sludge Disposal	$100 - 250/WT	12,775 WT/yr	$1,278,000	25,550 WT/yr	$6,388,000
Maintenance	Est.		$25,000		$50,000
Total O&M Costs			$1,418,500		$6,651,000

a. Dewatering chemicals inflation rate 40-50% since 2021 prices ($1.2/gal).
b. Commercial electricity pricing increased to $0.20/kWh since 2021 ($0.15/kWh) – USEIA
c. Range of sludge disposal costs for current ($100/WT) and future ($250/WT) conditions. There is uncertainty with respect to future sludge disposal costs given the regulatory concerns outlined in Section 1 above.

2.2 Incineration

2.2.1 Regulatory Overview

The air pollution control improvements at the City's SSI located at the WPCF are required to meet the emission limits of *40 CFR Part 60, Subpart LLLL Standards of Performance for New Sewage Sludge Incineration Units*. The emission limits in this standard are applicable to New SSIs and they are significantly more stringent than the emission limits for an Existing SSI. The USEPA has determined that the sludge incinerator at the West Haven WPCF should be classified as a New SSI and therefore the emission limits in the above standard are applicable. To meet the emission limits in this standard, extensive air pollution control (APC) improvements are required.

The proposed incineration process is shown in **Figure 2-2.**

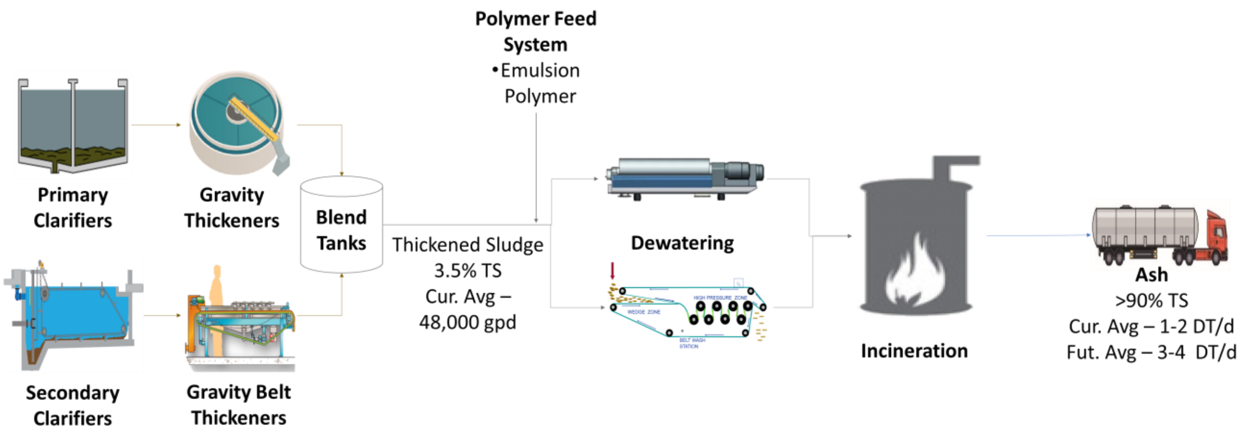


Figure 2-2
Sludge Incineration at West Haven WPCF

2.2.2 Required Emission Controls

The City has performed emissions testing in 2013, 2014, 2015 and 2016. The results of these emissions tests are presented in **Table 2-3**, as well as the emission limits of the above federal regulation and an indication of whether the existing Fluidized Bed Incinerator (FBI) meets or does not meet the emission limits stated in New SSI Standards of Performance, Subpart LLLL.

As shown in Table 2-2, new emission controls will be required to meet the emission limits for the following pollutants: particulate matter, cadmium, lead, hydrogen chloride, mercury, nitrogen oxides and sulfur dioxide. The cadmium emission is relatively close to meeting the LLLL Standard. However, the particulate and lead emissions are significantly greater than the LLLL Standard. Based on the limited lead data, an 80% reduction in the lead emission would be required to meet the LLLL Standard.

Table 2-3 Incinerator Emission Test Results and 40 CFR Part 60 Subpart LLLL Emission Limits

Pollutants	Units at 7% Oxygen	40 CFR Part 60 Subpart LLLL Limits	2013 Data	2014 Data	2015 Data	2016 Data	Meets 40 CFR Part 60 LLLL Std.
Particulate	mg/dscm	9.6	12.8	NA	NA	NA	No
Cadmium	mg/dscm	0.0011	NA	0.0005	0.0007	0.0013	No
Lead	mg/dscm	0.00062	NA	NA	NA	0.0032	No
Hydrogen Chloride	ppmvd	0.24	27.3	NA	NA	0.37	No
Carbon Monoxide	ppmvd	27	1.8	13.7	22.08	14.23	Yes
Mercury	mg/dscm	0.0010	0.0432	0.024	0.0451	0.0526	No
Nitrogen Oxides	ppmvd	30	NA	NA	NA	43.19	No
Sulfur Dioxide	ppmvd	5.3	NA	NA	NA	190.90	No
Dioxin/Furan (mass basis)	ng/dscm	0.013	NA	NA	NA	NA	Unknown
Dioxin/Furan (TEQ basis)	ng/dscm	0.0044	NA	NA	NA	NA	Unknown

mg/dscm: milligrams per dry standard cubic meter
ppmvd: parts per million, volumetric dry
ng/dscm: nanograms per dry standard cubic meter
ND = Not Detected
NA = Not Analyzed

2.2.3 Proposed Emission Control Improvements

To meet the 40 CFR Part 60, Subpart LLLL emission limits for the above pollutants, the following emission control systems are required.

- For particulate matter and metals – installation of a new quencher, tray scrubber and multi-venturi scrubber, caustic scrubber tray and wet electrostatic precipitator (WESP).
- For hydrogen chloride and sulfur dioxide – installation of caustic scrubbing trays which would be fed by a recirculated caustic solution.
- For mercury – installation of a carbon adsorption system with UHF and HEPA Filters, a carbon heat-up system consisting of an electric heater and recirculation fan and an ID fan.
- For nitrogen oxides – installation of a Selective Non-Catalytic Reduction (SNCR) system which would inject ammonia into the FBI freeboard and reduce nitrogen oxides to atmospheric nitrogen.

The new quencher, tray scrubber, multi-venturi scrubber, caustic scrubber tray, WESP and ID fan would be supplied by Envirocare International, or equal. Envirocare is the proprietary supplier of the multi-venturi scrubber. The carbon adsorber, UHF and HEPA filters, and carbon heat-up system would be supplied by APC Technologies, or equal. The carbon adsorption system supplied by APC Technologies can achieve greater than 95% control of mercury emissions, and thus is the recommended supplier of the mercury control system. For NOx control, a Selective Non-Catalytic

Reduction (SNCR) System, supplied by Fuel Tech, or equal, would inject ammonia into the freeboard of the FBI to reduce NOx to atmosphere nitrogen and oxygen.

The emission control system is based on a wet flue gas flow rate of 14,500 ACFM at 1000°F at the outlet of the secondary heat exchanger. The corresponding flow rate at the outlet of the proposed APC train is approximately 4,000 ACFM at 95°F. These flue gas flow rates are based on an incinerator sludge feed rate of 1,160 dry pounds per hour at 20% solids concentration. The new equipment consisting of a quencher, tray and multi-venturi scrubbers, WESP and carbon absorption system would be located in a new building addition adjacent to the Sludge Processing Building (SPB) with approximate dimensions of 61 ft x 31 ft x 35 ft in height. The new building addition would be on the west side of the SPB. A plan view of the building addition for the new APC equipment is shown in **Figure 2-3 (also in Appendix A)**. A traveling hoist on an I-beam will be required above the carbon adsorber to facilitate the loading of carbon into the carbon adsorber.

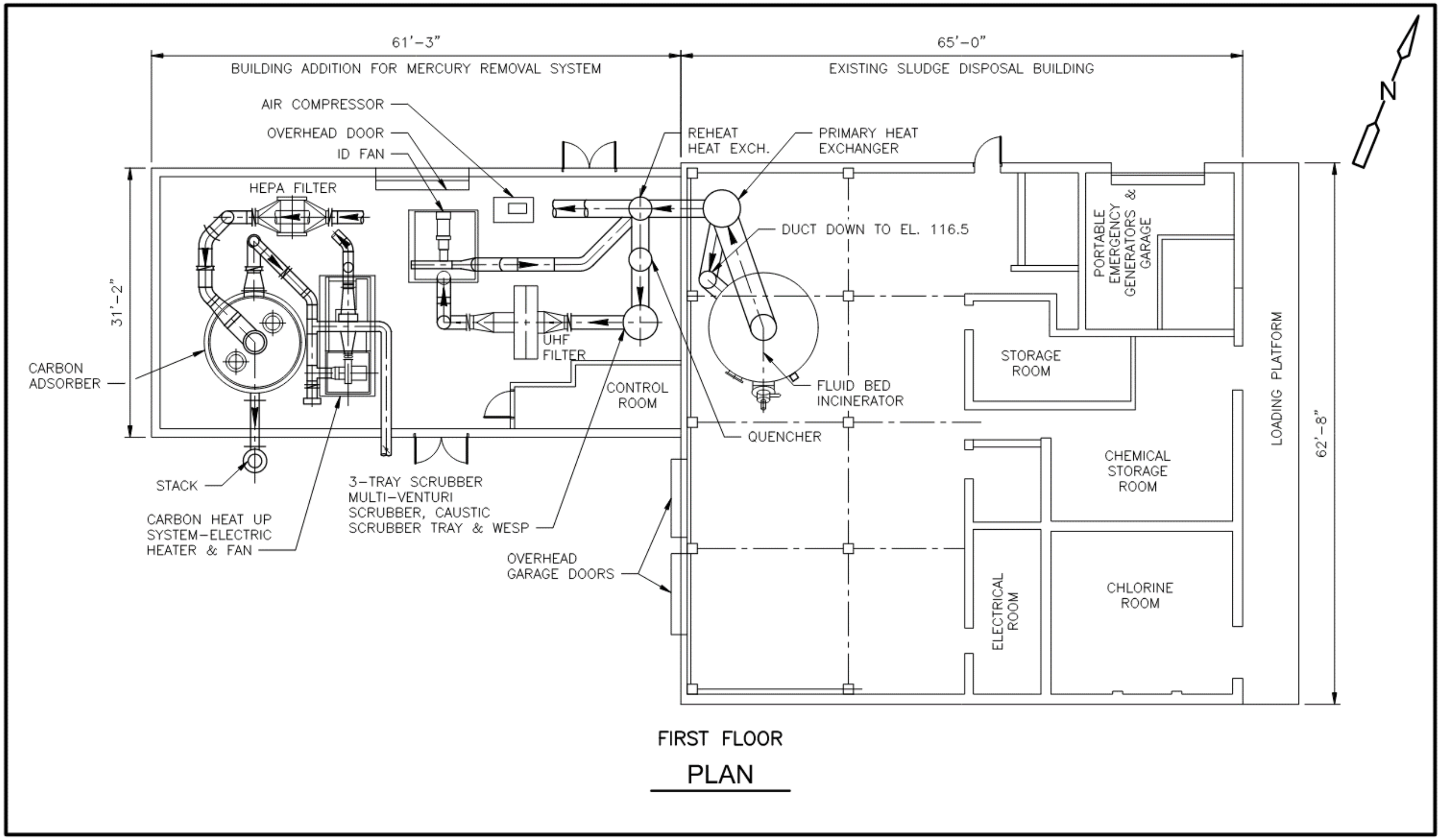
A 316L stainless steel stack would be supplied with stack sampling ports and a ladder and platform to facilitate stack sampling.

The new tray and multi-venturi scrubber system will use more plant water than the existing scrubber system. The existing scrubber system uses 60 gallons per minute (gpm) in the venturi and 160 gpm in the tray scrubber, total of 220 gpm. The new scrubber-WESP-SPC system will have the following plant water usage:

- Weir water – 50 gpm
- Quench water – 40 gpm
- Tray irrigator – 15 gpm
- Impingement trays – 200 gpm
- Venturi Stage – 34 gpm
- Ventury Through – 26 gpm
- WESTP washwater – 38 gpm – intermittent
- **Total Plant Water – 403 gpm**

The WPCF has three plant water pumps each rated at 800 gpm at 80 pounds per square inch (psi). Presently the plant usually uses just one plant water pump at a pumping rate of 400 to 500 gpm. Occasionally the plant uses two plant water pumps. The new wet scrubbing system will require that two of the existing plant water pumps will be in operation whenever the incinerator is in operation.

A caustic recycle tank of approximately 300-gallon capacity and two caustic recirculation pumps each rated at 80 gpm will feed a dilute caustic solution to the caustic tray. The caustic recycle tank and pumps will be located on the first floor beside the incinerator. Concentrated caustic at 30% solution will be pumped from a caustic storage tank to the caustic recycle tank by two caustic metering pumps, each with a variable frequency drive at a flow rate of 0 – 10 gallons per hour. A 500-gallon caustic storage tank and metering pumps will be located in the existing Chemical Storage area which is shown in **Figure 2-3** and in **Appendix A**.



CDM Smith

INCINERATION IMPROVEMENTS
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Figure 2-3
Sludge Incineration Improvements at West Haven WPCF

A Storage Room will be needed in the space where an unused lime slurry tank presently is. The caustic storage tank will be inside a containment cell with approximate dimensions of 7 ft x 7 ft x 2.5 ft in height. The caustic metering pumps would sit on top of the containment wall.

The SNCR system for NOx control will require a 500-gallon aqua ammonia (ammonium hydroxide) storage tank and two metering pumps. In addition, eight ammonia injection nozzles will be required to inject and disperse the ammonia solution into the freeboard of the FBI. The storage tank and pumps would also be located in the Chemical Storage Room. A separate containment cell will be provided for the aqua ammonia tank and pumps.

2.2.4 Construction Cost Estimate

The total opinion of probable construction cost (OPCC) is $20.4M and the breakdown of this cost is shown in Appendix B. The cost includes demolition, the Envirocare scrubber system consisting of quencher, tray scrubber, multi-venturi scrubber and WESP, the APC Technologies carbon adsorption system with UHF and HEPA filters, reheat heat exchanger, ID fan, the caustic and ammonia storage and recirculation tanks and pumps, the building addition to house the new equipment, electrical work, controls and instrumentation, process and drain piping, overhead and profit, contingency, and engineering design and services during construction. After construction is complete there will be additional cost for startup, testing and coordination with USEPA for final acceptance of the system.

2.2.5 Operating and Maintenance Cost Estimate

Operation and maintenance (O&M) costs for the current and future sludge flows are presented in **Table 2-4**, including unit costs and quantities. O&M costs are estimated for operating labor, caustic for the wet scrubber, ammonia for the NOx control system, natural gas, electricity, maintenance-parts, contract maintenance, stack testing and ash hauling and disposal. The total estimated annual costs at the current and future sludge flows are $1.1 and $1.9 million per year, respectively.

Table 2-4 Operational Costs of Sludge Incineration

O&M Costs	Unit Costs	Current Sludge Flows		Future Sludge Flows	
		Quantity	Annual Costs	Quantity	Annual Costs
Labor	$95,000/FTE/yr	1.5 FTE	$142,500	2 FTE	$190,000
Dewatering Chemicals	$1.8/gal[a]	15,000 gal/yr	$28,000	30,000 gal/yr	$55,000
Electricity for Dewatering	$0.20/kWh	230,000 kWh/yr	$45,000	320,000 kWh/yr	$63,000
Caustic for Wet Scrubber	$1.2/gal	27,600 gal/yr	$33,000	55,200 gal/yr	$66,200
Ammonia for NOx Control	$1.3/gal	16,560 gal/yr	$21,500	33,100 gal/yr	$43,100
Natural Gas	$16/MMBTU[b]	20,000 MMBTU/yr[e]	$321,000	40,100 MMBTU/yr	$642,000
Electricity	$0.20/kWh	667,000 kWh/yr	$133,400	1,334,000 kWh/yr	$266,800
Maintenance – Parts	various	various	$100,000	various	$150,000

O&M Costs	Unit Costs	Current Sludge Flows		Future Sludge Flows	
		Quantity	Annual Costs	Quantity	Annual Costs
Contract Maintenance	various	various	$200,000	various	$250,000
Stack Testing	$35,00	Once per year	$35,000	Once per year	$40,000
Ash Hauling & Disposal	$90/wet ton	805 wet tons/yr	$72,500	1610 wet tons/yr	$144,900
TOTAL			$1,131,900		$1,911,000

a. Caustic and ammonia inflation rate 40-50% since 2021 prices ($1.2/gal & $1.3/gal)
b. Commercial natural gas pricing increased to $16/MMBTU since 2021 ($14/MMBTU) - USEIA
c. Commercial electricity pricing increased to $0.20/kWh since 2021 ($0.15/kWh) – USEIA
d. Estimated 25% increase in ash disposal costs compared to 2021 ($72/WT)

2.3 Anaerobic Digestion

Anaerobic digestion is a biological process that relies on microorganisms that grow in an oxygen free environment to convert organic material in wastewater sludge to biogas. The process reduces the mass of total solids and improves the quality of the material to reduce pathogen count and odors. Additionally, biogas produced during decomposition is methane rich and can be used as a renewable source of energy and heat.

In 2021, CDM Smith completed a study titled "West Haven CT – On-Site Anaerobic Digestion Conceptual Layout" that described the capital and operational requirements to support anaerobic digestion of WPCF sludge. The sludge loads used for that conceptual design are the same shown in Table 1-2. Therefore, the key findings of that report are applicable to this study.

2.3.1 Conceptual Design

The conceptual design of the anaerobic digestion facility was developed based on the future sludge loads described in Section 2.1, existing sludge properties, and industry standard design parameters (e.g., HRT/SRT, biogas yield, VS destruction).

The proposed design includes two 675,000-gallon mesophilic anaerobic digesters (1.35 million gallons in total capacity), which supports at least 20-day HRT at current average sludge flows estimated via the WEF MOP 8 method. At design flows and loads, the WPCF will generate more sludge that will need to be processed through the proposed anaerobic digesters. At that time, there are three options to expand digester capacity, including adding additional tanks, increasing the feed sludge solids content via thickening improvements, or increasing the digester solids content via recuperative thickening. For this analysis, an additional pre-thickening process was assumed. The costs of supporting equipment including feed pumps, heat exchangers, and boilers were designed to support future flows (90,000 gpd of sludge).

Other design assumptions for the conceptual anaerobic digestion process are shown below:

- Sludge Load – 13,800 to 26,300 lbs dry solids/day (WEF MOP 8)
- Thickened Sludge Flow to Digesters – 47,000 to 90,000 gpd at 3.5% solids
- Volatile Solids/Total Solids (VS/TS) – 74%
- Digester Type – Complete Mixed Reactor (CMR); Concrete with insulated steel roof
- Digester Volume – 1,350,000-gal total (2 digesters at 675,000 gallons each)

The process flow diagram for the proposed process is shown in **Figure 2-4**.

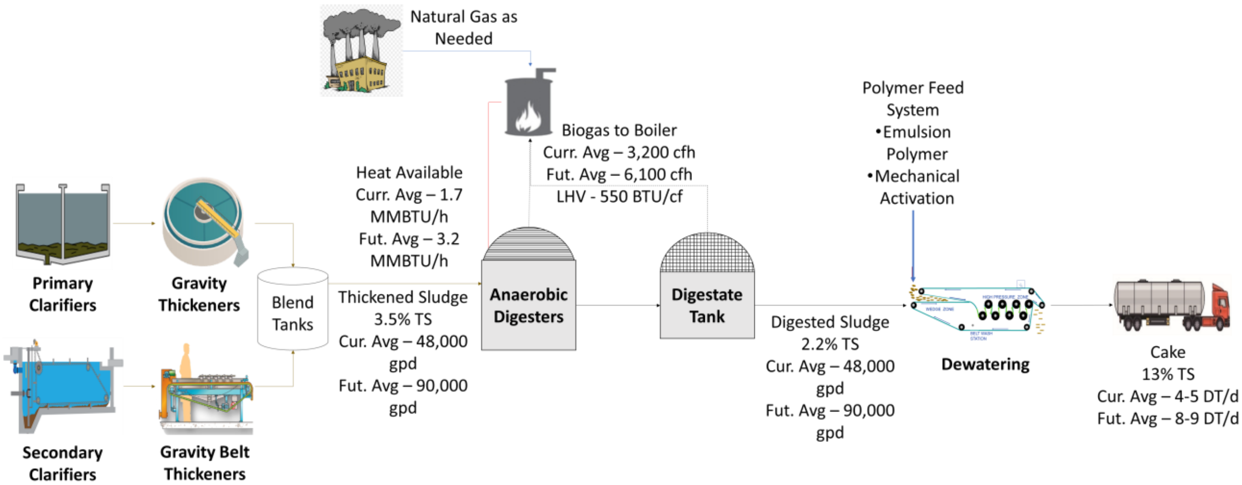

Figure 2-4
Anaerobic Digestion Conceptual Process Flow Diagram

2.3.1.1 Equipment

The following preliminary equipment selections were included as part of the conceptual design:

- Digester Feed Pumps – Two (one duty, one spare)
  - Max Flow/Head: 75 gpm at 60 ft TH; 3.5% solids
  - Rotary lobe type; 5 hp; <150 rpm; Equipped with suction-side grinder
- Digesters – 2 tanks
  - Volume – 675,000 gallons each (1.35 MG total)
  - 50 ft Diameter; 50 ft tall
  - 24” concrete sidewalls; conical bottom
  - Fixed steel cover
- Digester Mixing System– Two (one per tank)
  - Pumped mixing system with nozzles internal to tanks
  - 75 hp chopper style pumps
  - Total pumps – 3 (one per tank, one spare)
- Digester Heating System
  - 100-hp biogas fired boilers – Two (one duty, one spare)
  - MMBTU/h Tube in Tube Heat Exchangers - 2 (one per digester)
  - Sludge recirculation pumps - Three (one per tank, one spare)
  - 200 gpm at 50 ft TH; 15 hp chopper pumps
  - Hot water recirculation pumps – Three (one per HEX, one spare)
    - *200 gpm at 35 ft TH; 3 hp centrifugal*

- Digestate Transfer Pumps – Two (one duty, one spare)
  - Max Flow/Head: 75 gpm at 60 ft TH; 2.2% solids
  - Rotary lobe type; 5 hp; <150 rpm; Equipped with suction-side grinder
- Digestate Storage Tank – One tank
  - Volume – 140,000 gallons (1.5-3.0 days storage)
  - 30 ft Diameter; 30 ft tall
  - 24" concrete sidewalls; conical bottom
  - Dual membrane cover – ½ dome; 7,800 ft3 biogas storage
- Digestate Tank Mixing System– One
  - Pumped mixing system with nozzles internal to tanks
  - 25 hp chopper style pumps
  - Total pumps – Two (one duty, one spare)
- Dewatering Feed Pumps – 2 (one duty, one spare)
  - Max Flow/Head: 110 gpm at 60 ft TH; 2.2% solids
  - Rotary lobe type; 5 hp; <200 rpm; Equipped with suction-side grinder
- Belt Filter Press Dewatering – Two (one duty, one spare)
  - Belt Size: 1.5 meter
  - Hydraulic/Solids Loading Capacity: 90 gpm; 1,350 dry lb/h each
  - Wash Water Pump: 5 hp; Belt Drive Motor: 3 hp; Hydraulic Power Unit: 2 hp
  - Operating Schedule at Current Flows – appx. 60 h per wk
  - Operating Schedule at Future Flows – appx. 120 h per wk
  - Emulsion polymer system
- Waste Gas Flare – Enclosed Type – 240 cfm; 4" W.C. gas pressure

2.3.2 Conceptual Facility Layout

The anaerobic digestion facility would require two 50-ft diameter concrete anaerobic digesters with fixed steel covers constructed west of the existing SPB. This location was selected due to available space, few utility conflicts, and it allows for less complex equipment arrangement for digestion equipment in the proposed new Biosolids Processing Building. The conceptual layout assumes that the existing SPB will be demolished.

A new Biosolids Processing Building would be constructed to house equipment including pumping, mixing, heating, and dewatering systems. The conceptual building layout was developed to provide adequate space for equipment access, chemical shipments, and effective cake distribution to roll-of containers.

A 30-ft diameter concrete digestate holding tank with dual membrane cover would be constructed east of the proposed Biosolids Processing Building. The dual membrane cover would provide approximately 7,800 ft^3 of biogas storage, which provides a buffer to provide consistent biogas flow to the Boilers during periods of fluctuating digestion performance.

An enclosed flare would be installed on the southeast side of the proposed facility between the Biosolids Processing Building and the existing Garage. The flare would be located at least 50 ft from any gas source to meet appropriate safety codes.

Details of the conceptual layout are shown in **Appendix B**.

2.3.3 Capital and Operational Costs

2.3.3.1 Capital Cost Opinion

In 2021, CDM Smith developed an OPCC for the proposed upgrades project outlined in Appendix B. The conceptual design details were revisited to account for inflated prices in 2022 compared to 2021. The OPCC for the conceptual process is approximately $36M.

2.3.3.2 Operational Cost Opinion

The anticipated O&M costs for the proposed project are summarized in **Table 2-5**. The annual operational costs could exceed $2.6M/year at current flows. Most of the costs are associated with sludge disposal, maintenance, labor, and electricity for the digestion process. Electricity demands at the liquid side treatment train will also increase due to return loads of BOD and TKN.

Table 2-5 Operational Costs of Digestion Facility

O&M Costs	Unit Costs	Current Sludge Flows		Future Sludge Flows	
		Quantity	Annual Costs	Quantity	Annual Costs
Labor	$95,000/FTE/yr	3 FTE	$285,000	3 FTE	$285,000
Dewatering Chemicals	$1.8/gal[a]	9,000 gal/yr	$16,200	18,000 gal/yr	$32,400
Natural Gas	$16/MMBTU[b]	19.475 MMBTU/yr[e]	$310	0 MMBTU/yr	$0[e]
Electricity for Digestion	$0.20/kWh	1,362,000 kWh/yr	$272,400	1,451,000 kWh/yr	$290,200
Electricity from Return Stream Loads (BOD/TKN)	$0.20/kWh	313,000 kWh/yr	$62,600	588,000 kWh/yr	$117,600
Sludge Disposal	$90/WT	11,600 WT/yr	$1,044,000	22,200 WT/yr	$1,998,000
Maintenance	2% of OPCC		$980,000		$980,000
Total O&M Costs			$2,660,510		$3,703,200

a. Dewatering chemicals inflation rate 40-50% since 2021 prices ($1.2/gal).
b. Commercial natural gas pricing increased to $16/MMBTU since 2021 ($14/MMBTU) - USEIA
c. Commercial electricity pricing increased to $0.20/kWh since 2021 ($0.15/kWh) – USEIA
d. Estimated 25% increase in sludge disposal costs compared to 2021 ($72/WT)
e. Assumes all gas used for heating digesters. 19.5 MMBTU/yr additional natural gas needed at current flows. 340 MMBTU/year excess biogas at future flows.

2.3.3 Biogas Utilization Analysis

An analysis of biogas flows, energy content, and recent equipment and operational costs was conducted to determine the best use of biogas. At current flows, the estimated power production from a combined heat and power system is approximately 200 kW which is on the low end of typical engine sizing. Additionally, the added cost of a gas treatment system to remove hydrogen sulfide, moisture, and siloxanes prior to combustion in the new engine would be significant. Due to these costs and operational challenges, combustion of the raw biogas in the process boilers to provide the heat needed for the anaerobic digestion process is recommended in lieu of cogeneration. As shown in Table 2-4, there would not be enough biogas to support full heating load of the digesters. Some supplemental heat would be available at future flows. However, the added heat value (340 MMBTU/year; 0.04 MMBTU/hr) is not significant, and additional equipment to recoup this heat would not be cost effective. An alternative solution is gas upgrading equipment to generate renewable natural gas (RNG), which is currently a lucrative market. However, equipment costs are high and should be considered.

2.3.4 Conclusions and Recommendations

The results of the study showed that construction of an anaerobic digestion system is technically feasible, and the most suitable location for the system is in the area of the existing sludge processing building. The construction cost for the digestion system is $36M, with associated operational costs of $2,600,000/yr (current flows) to $3,700,000/yr (at future flows).

Overall, the cost of this approach is significantly higher than the others currently in consideration. While the total mass of sludge disposed will decrease due to solids destruction, it does not address concerns such as PFAS, the capital cost of the process is high, sludge disposal costs are still significant, and other operational costs are high. PFAS is not destroyed during the digestion process, and a significant quantity of dewatered biosolids still need to be managed. The biosolids from this process are also considered Class B biosolids according to 40 CFR 503 regulations, which have few disposal outlets in the region. Therefore, the anaerobic digestion process is not recommended on site. However, there is a planning effort to develop a New England Regional Biosolids Facility, which could be designed around anaerobic digestion technology. If the facility is developed, the City could consider hauling to this site if at lower cost.

2.4 Sludge Drying

2.4.1 Thermal Drying Overview

Thermal drying can be used to reduce sludge volume and mass, while creating a stabilized (usually Class A) product for beneficial use, as defined in the U.S. EPA 40 CFR Part 503 regulations. Thermal drying processes deliver heat energy to the sludge to evaporate water and can produce biosolids with greater than 90% solids content and nutrient value dependent on the sludge composition. The thermal energy needed for the drying process can be provided by the use of surplus heat or by the combustion of fuels. In general, the dryer will not oxidize organic material, thus preserving the nutrient and organic content of the biosolids.

The goal of the dryer is to maximize total solids content while maintaining a safe solids temperature within the system to prevent combustion. Evaporative capacity, run time, solids residence time in the dryer and operating temperatures are key design guidelines.

There are many uses of thermally dried biosolids, such as land application on farms, landfilling, and as a precursor to downstream thermal destruction technologies. The product quality depends on how the biosolids are fed into the dryer, the dryer type, and any post processing equipment. Performance of the mechanical dewatering system greatly impacts the size of the dryer and energy requirements, with dewatering typically being more cost effective in removing water. Therefore, dewatering processes upstream of the dryer equipment should be operated to maximize total solids content. Centrifuges are commonly observed upstream of dryers.

2.4.2 Dryer Types

Based on a review of the WPCF operations, it is recommended to only consider dryer technologies that are appropriate for small to moderate sized WPCFs (<20MGD). Additionally, concerns about process safety are significant. Therefore, only rotary drum dryers and belt dryers were considered.

2.4.2.1 Rotary Drum Dryer

In this system, wet sludge is blended with recycled dry material to produce a dryer feed of approximately 65% TS. Heat is generally produced by the direct combustion of natural gas or biogas with excess air to produce exhaust gas with temperatures that exceed 1,500°F. Dehumidified exhaust gas is generally recycled in the dryer system to produce temperatures at the furnace outlet in the range of 850°F – 1,000°F.

Andritz and Baker-Rullman are two rotary drum dryer manufacturers often seen with others such as Uzelac Industries. Uzelac offers a rotary drum dryer system without backmixing. The Uzelac system is the dryer used in EcoRemedy’s gasification technology. Generally, the technology is comparable between the three manufacturers. A schematic of a rotary drum dryer system courtesy of Andritz is shown in **Figure 2-5.**

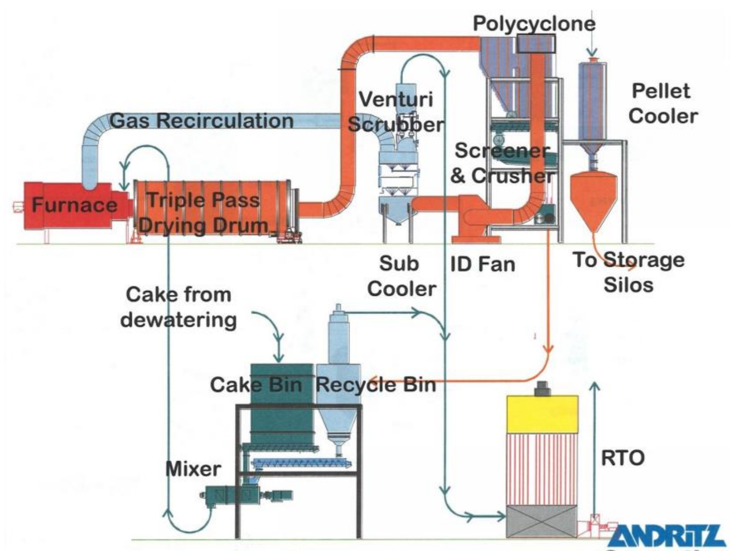

Figure 2-5
Rotary Drum Dryer Schematic

Advantages and Disadvantages of Rotary Drum Dryer are listed in **Table 2-6**.

Table 2-6 Advantages and Disadvantages of Rotary Drum Dryers

Advantages	Disadvantages
Large throughput capacity	Mechanically intensive process
Proven large capacity system	Recommend screening of liquid sludge to remove fiber and trash
High quality pellet	Safety concerns – can be managed but operators need to be well-trained
	Downtime for preventative maintenance can be substantial and provisions for equipment redundancy or disposal options necessary.
	Not widely used at small to moderate size WPCFs (<20MGD)

2.4.2.2 Belt Dryer

Belt dryers were originally designed to support small- to medium-loads in continuous operation. Manufacturers' belt material and configurations vary, with some using a single synthetic belt and others using multiple mesh or stainless steel belts. Solids feed systems also vary. Several manufacturers extrude the dewatered sludge onto the belt, while others use back-mixing of dried product with incoming cake.

Most belt dryers rely on pressurized extruders to develop strings of sludge that are carried on a belt and a rotating assembly that pushes sludge cake through fine openings of a screen with or without a leveling screw underneath. The intent of the extruder is to increase the surface area of the sludge and evenly spread it across the width of a perforated or porous belt. Once on the belt, the extruded sludge is conveyed through the dryer and is heated by recirculating hot gases.

Belt dryers operate with very high air-flow rates but at relatively low gas temperatures (260-330°F). The operating temperature inside the dryer is much less. These systems can use various heat sources such as hot air from natural gas or biogas combustion but can also use waste heat (i.e. hot water or steam from a cogeneration engine).

There are a number of manufacturers in the U.S. including Andritz, Gryphon, Huber, Veolia, and Centrysis. Other European manufacturers, such as SEVAR, are active in the US market. Some key differentiating features of these dryers include:

- Andritz – only one that recycles a portion of the finished product to form a pellet, and no extruder or sifter. Heating options range from direct natural gas fired to indirect hot water systems. Andritz usually requires that backmixing be included as part of their system.
- Gryphon – very compact layout with sludge inlet sifter. Direct dryer with high operating total connected motor hp. Very low exhaust flow to compared to others but more elaborate condensation removal system and recirculation of air through dryer.
- Huber – only offers an indirect hot water heating system and utilizes a feed sludge extruder. They have also gone away from the use of condensers and product coolers, but the exhaust volume is higher in general compared to others.

- Veolia – indirect heating of air with thermal oil system and utilizes a feed sludge extruder. Stainless steel belts offer low operating costs. They offer an energy recovery system add-on with an incinerator and flue gas treatment. The dryer plus incinerator option is not often cost effective especially at smaller plants with digested sludge that has a low heat value.
- Centrysis – indirect heating of air with hot water system and utilizes feed sludge extruder. Utilize a low-profile design to minimize height requirements. The heat recovery system is modular (multiple fans) and does not require an external heat exchanger. The system is based on the former Suzle Klein dryer from Germany.
- SEVAR – direct or indirect heated system with sludge extruder system. Modular design with condensation and air recirculation system. Smaller areal footprint compared to others due to higher vertical footprint.

A schematic of an indirect style of belt dryer with extruder, courtesy of Andritz, is shown in **Figure 2-6**.

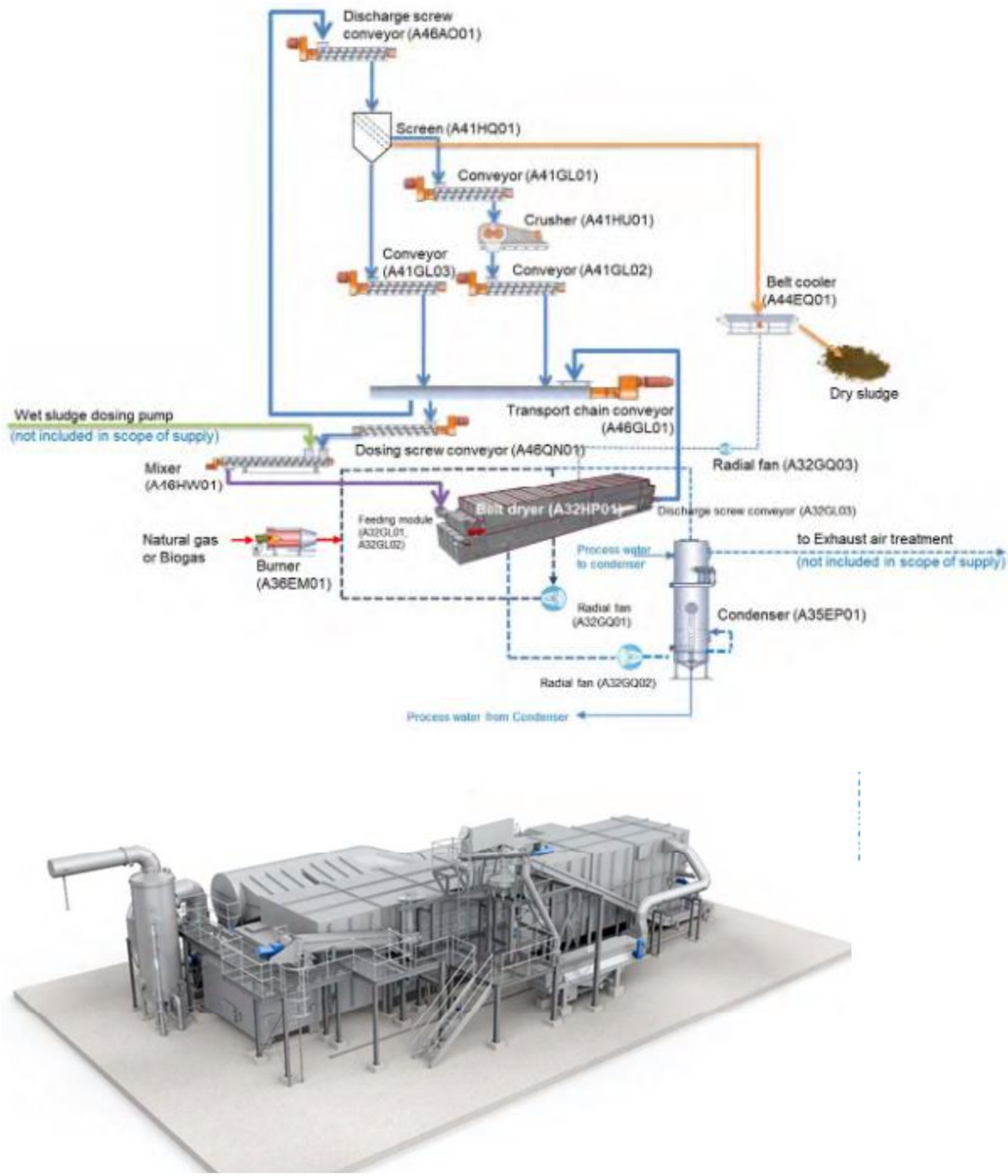

Figure 2-6
Indirect Belt Dryer Schematic (courtesy of Andritz)

Advantages and disadvantages of belt dryers are listed in **Table 2-7.**

Table 2-7 Advantages and Disadvantages of Belt Dryers

Advantages	Disadvantages
Simpler system, less materials handling	Extruder plugging/maintenance
Low temperature system and Class A compliance	Larger footprint
Granular product with some systems	Irregular shape product, potential fines
Intermittent operation	

2.4.3 Ancillary Equipment

2.4.3.1 Cake Hopper and Pumps

This system aids in providing a buffer between the dewatering equipment and the drying equipment and helps ensure a constant supply of dewatered cake is available for the dryer so that it can run continuously per the intended operating schedule. Sludge is conveyed out of the hopper and to the dryer generally by positive displacement pumps or via conveyors such as shaftless screws or belt conveyors. Belt conveyors are preferred when agitation of the sludge can impact quality and the ability to extrude sludge at the dryer.

2.4.3.2 Dried Sludge Conveyance and Storage

Dried product from the dryer needs to be conveyed to storage facilities or trucks. Common conveyance equipment for dried solids includes screw conveyors (shafted or shaftless), belt conveyors, bucket conveyors, drag conveyors, and pneumatic conveyors. Each conveyance type has advantages and disadvantages, and the choice of conveyance equipment is highly dependent on-site constraints and the selected storage method. For example, pneumatic transport systems are utilized in areas with limited footprint and dried product solids storage. However, pneumatic conveyance leads to higher dust production and is more energy intensive than other options. Lower energy options such as shafted screw conveyors can be used when limited vertical lift is needed.

Elevated dried product silos are very common storage methods at dryer facilities, to allow for seasonal storage when agricultural land application is the product outlet. However, these are often expensive and not feasible to fit in site constrained moderate sized WPCFs. Recently, the use of pole barns and direct discharge to trucks and/or dumpsters is preferred. These options are less expensive and require less space.

2.4.3.3 Odor Control

Off gas from dryers contain numerous odor causing compounds (i.e. volatile organic compounds, hydrogen sulfide, organic sulfur compounds, ammonia, and amines) which can be directed to odor control systems to reduce complaints associated with odors from nearby sensitive communities. This can be achieved via chemical or biological odor control or activated carbon technologies.

2.4.4 Basis of Evaluation

Based on the discussion above, belt drying is the preferred dryer technology and offers the most options with respect to the number of manufacturers, a higher degree of operational flexibility with the ability to run the system intermittently, is less complicated to maintain than some, and poses less safety concerns than other dryer types. Only indirect hot water belt dryers with known US installations were considered (Andritz, Huber, Centrysis, SEVAR). Hot water heat recovery was considered much easier to operate and control and thus amenable for operations staff compared to other heat recovery options (e.g., hot air).

2.4.4.1 Recommended Vendor for Dryer Only Alternative

The Dryer Only Alternative considers a belt dryer system from Andritz, or equal. The Andritz system was selected as the basis for this alternative due to higher product quality due to the backmixing system, and because it is installed at more municipal biosolids facilities than any other vendor. High product quality could be important to mitigate dust production during transport and increase the available outlets such as land application. Should the Dryer Only Alternative be selected by the City, the consideration of other lower cost belt dryer vendors with indirect heating could be re-evaluated. Additionally, there currently is not a strong market for Class A dried biosolids, so the requirement for backmixing may not be necessary.

2.4.5 Conceptual Design

The conceptual design of the sludge drying facility was developed based on the future sludge loads described in Section 2.1, existing sludge properties, and industry standard design parameters. Design conditions for the sludge dryer facility is shown in **Table 2-8** below:

Table 2-8 Dryer Design Basis

	Future Sludge Production	Current Sludge Production
Solids Production	70 WTPD	49 WTPD
Total Solids Content	20%	
Volatile Solids Content	74%	
Dryer Manufacturer	ANDRITZ BDS 22 Belt Dryer	ANDRITZ BDS 22 Belt Dryer
# of Dryers	1	1
Operational Frequency	24/7 operation	24/5 operation
Dryer Feed Rate	1,108 dry lbs/hr	776 dry lbs/hr
Evaporative (Water) Load	4,310 lb/hr	3,017 lb/hr
Heat Requirement	1,400± BTU/lb water evaporated	
Dryer Max Evaporative Capacity	4,840 lb/hr	
Solids in Dried Product	90%+	
Dried Product	15 wet ton/day	10 wet ton/day (7 wet ton/d)*
	31 CY/day	22 CY/day (15 CY/day)*

*product generation in parentheses shows annual average.

The proposed design includes one ANDRITZ BDS 22 thermal belt dryers (4,840 lb/hour evaporative capacity), which supports a 24 hour per day, 7 day per week operational schedule at future average dewatered cake flows estimated via the WEF MOP 8 method. At current sludge cake production, the dryer will have excess capacity to support operation at a less intensive operating schedule (example shown as 24 hours per day, 5 days per week). The proposed design assumes a dewatered cake with a 20% TS content. Should the proposed centrifuge operations lead to higher solids content, the dryer could be operated at a further reduced operating schedule. The process flow diagram for the proposed process is shown in **Figure 2-7**.

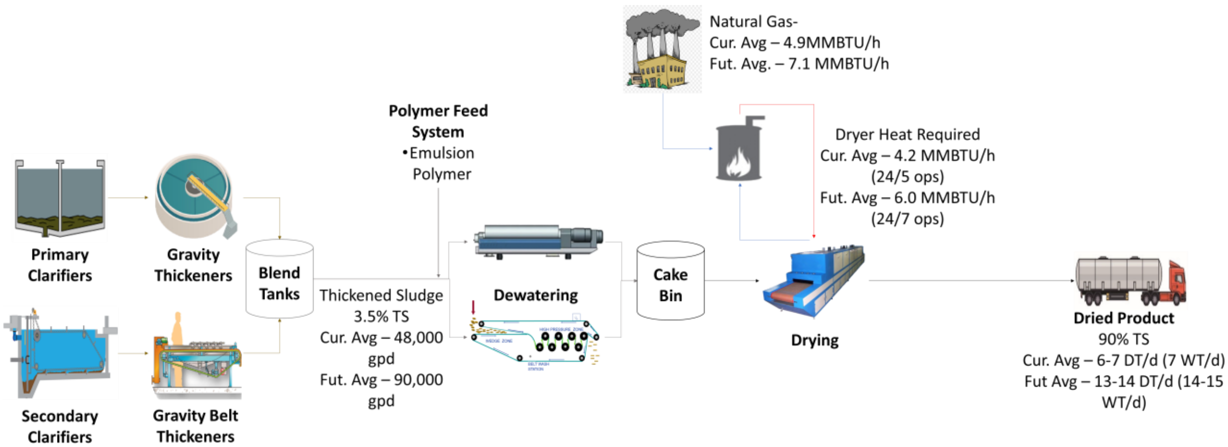

Figure 2-7
Sludge Drying Conceptual Process Flow Diagram

2.4.5.1 Equipment

The following preliminary equipment selections were included as part of the conceptual design:

- Dewatering Feed Pumps – Two (one duty, one spare)
  - Max Flow/Head: 110 gpm at 60 ft TH; 3.5% solids
  - Rotary lobe type; 5 hp; <200 rpm; Equipped with suction-side grinder
- Centrifuge Dewatering – Two (one duty, one spare)
  - Decanter Centrifuge
  - Hydraulic/Solids Loading Capacity: 70 gpm; 1,225 dry lb/h each
  - Main Motor: 50 hp; Secondary Motor: 10 hp
  - Operating Schedule at Current Flows – appx. 120 h per wk
  - Operating Schedule at Future Flows – appx. 168 h per wk
  - Emulsion polymer system (20 lb/DT)
- Wet Product Bypass Conveyance
  - 80 ft horizontal shaftless screw conveyor with multiple exit points
  - 30 ft horizontal shaftless screw conveyor to discharge to dumpster/trucks
- 100 CY Wet Cake Bin (in dryer manufacturer scope)
  - Two day storage at current sludge load
  - Live bottom bin
- Wet Cake Pump for dryer feed
- Dryer Equipment - Andritz BDS 22 Belt Dryer System – 4,840 lb H2O/hour max capacity
  - Indirect hot water heating system with 100% natural gas burner
  - Process fan and ductwork

  - Condenser (wet scrubber with internal spray mist trays and exhaust fan)
  - Dry product back mix system including mixer, screw conveyors, crusher and screen
  - Final product cooler
  - Support steelwork, access platforms and stairs for dryer system equipment
- Odor control included
- Dried Product Conveyance
  - Inclined shafted screw conveyor – 30 degree angle of incline (two exit points)
  - Two dried product shafted distribution conveyors – horizontal (two exit points)

2.4.6 Conceptual Facility Layout

The dryer facility would be constructed in a similar location of the existing SPB. This location was selected due to available space, few utility conflicts, and it allows for less complex equipment arrangement for equipment in the proposed Biosolids Processing Building. The conceptual layout assumes that the existing SPB will be demolished.

A new two-story Biosolids Processing Building would be constructed to house equipment including pumping, heating, dewatering and conveyance systems. The conceptual building layout was developed to provide adequate space for equipment access, chemical shipments, and effective distribution of wet cake or dried product to roll-of containers.

The dryer would be constructed in a one-story area adjacent and west of the proposed Biosolids Processing Building. The dryer facility would include the belt dryer, all fans/blowers for the dryer, the condenser, and internal conveyance systems to support backmixing. Wet cake would be conveyed from the Biosolids Building to the dryer building. Dried product from the dryer would be conveyed back to the Biosolids Building to the roll of containers on the northwest side. This will allow efficient movement of product out of the WPCF. Dried product storage was not included due to low cost, and uncertainty regarding agricultural land application outlets.

An odor control system would be installed either on the roof of the Biosolids Building or adjacent to the dryer building or Biosolids Building.

Details of the conceptual layout are shown in **Appendix C**.

2.4.7 Capital and Operational Costs

2.4.7.1 Capital Cost Opinion

The OPCC for the conceptual process is approximately $38M.

2.4.7.2 Operational Cost Opinion

The anticipated O&M costs for the proposed project are summarized in **Table 2-9**. The annual operational costs could exceed $1.9M/year at current flows. Most of the costs are associated with maintenance, natural gas, labor, and electricity for the process. Electricity demands at the liquid side treatment train will also increase due to return loads of BOD and TKN, albeit at minor quantities.

Table 2-9 Opinion of Operational Costs for Sludge Dryer System

O&M Costs	Unit Costs	Current Sludge Flows		Future Sludge Flows	
		Quantity	Annual Costs	Quantity	Annual Costs
Labor	$95,000/FTE/yr	2 FTE	$190,000	2 FTE	$190,000
Dewatering Chemicals	$1.8/gal	15,000 gal/yr	$28,000	30,000 gal/yr	$55,000
Natural Gas	$16/MMBTU	26,000 MMBTU/yr	$424,000	53,000 MMBTU/yr	$848,000
Electricity for Dryer	$0.20/kWh	1,373,000 kWh/yr	$275,000	1,918,000 kWh/yr	$384,000
Electricity from Return Stream Loads (BOD/TKN)	$0.20/kWh	10,000 kWh/yr	$2,000	19,000 kWh/yr	$4,000
Odor Control	TBD	TBD	$25,000	TBD	$50,000
Sludge Disposal	$90/WT	2,700 WT/yr	$243,000	5,400 WT/yr	$486,000
Maintenance	2% of OPCC		$960,000		$960,000
Total O&M Costs			**$2,147,000**		**$2,977,000**

2.5 Emerging Thermal Treatment Technologies

This section presents thermal treatment technologies currently in various stages of development to support PFAS destruction. Three technologies are evaluated, including drying + pyrolysis, drying + gasification, and supercritical water oxidation.

2.5.1 Drying + Pyrolysis

Pyrolysis is the thermal decomposition of materials at high temperatures (>450–600°C) in the absence of oxygen. The process involves conveying dried sewage sludge (typically 80-90% solids although some systems are designed at lower solids content) to a closed pressurized high-temperature reactor vessel. The final products include synthesis gas ("syngas"; H_2+CO+CO_2+others), and biochar. The mass distribution of each product is dependent on the design and operating conditions of the system. A schematic of the pyrolysis process is shown in **Figure 2-8**.

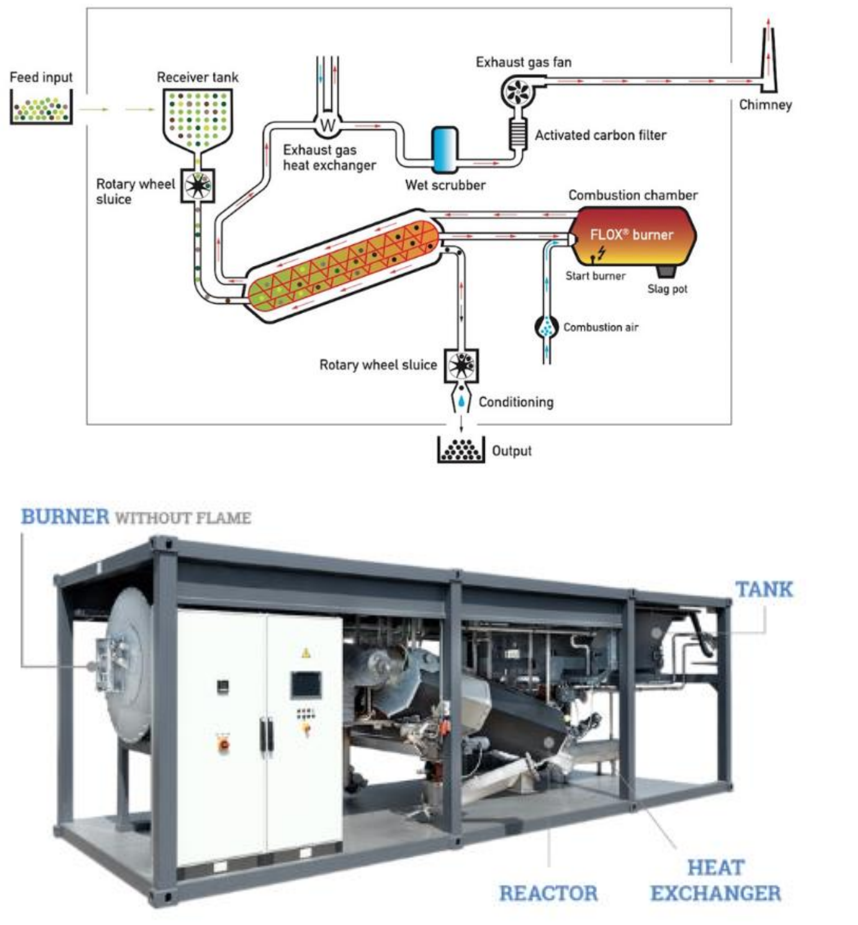

Figure 2-8
Pyrolysis Process and Reactor (Source -BioForceTech)

Syngas can be combusted, and energy recovered from combustion can be used for heat in the pyrolysis and upstream sludge drying processes. Meanwhile, the solid biochar product is a carbon-rich residual with multiple end-uses. Biochar is hydroscopic so it retains moisture and nutrients when land applied, it reduces fertilizer run-off and resists degradation. Higher value markets include filtration media, colorant for plastics and rubbers, and other uses.

The key benefits of pyrolysis is that it reduces the mass of products that must be disposed and the gas produced can be combusted for energy recovery to satisfy thermal needs of the system; generally with a surplus of heat available for beneficial reuse onsite. Recent research shows no detectable PFAS in biochar after pyrolysis, suggesting the process can remove PFAS molecules in dried municipal sludge[10].

The downside of the technology is that it is relatively unproven with only one installation at a U.S. WPCF (Silicon Valley CA). Additionally, over the past 30+ years several companies have

[10] USEPA Science Inventory: Pyrolysis Processing of PFAS-Impacted Biosolids, a Pilot Study. March 2022. https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=354243&Lab=CEMM

attempted to bring the technology to market with limited success implying the technology carries risk. Additionally, a recent high-profile facility (Schenectady NY) recently was shut down due to process issues.

There is also regulatory uncertainty with respect to pyrolysis and gasification, as the USEPA is considering how to include the technologies into the Clean Air Act[11]. Another major downside is that the operating temperatures (450–600°C) are lower than the combustion temperatures of most PFAS compounds (>1,000°C)[12] implying the PFAS in the dried sewage sludge may not be fully destroyed and could be present in the syngas. Although recent scientific reports showed few PFAS compounds in biochar and effluent water after pyrolysis, the PFAS in exhaust gas was poorly defined.

However, the syngas combustion equipment operates near or above 1,000°C and may be hot enough to destroy PFAS compounds. PFAS compounds from syngas combustion may also be present in scrubber water required for combustion air treatment. Additionally, there are three additional pyrolysis processes planned to be commissioned or constructed by 3rd quarter of 2022 (see **Table 2-10**).

Table 2-10 Pyrolysis Facilities in Implementation

Facility/Location	Vendor	Size (WT/d)	Status
Silicon Valley Clean Water, CA	Bioforcetech	20	Operating since 2017
Ephrata PA	Bioforcetech	20	Construction 4Q, 2022
Schenectady, NY	Biowaste Pyrolysis Solutions	100	Commissioned 3Q, 2022. Abandoned late 2022 due to process issues.
Rialto, CA	Anaergia	300	Commissioning 1Q, 2023

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2.5.2 Sludge Drying and Gasification

Gasification involves the application of high temperatures to organic solids in an oxygen starved environment; note some oxygen is still present albeit at low concentrations which makes this process different from pyrolysis. This system also generally operates at higher temperatures than pyrolysis (675-815°C vs 450-600°C respectively). The higher temperature results in more syngas produced with generally a higher energy content. However, the solids product is generally an ash rather than biochar which has minimal beneficial end uses. Like in pyrolysis, the syngas produced during gasification can be combusted and energy recovered from combustion can be used for heat in the gasifier as well as the required upstream sludge drying processes.

The key benefit of gasification is that it yields more energy than pyrolysis and should have a slightly smaller quantity of solids product that would require ultimate management.

Disadvantages of gasification include the fact that the emissions in the off gas have not been well defined, which could necessitate stringent air permits. Any oxygen addition to the reactor could

[11] USEPA. Advance Notice of Proposed Rulemaking on Pyrolysis and Gasification Unit. https://www.epa.gov/stationary-sources-air-pollution/advance-notice-proposed-rulemaking-pyrolysis-and-gasification#rule-summary
[12] Examining thermal destruction for PFAS waste. Fred Taylor. Doug Smith. Chris Hertle. GHD. 2020. https://www.ghd.com/en/about-us/examining-thermal-destruction-for-pfas-waste.aspx

cause regulators to perceive the technology as an incineration process and require similar permitting restrictions. The USEPA is currently evaluating how to regulate pyrolysis and gasification as part of the Clean Air Act, and in some regions have already established gasification as an incineration technology.

There are very few installations on this technology running on biosolids alone, as shown in **Table 2-11**. There is limited data available to support claims that gasification removes PFAS from sludge. It is recommended to monitor progress at the sites expected to be commissioned in late 2023 before considering this alternative in further detail. It is also unclear if these sites are operating on biosolids alone. Most gasification systems have required higher BTU value feedstocks such as woodchips to maintain operations.

Table 2-11 Gasification Facilities in Implementation at Wastewater Facilities

Facility/Location	Vendor	Size (WT/d)	Status
Edmonds, WA	Ecoremedy, LLC	40	Commissioning 1Q, 2023
Linden Roselle Sewage Authority, NJ	Aries Clean Energy	430	Commissioning not completed
Derry Township, PA	Ecoremedy, LLC	70	Construction Q3, 2023
Bethel, PA	Earthcare, LLC	200	Operations Mid 2023

2.5.3 Supercritical Water Oxidation

Supercritical water oxidation of wastewater sludge involves heating and pressurizing dewatered cake (nominally 10-15% solids) to the critical point of water (374°C, 221 bar) while injecting air or high purity oxygen. Under these conditions, water exists as a supercritical fluid and is a good solvent for nonpolar materials such as hydrocarbons and oxygen gas and is a poor solvent for salts and other ionic compounds.[13] This provides an excellent medium for rapid oxidation of aqueous organic wastes. A schematic of the SCWO process is shown in **Figure 2-9**.

[13] Supercritical Water Oxidation – Current Status of Full-scale Commercial Activity for Waste Destruction. Philip A. Marrone. Science Applications International Corporation (SAIC). 2013. The Journal of Supercritical Fluids 79: 283-288. https://www.sciencedirect.com/science/article/abs/pii/S0896844612003919

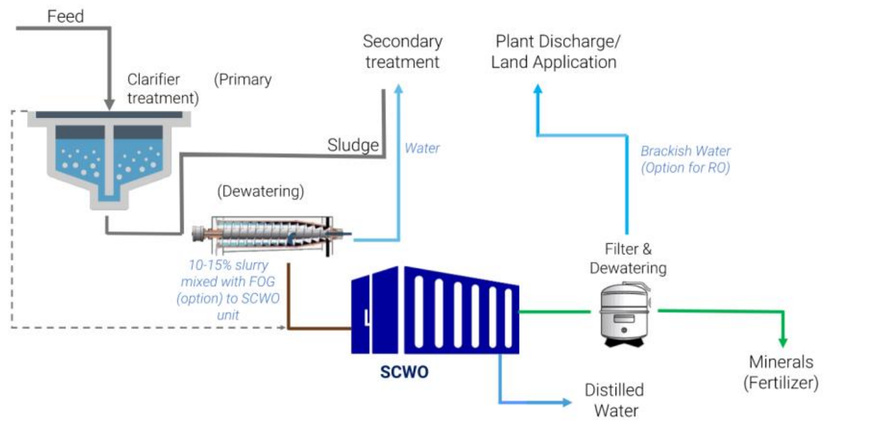

Figure 2-9
Supercritical Water Oxidation Process (Source - 374water[14])

There are several benefits to supercritical water oxidation including nearly complete oxidation of solids within seconds of detention time and the process can be fed at 10–15% solids which does not require an upstream dryer. Additionally, temperatures of the reaction are low enough that NOx and SOx are not produced; the end products of oxidation are relatively innocuous (carbon dioxide, nitrogen gas, and $CaSO_4$). Recycle streams from this process are negligible and so air permitting concerns are minimal. Finally, the system has been shown to break the carbon–fluoride bonds in PFAS compounds, meaning the system could be used to meet future PFAS regulations.

The downside of the system is that there are no known commercial installations at AWRFs (Orange County, California will be commissioned in 2023). Additionally, there are likely high energy demands to start the system, though the reaction is self-sustaining after startup and produces surplus heat which can be recovered to drive a steam turbine or an organic-Rankine cycle engine for electricity production. Furthermore, the salts produced are expected to be highly corrosive at the extreme temperatures and pressure required for the reaction. Specialty operators may be required for the high temperature/high pressure conditions of the reaction. There are also concerns that the technology has difficulty breaking down short chain fluorinated hydrocarbons, and emergency discharge of supercritical aqueous fluids is a concern[15][16].

Several companies attempted to commercialize SCWO in the past 20 years, with very limited success due to the varying issues described above (e.g., insufficient heat recovery, corrosivity). However, there is considerable interest from research organizations such as Duke University (374 Water collaborator), Batelle (contract research organization)[17], and the USEPA[18].

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[14] Invent the Future with Us Resource Recovery with Supercritical Water Oxidation (SCWO) NEBRA 2020. Doug Hatler. 374water.com
[15] Li, Y., Wang, S., Xu, T., Li, J., Zhang, Y., Xu, T., Yang, J. 2021. Novel designs for the reliability and safety of supercritical water oxidation process for sludge treatment. Process Safety and Environmental Protection 149: 385-398.
[16] Li, J., Austin, C., Moore, S. Pinkard, B.R., Novosselov, I.V. 2023. PFOS destruction in a continuous supercritical water oxidation reactor. Chemical Engineering Journal 451: 139063.
[17] Don't Move PFAS. Destroy It. PFAS Annihilator™ Destruction Technology. https://www.battelle.org/docs/default-source/environment/white-papers/774_pfas-annihilator-white-paper.pdf?sfvrsn=5900ef94_12
[18] Krause, M.J., Thoma, E., Sahle-Damesessie, E., Crone, B., Whitehill, A., Shields, E., Gullett, B. 2022. Supercritical Water Oxidation as an Innovative Technology for PFAS Destruction. Journal of Environmental Engineering 148: 2.

2.5.4 Summary of Thermal Technologies

There are several thermal treatment technologies currently under development that can be applied for further solids removal, PFAS destruction, and energy recovery. Each of the technologies have different advantages and disadvantages and are at various technology readiness level. **Table 2-12** summarizes the findings from the evaluation of these techniques.

Table 2-12 Thermal Destruction Technology Comparison

Technology	Full Scale Installations	Advantages	Disadvantages
Pyrolysis	1 (4)	• High quality product (biochar) • Heat recovery for drying • PFAS removal in peer reviewed studies	• Requires dryer purchase upfront • PFAS destruction in gas stream not verified
Gasification	2 (4)	• High heat recovery for drying/additional energy	• Requires dryer purchase upfront • PFAS removal claims not verified in peer review • Other air contaminants possible
Supercritical Water Oxidation	0 (1)	• PFAS removal in peer reviewed studies • Lowest volume of waste product • No drying required upstream • Energy/electricity recovery	• Only 1 install planned at WWTP in 2023 • Some evidence of short chain PFAS in water stream

Based on the results in Table 2-12, there are several facilities currently constructing and/or piloting the thermal PFAS destruction technologies described above. There appears to be most interest in pyrolysis, gasification, and supercritical water oxidation due to preliminary testing results showing removal of PFAS from the biosolids matrix. However, it appears that additional testing is warranted to close the fluorine balance to determine whether PFAS is simply removed and transferred to other matrices (air, water) or actually destroyed. Supercritical water oxidation appears to be the only technology that destroys PFAS directly due to high temperature/pressure and oxidative conditions. Meanwhile, it appears that PFAS is volatilized to the syngas phase in pyrolysis/gasification projects, and the high temperature thermal oxidizer is required to destroy PFAS in the gas phase. Overall, it is recommended to monitor the technologies above. If one of the technologies is selected, piloting is strongly recommended prior to implementation.

2.5.5 Drying + Gasification Detailed Analysis

There was significant interest by the City to investigate the Drying + Gasification option further. The section below shows an assessment of the technology so it can be compared to the other alternatives considered. Not included herein is the ongoing O&M costs required for air permitting compliance, however EPA Region 1 may consider gasification an incineration technology, which would require similar monitoring and reporting as a newly permitted SSI.

2.5.5.1 Vendor Provided Information

CDM Smith requested information from EcoRemedy on the cost to install a dryer+ gasification system at the WPCF. However, no information such as budgetary proposals, footprint, operational costs were provided from the vendor. The only information available was a brochure provided to the City with a generalized arrangement for a packaged drum dryer + gasification system. The system footprint was approximately similar to the belt dryer option described in Appendix B and the text above. Per the documents provided (**Appendix C**), the maximum throughput of the system is 10,000 WT per day. Using the information above CDM Smith developed a conceptual cost for the approach.

2.5.5.2 Conceptual Design

The conceptual design of the sludge drying + gasification facility was developed based on the future sludge loads described in Section 2.1, existing sludge properties, and industry standard design parameters. Design conditions for the sludge dryer facility is shown in **Table 2-13**.

Table 2-13 Dryer + Gasification Design Basis

	Future Sludge Production	Current Sludge Production
Solids Production	70 WTPD	49 WTPD
Total Solids Content	20%	
Volatile Solids Content	74%	
Dryer + Gasification Manufacturer	EcoRemedy	EcoRemedy
# of Systems	1	1
Maximum Throughput	10,000 WT per year	10,000 WT per year
	37 WTPD	37 WTPD
Bypassed Cake	**33 WTPD**	**12 WTPD**
Operational Frequency	24/7 operation	24/5 operation
System Feed Rate	457 dry lbs/hr	639 dry lbs/hr
Evaporative (Water) Load	1,776 lb/hr	2,486 lb/hr
Heat Requirement	1,400± BTU/lb water evaporated	
Volatile Solids to Gasification	338 lb VS/hr	473 lb VS/hr
Energy Content of Solids	10,500 BTU/lb VS	10,500 BTU/lb VS
Energy Potential of VS Combustion	3.6 MMBTU/hr	5.0 MMBTU/hr[1]
Ash Production	1.5 WT/day	1.5 WT/day
	4 CY/day	4 CY/day

1. Theoretically adequate to provide dryer heating requirements (not considering combustion efficiency, HEX efficiency, etc.)
2. Based on available information from EcoRemedy, the maximum throughput is 10,000 WT/day, which is below the current and future production rate at the facility. Therefore, some wet cake would need to be bypassed.

The proposed design includes one 10,000 WT per year dryer and gasification system, which supports a partial treatment of biosolids at current and future flows. At current design flows, the system should be able to provide treatment of 75% of sludge, while 25% of the dewatered cake would need to be bypassed.

The process flow diagram for the proposed process is shown in **Figure 2-10**.

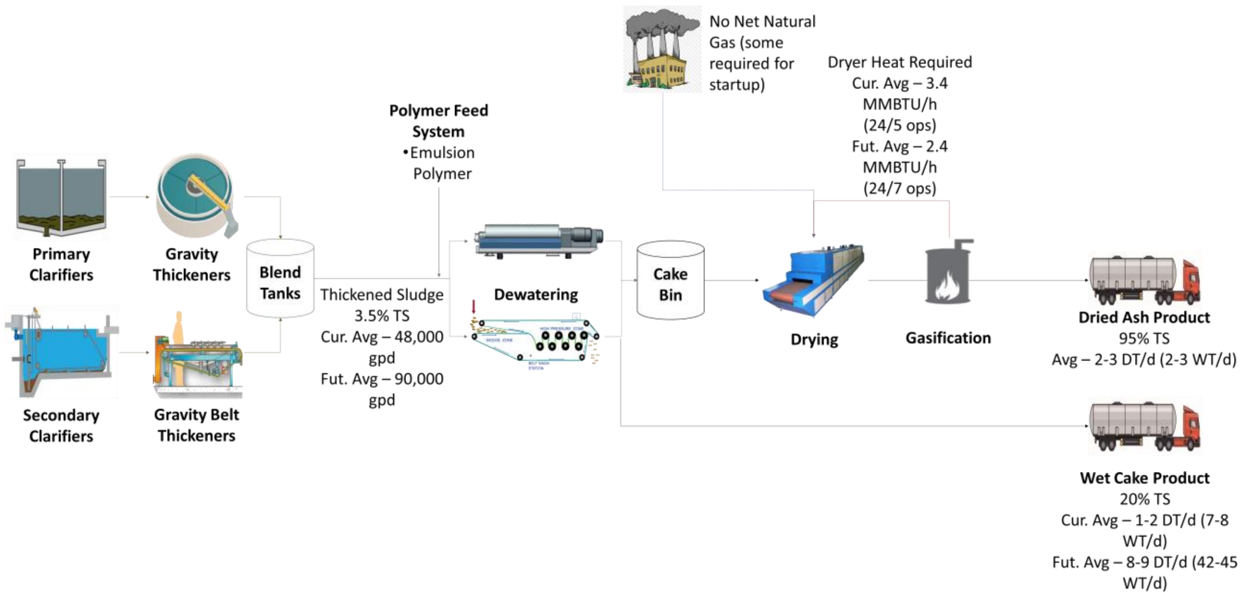

Figure 2-10
Sludge Drying and Gasification Conceptual Process Flow Diagram

2.5.5.3 Equipment

The following preliminary equipment selections were included as part of the conceptual design:

- Dewatering Feed Pumps – Two (one duty, one spare)
  - Max Flow/Head: 110 gpm at 60 ft TH; 3.5% solids
  - Rotary lobe type; 5 hp; <200 rpm; Equipped with suction-side grinder
- Centrifuge Dewatering – Two (one duty, one spare)
  - Decanter Centrifuge
  - Hydraulic/Solids Loading Capacity: 70 gpm; 1,225 dry lb/h each
  - Main Motor: 50 hp; Secondary Motor: 10 hp
  - Operating Schedule at Current Flows – appx. 120 h per wk
  - Operating Schedule at Future Flows – appx. 168 h per wk
- Emulsion polymer system (20 lb/DT)
  - Wet Product Bypass Conveyance
  - 80 ft horizontal shaftless screw conveyor with multiple exit points
  - 30 ft horizontal shaftless screw conveyor to discharge to dumpster/trucks
- 100 CY Wet Cake Bin – Two day storage at current sludge load
  - Live bottom bin
  - Wet Cake Pump for dryer feed

- Dryer and Gasification Equipment – EcoRemedy System
- Dried Product Conveyance
  - Inclined shafted screw conveyor – 30 degree angle of incline (two exit points)
  - Two dried product shafted distribution conveyors – horizontal (two exit points)

2.5.5.4 Conceptual Facility Layout

The dryer facility would be constructed in a similar location of the existing SPB. This location was selected due to available space, few utility conflicts, and it allows for less complex equipment arrangement for equipment in the proposed Biosolids Processing Building. The conceptual layout assumes that the existing SPB will be demolished.

A new two-story Biosolids Processing Building would be constructed to house equipment including pumping, heating, dewatering and conveyance systems. The conceptual building layout was developed to provide adequate space for equipment access, chemical shipments, and effective distribution of wet cake or dried product to roll-of containers.

The dryer + gasification system would be constructed in a one-story area adjacent and west of the proposed Biosolids Processing Building. The facility would include the rotary drum dryer, all fans/blowers for the dryer, the condenser, and internal conveyance systems to support backmixing. Wet cake would be conveyed from the Biosolids Building to the gasification building. Ash from the system would be conveyed back to the Biosolids Building to the roll of containers on the northwest side. This will allow efficient movement of product out of the WPCF. Ash storage was not included due to low cost, and uncertainty regarding agricultural land application outlets.

An odor control system would be installed either on the roof of the Biosolids Building or adjacent to the dryer building or Biosolids Building. The conceptual layout would be equivalent to that shown in Appendix C, but the gasification system/dryer system would be in place of the Andritz Belt Dryer System.

2.5.5.5 Capital Cost Opinion

The OPCC for the conceptual process is approximately $56M.

2.5.5.6 Operational Cost Opinion

The anticipated O&M costs for the proposed project are summarized in **Table 2-14**. The annual operational costs could exceed $2.4M/year at current flows. Most of the costs are associated with sludge disposal, maintenance, labor, and electricity for the process. Electricity demands at the liquid side treatment train will also increase due to return loads of BOD and TKN, albeit at minor quantities.

Table 2-14 Dryer + Gasification Operational Costs

O&M Costs	Unit Costs	Current Sludge Flows		Future Sludge Flows	
		Quantity	Annual Costs	Quantity	Annual Costs
Labor	$95,000/FTE/yr	2 FTE	$190,000	2 FTE	$190,000
Dewatering Chemicals	$1.8/gal	15,000 gal/yr	$28,000	30,000 gal/yr	$55,000
Natural Gas	$16/MMBTU	0 MMBTU/yr	$0	0 MMBTU/yr	$0
Electricity for System	$0.20/kWh	1,635,000 kWh/yr	$327,000	2,284,000 kWh/yr	$457,000
Electricity from Return Stream Loads (BOD/TKN)	$0.20/kWh	10,000 kWh/yr	$2,000	19,000 kWh/yr	$4,000
Odor Control	TBD	TBD	$25,000	TBD	$50,000
Sludge Disposal (Wet Cake)	$200/WT	2,800 WT/yr	$554,000	15,600 WT/yr	$3,102,000
Ash Disposal	$90/WT	600 WT/yr	$50,000	600 WT/yr	$50,000
Maintenance	2% of OPCC		$1,320,000		$1,320,000
Total O&M Costs			$2,496,000		$5,228,000

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Section 3

Conclusions and Recommendations

3.1 Alternatives Comparison

The annualized cost of the five alternatives considered is shown in **Table 3-1**. The results show that **incineration has the lowest capital and operational costs** out of the four upgrade alternatives (Incineration, Anaerobic Digestion, Drying and Drying + Gasification) considered at both current and future sludge flows ($931/DT and $618/DT). The hauling and disposal alternative is comparable to incineration at current flows. However, the cost of sludge hauling and disposal is extremely volatile and unpredictable, and costs could increase to over $1,000/DT in the next few years.

Table 3-1 Comparison of Sludge Handling Alternatives

Technology	Construction Cost	Annual Cost of Constr. Capital ($/yr)[1]	Operational Costs ($/yr)		Total Annualized Cost ($/yr)		Cost per DT	
			Current	Future	Current	Future	Current	Future
Hauling + Disposal	$0	$0	$1.4M	$6.6M	$1.4M	$6.6M	$555	$1,302
Incineration	$20.4M	$1.2M	$1.1M	$1.9M	$2.38M	$3.2M	$931	$618
Anaerobic Digestion	$38M	$2.3M	$2.7M	$3.7M	$5.0M	$6.0M	$1,951	$1,179
Drying	$38M	$2.3M	$2.2M	$3.0M	$4.5M	$5.3M	$1,750	$1,040
Drying + Gasification	$56M	$3.4M	$2.5M	$5.3M	$5.9M	$8.7M	$2,317	$1,693

1. 20 year project life, 2 percent interest rate
2. Current sludge hauling/disposal costs estimated as estimated current sludge flows (12,775 WT/yr) * current sludge costs ($100/WT)
3. Future sludge hauling/disposal costs are estimated at the future sludge flows (2 X 12,775 or 25,550 WT/yr) * estimated future sludge costs ($250/WT). There is uncertainty that both the sludge quantity will double and the cost for hauling cake will more than double from $100/WT to $250/WT.

Currently, an onsite thermal treatment technology (e.g., dryer and gasification) system does not appear financially viable compared to other alternatives considered. Additionally, future work is needed to verify PFAS destruction claims from this (and other) emerging technologies. Several of the PFAS destruction technologies (gasification, SCWO, pyrolysis) will come online during 2023. The status of these pilot and full scale systems and future PFAS regulations should be monitored. Sludge drying may be a good hedge against future regulations, since a dried Class A product could have more favorable external outlets. This could be critical considering several PFAS destruction technologies (pyrolysis/gasification) require a dried feedstock.

Overall, it is suggested that the City consider an upgrade to the existing Incineration system to reduce hauling and disposal costs for sludge. While the system comes with permitting risk, the benefits of having an incinerator on site result in lower capital costs compared to other alternatives considered.

Based on the City's Title V Operating Permit Capacity (appx. 14 DTPD), there is an opportunity for the WPCF to take in outside sludge from neighboring facilities at current flows (7 DTPD). At 7DTPD of outside sludge at $130/WT ($650/DT at 20% solids), approximately $1.6M in annual revenue could be accrued until the West Haven WPCF reaches its rated plant capacity. This would serve as a revenue source for the City to offset capital and operational costs long-term. It would also serve as relief for the state and region that currently has insufficient sludge processing capacity. Alternatively, the City could entertain bringing in a 3rd party to operate the incinerator as a merchant facility similar to Naugatuck or Waterbury, which could offset their capital investment and long-term sludge management costs.

3.2 Total Project Cost Estimate - Incineration

The total opinion of probable construction cost (OPCC) is $20.4M is shown in **Table 3-2** below. The cost includes demolition, the Envirocare scrubber system consisting of quencher, tray scrubber, multi-venturi scrubber and WESP, the APC Technologies carbon adsorption system with UHF and HEPA filters, reheat heat exchanger, ID fan, the caustic and ammonia storage and recirculation tanks and pumps, the building addition to house the new equipment, electrical work, controls and instrumentation, process and drain piping, overhead and profit, contingency, and engineering design and services during construction.

The estimated annual costs for operations and maintenance at the current and future sludge flows are $1,131,900/yr and $1,911,000/yr, respectively.

Table 3-2 Incineration - Engineers Opinion of Probable Construction Cost

No	Description of Item	Cost ($)
1	Demolition and Sitework	$300,000
2	Envirocare wet scrubbing system - quencher, tray scrubber, multi- venturi scrubber, WESP	$1,530,000
3	APC Technologies Carbon Adsorption System - carbon adsorber, UHF and HEPA filters, start-up heater skid, reheat heat exchanger, ID fan & ductwork	$1,500,000
4	NOx Control system, 500 gals. ammonia storage tank, two metering pumps, 8 injectors, piping, valves and instrumentation	$400,000
5	Caustic storage tank, 500 gals, recirculation tank 300 gals, two recycle pumps, two metering pumps with VFDs, valves & piping	$450,000
6	Installation of Envirocare & APC Technologies equipment - quencher, scrubbers, WESP, carbon adsorber, UHF & HEPA filters, heat-up skid, ID fan, ductwork, caustic and ammonia systems including tanks, pumps and piping	$2,330,000
7	Building addition 61 ft x 31 ft x 35 ft ht. to Solids Processing Building with platforms to access wet scrubbers, WESP and carbon adsorber, containment cells around caustic & ammonia storage tanks	$1,500,000
8	Electrical work and wiring	$750,000
9	Controls and instrumentation	$400,000
10	Process piping including drain piping	$500,000
11	Subtotal	$9,660,000
12	Contractor's general conditions, overhead & profit @ 30%	$2,900,000
13	Subtotal cost with overhead & profit	$12,560,000
14	Contingency @ 30%	$3,770,000
15	Subtotal with overhead & profit & contingency	$16,330,000
16	Engineering design and services during construction @ 25%	$4,080,000
17	**Opinion of Probable Project Cost**	**$20,410,000**

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Appendix A

Incineration Improvements

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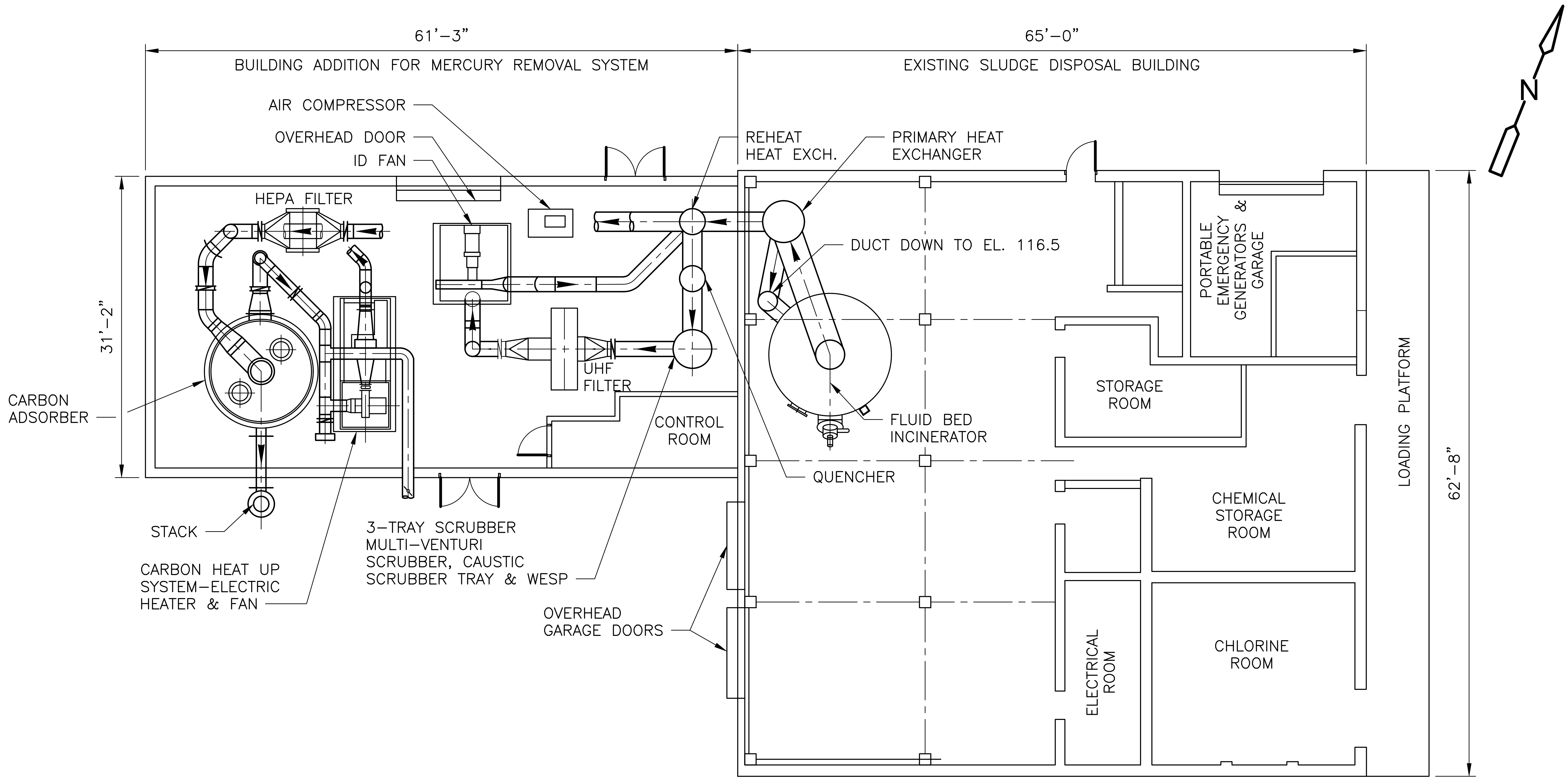

FIRST FLOOR PLAN

CDM Smith

Appendix B

Digester Improvements

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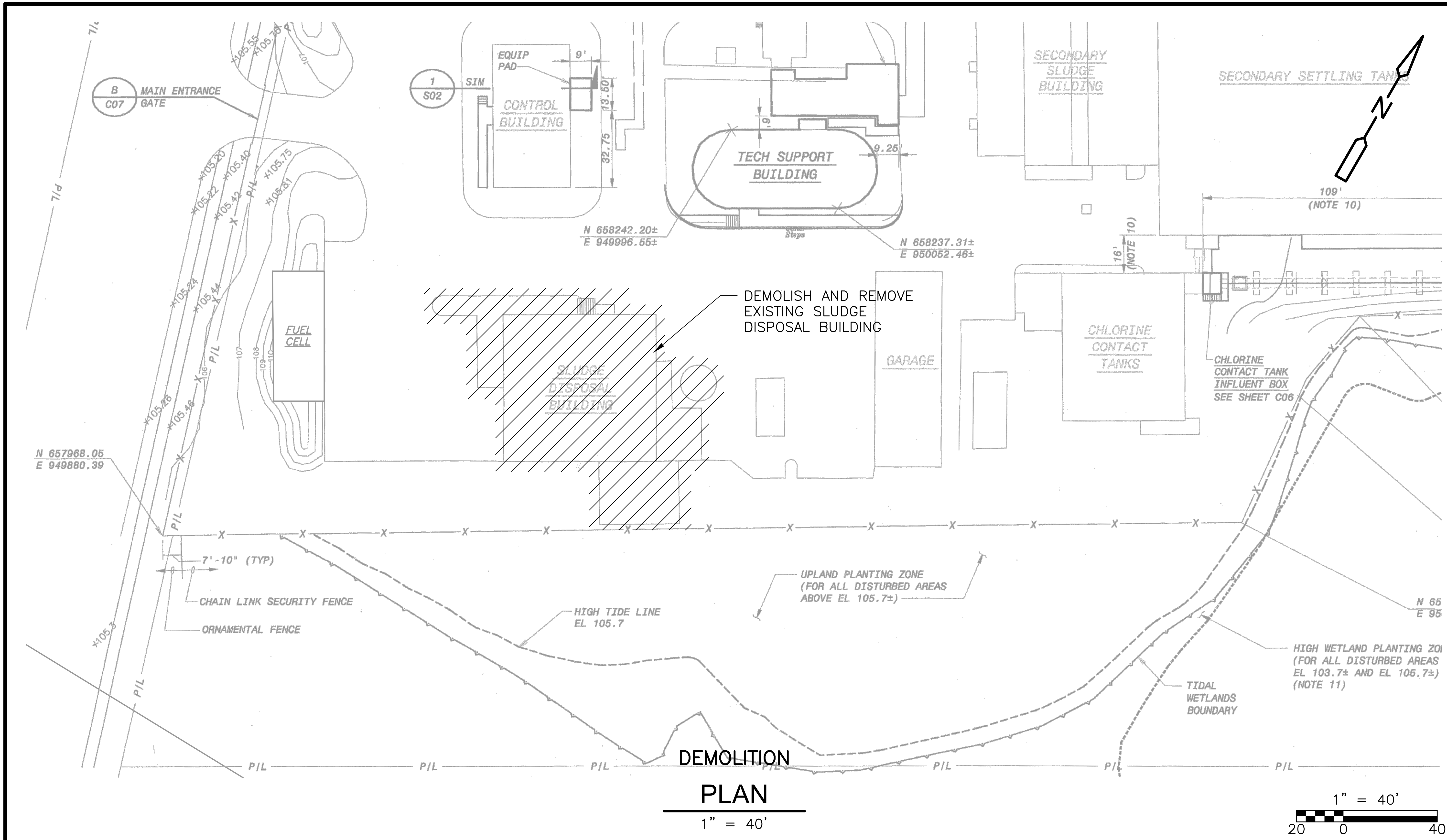
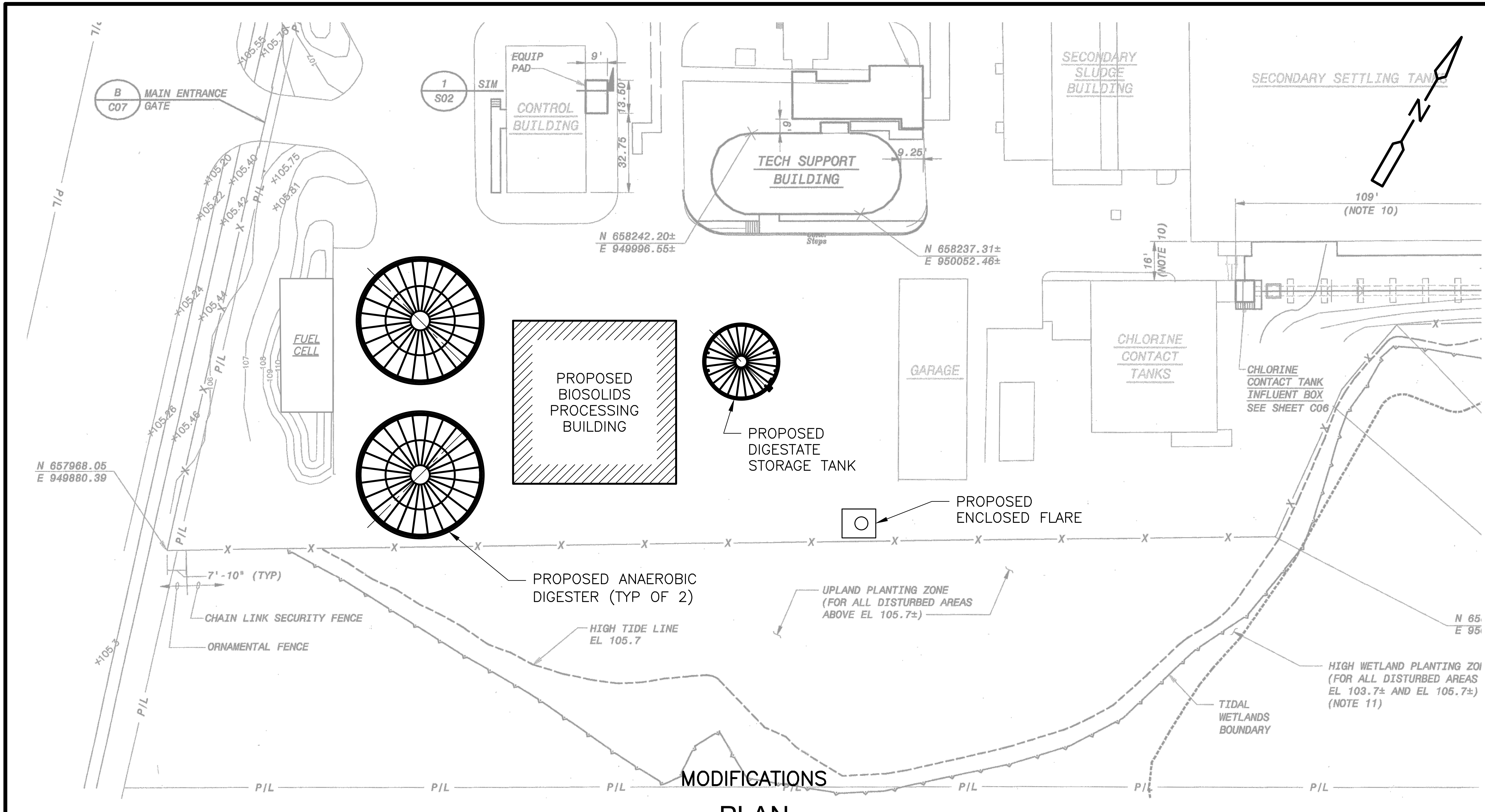


DEMOLITION PLAN

1" = 40'

CDM Smith

Figure No. C-1
ANAEROBIC DIGESTION FACILITY
NOVEMBER 2021

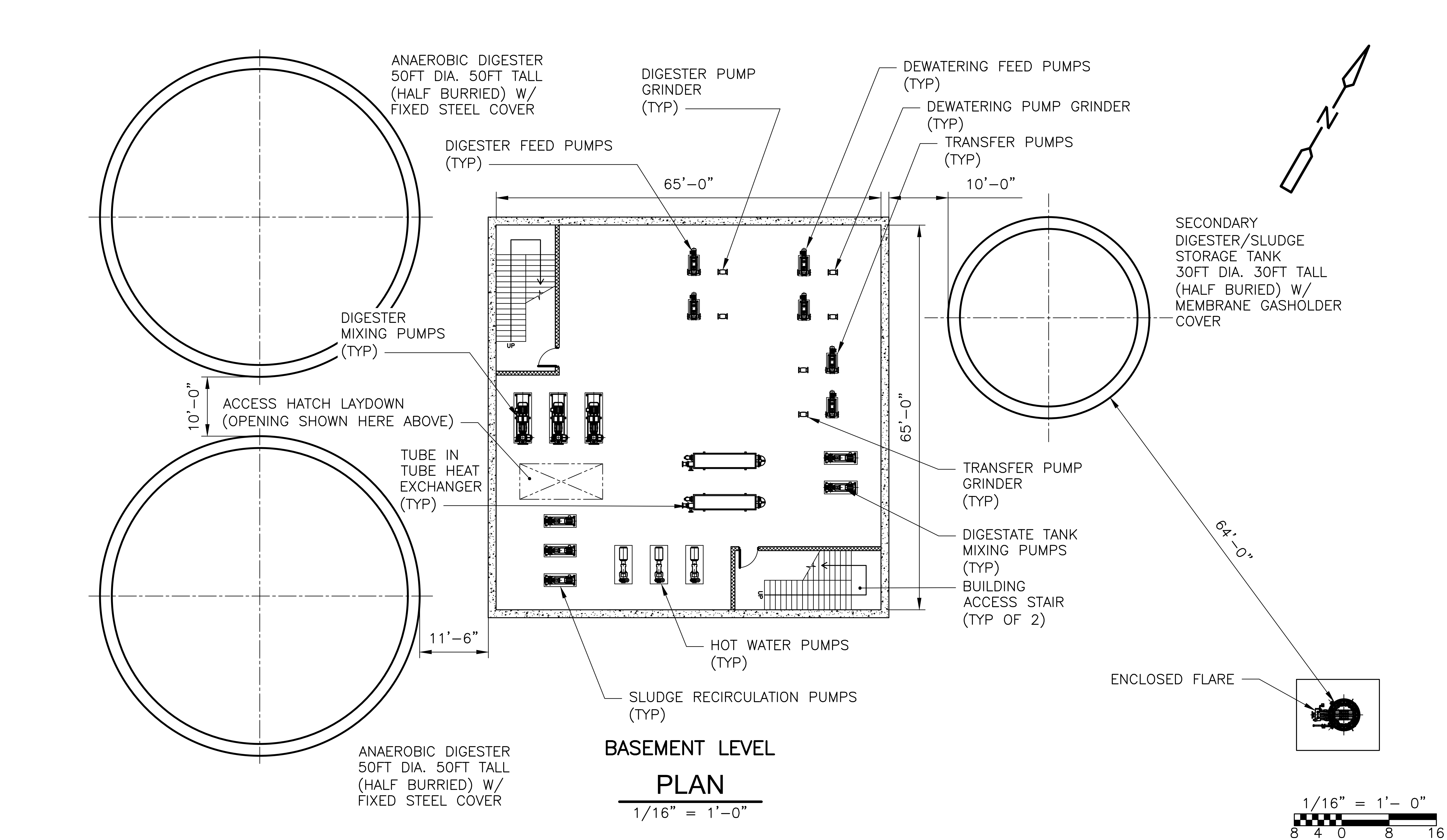


MODIFICATIONS PLAN

1" = 40'

CDM Smith

Figure No. C-2
ANAEROBIC DIGESTION FACILITY
NOVEMBER 2021



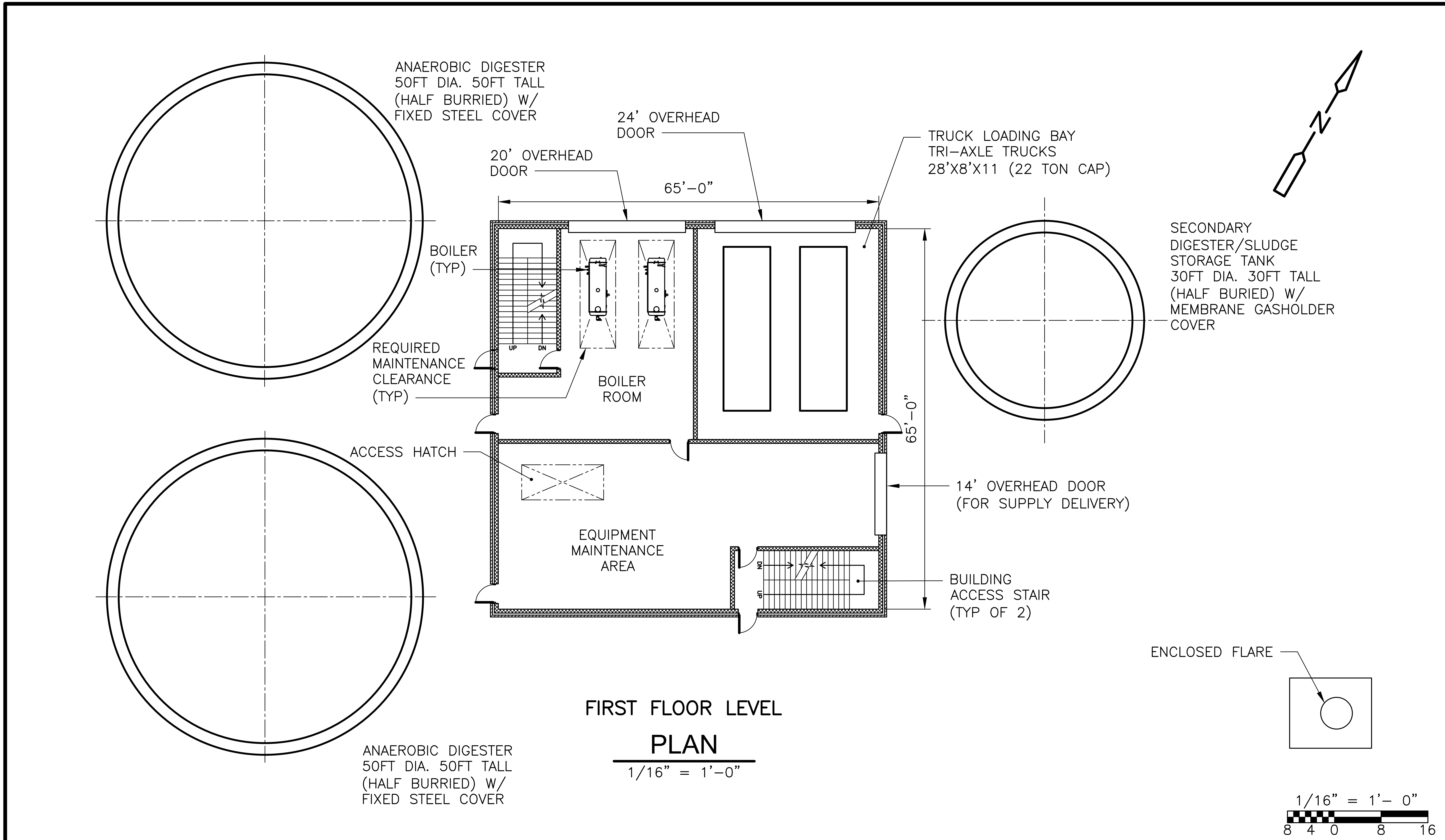
BASEMENT LEVEL

PLAN

1/16" = 1'-0"

CDM Smith

Figure No. M-1
BIOSOLIDS PROCESSING BUILDING
NOVEMBER 2021

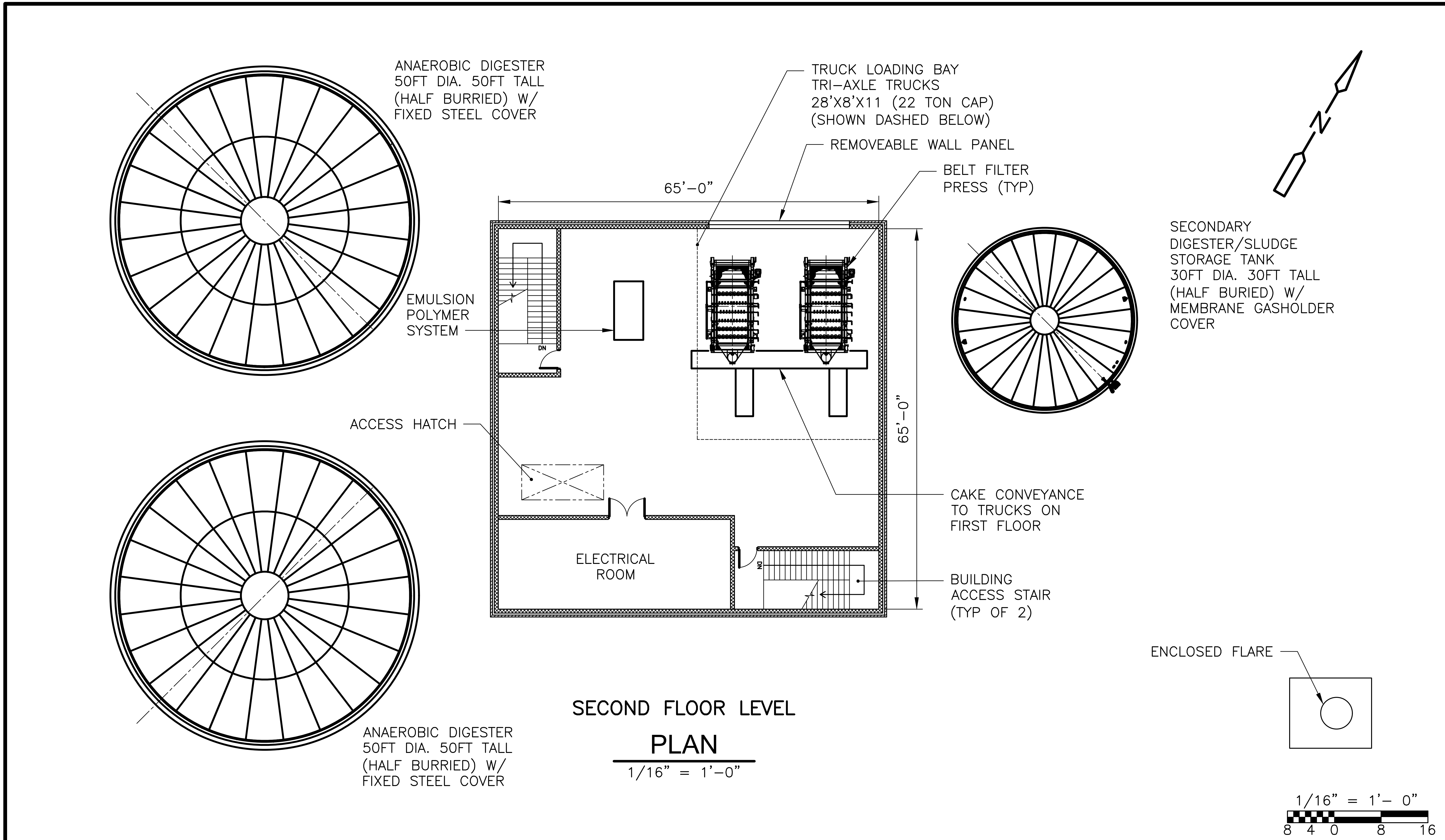


CDM Smith

Figure No. M-2

BIOSOLIDS PROCESSING BUILDING

NOVEMBER 2021



CDM Smith

Figure No. M-3
BIOSOLIDS PROCESSING BUILDING
NOVEMBER 2021

Appendix C

Dryer Improvements

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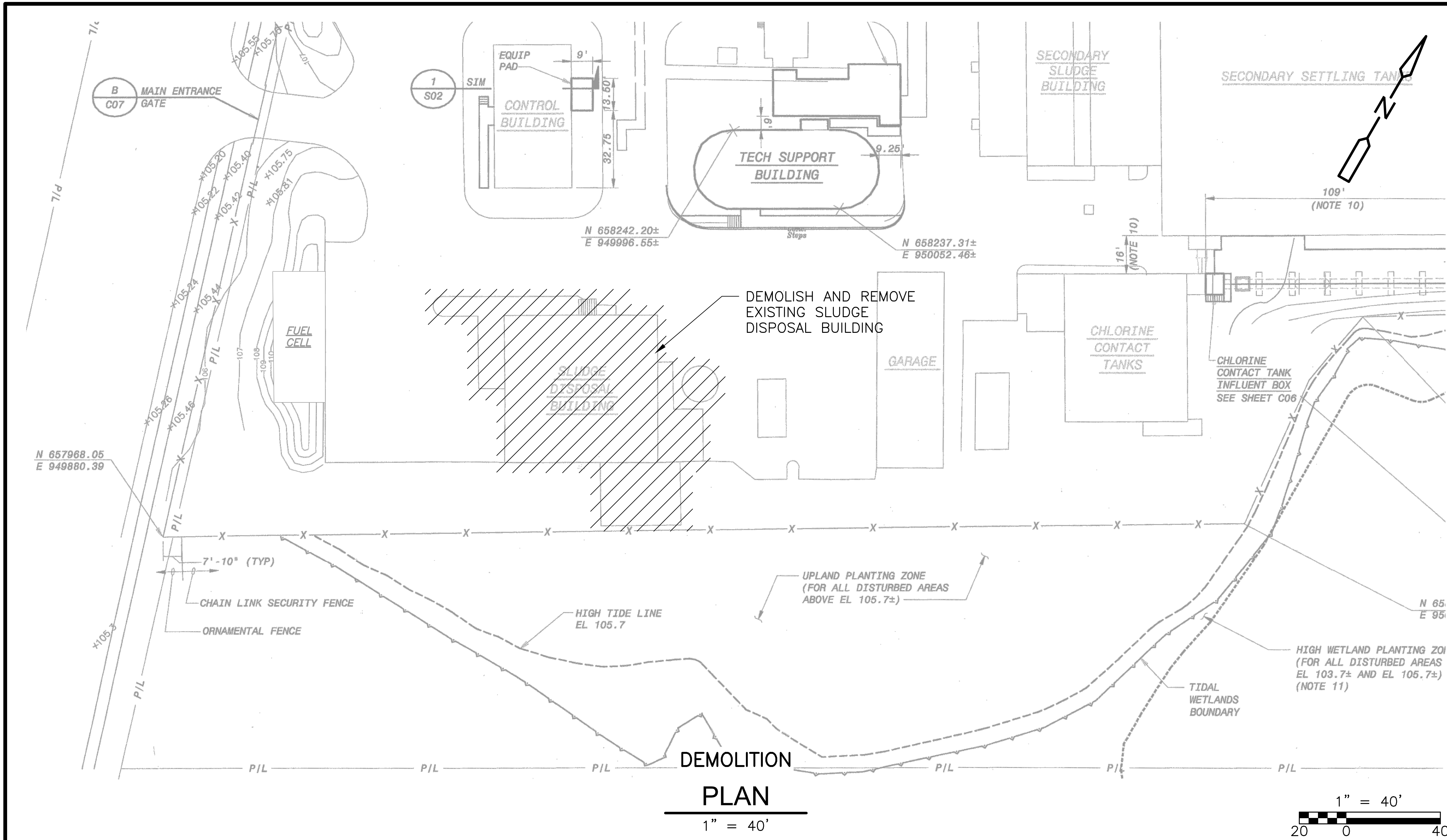


DEMOLITION PLAN

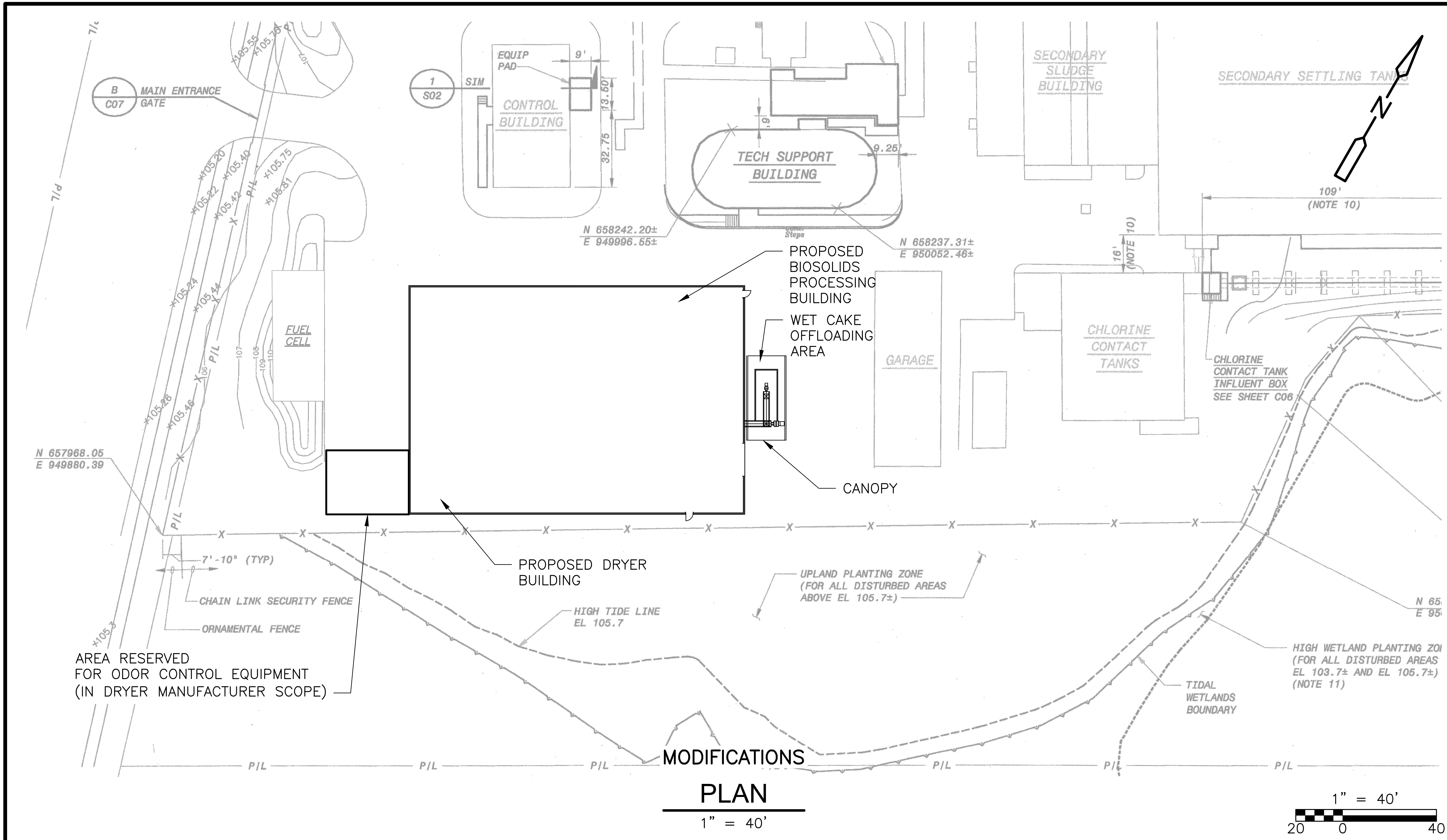
1" = 40'

CDM Smith

Figure No. C-1

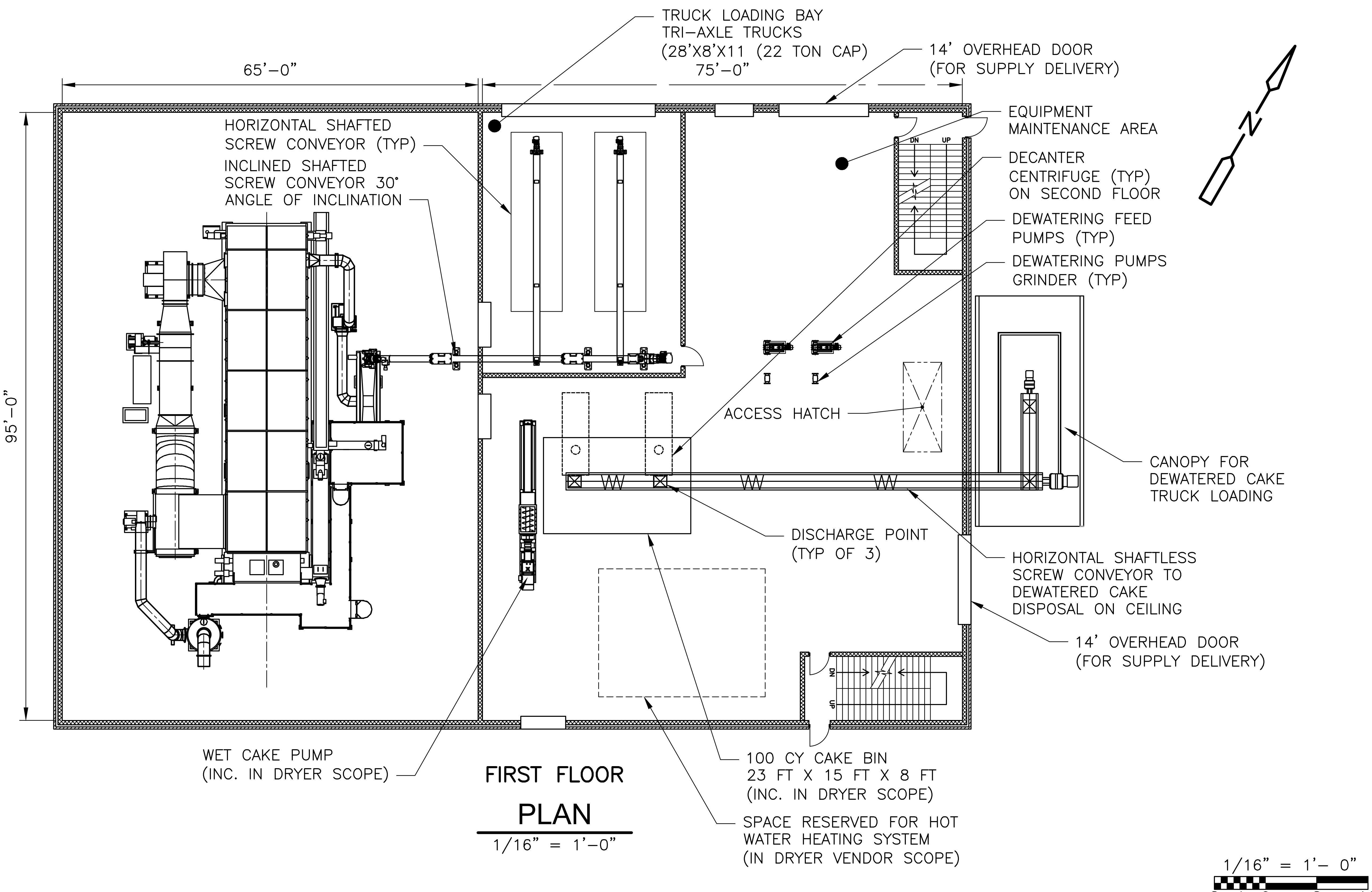
DRYER FACILITY

DECEMBER 2022



CDM Smith

Figure No. C-2
DRYER FACILITY
DECEMBER 2022



FIRST FLOOR

PLAN

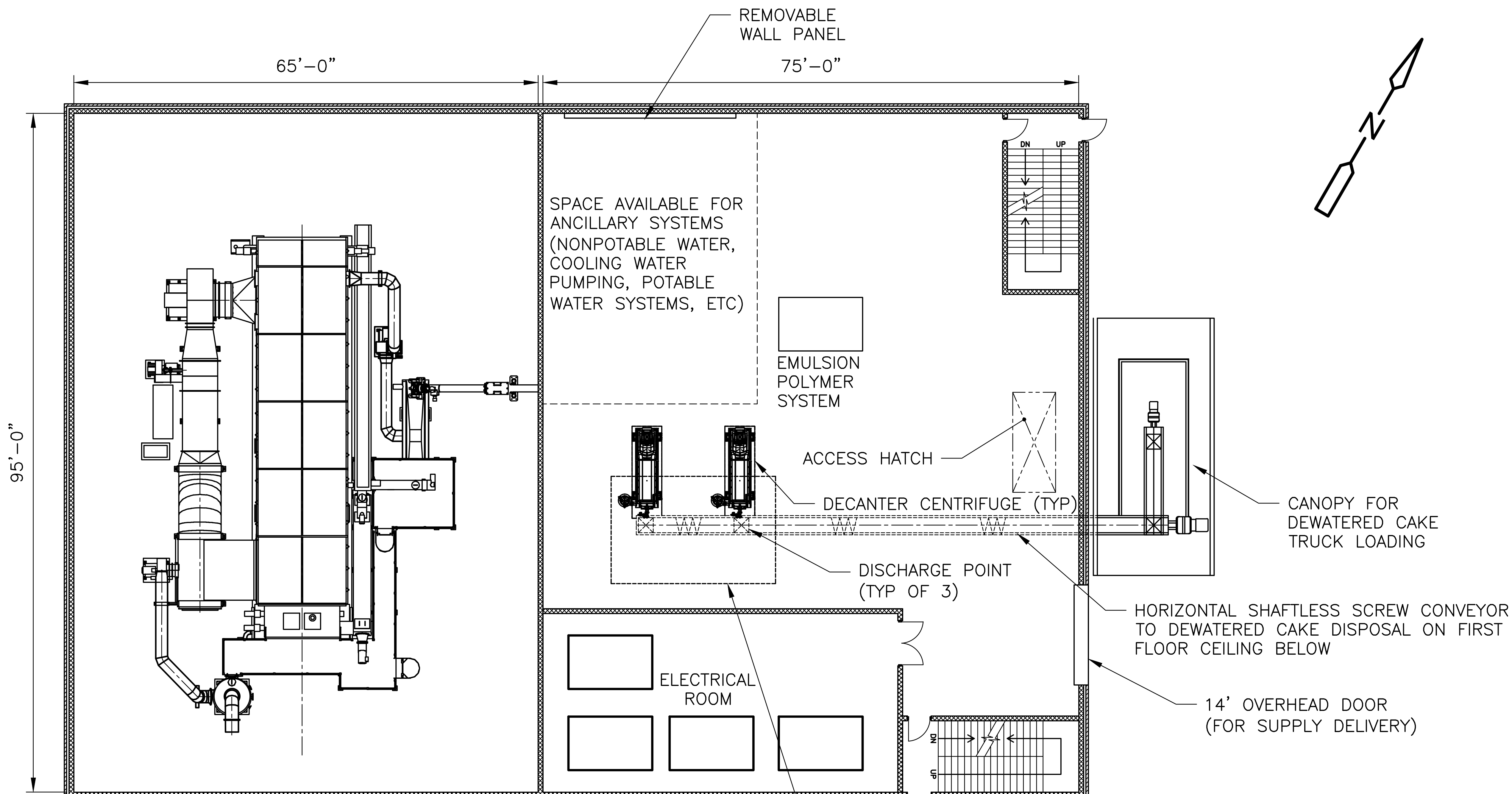
1/16" = 1'-0"

CDM Smith

Figure No. M-1

DRYER AND BIOSOLIDS PROCESSING BUILDING

DECEMBER 2022



SECOND FLOOR

PLAN

1/16" = 1'–0"

CDM Smith

Figure No. M-2

DRYER AND BIOSOLIDS PROCESSING BUILDING

DECEMBER 2022

Appendix D

Vendor Provided Information - Gasification

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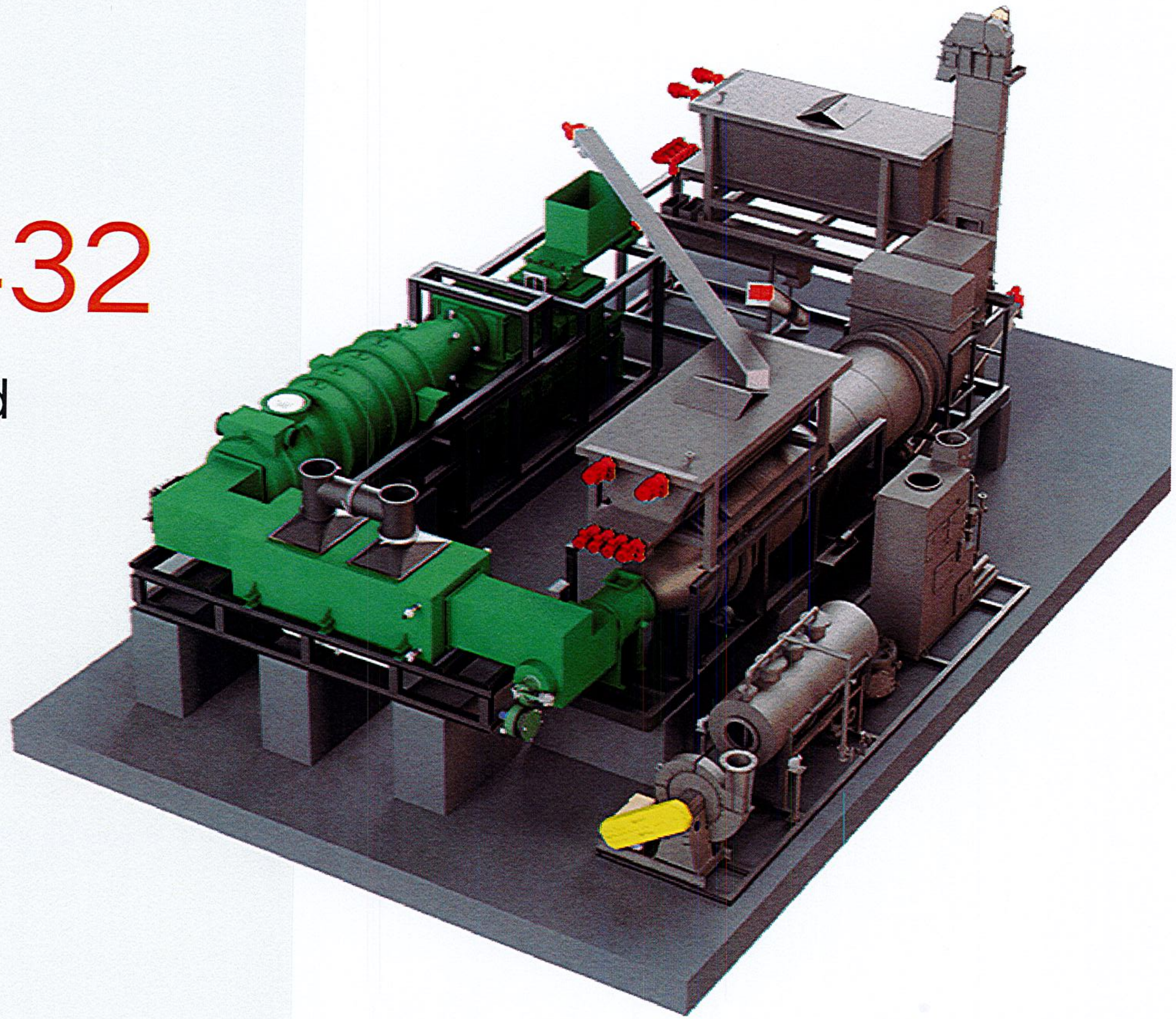
ECR-432

Pre-Fabricated Systems

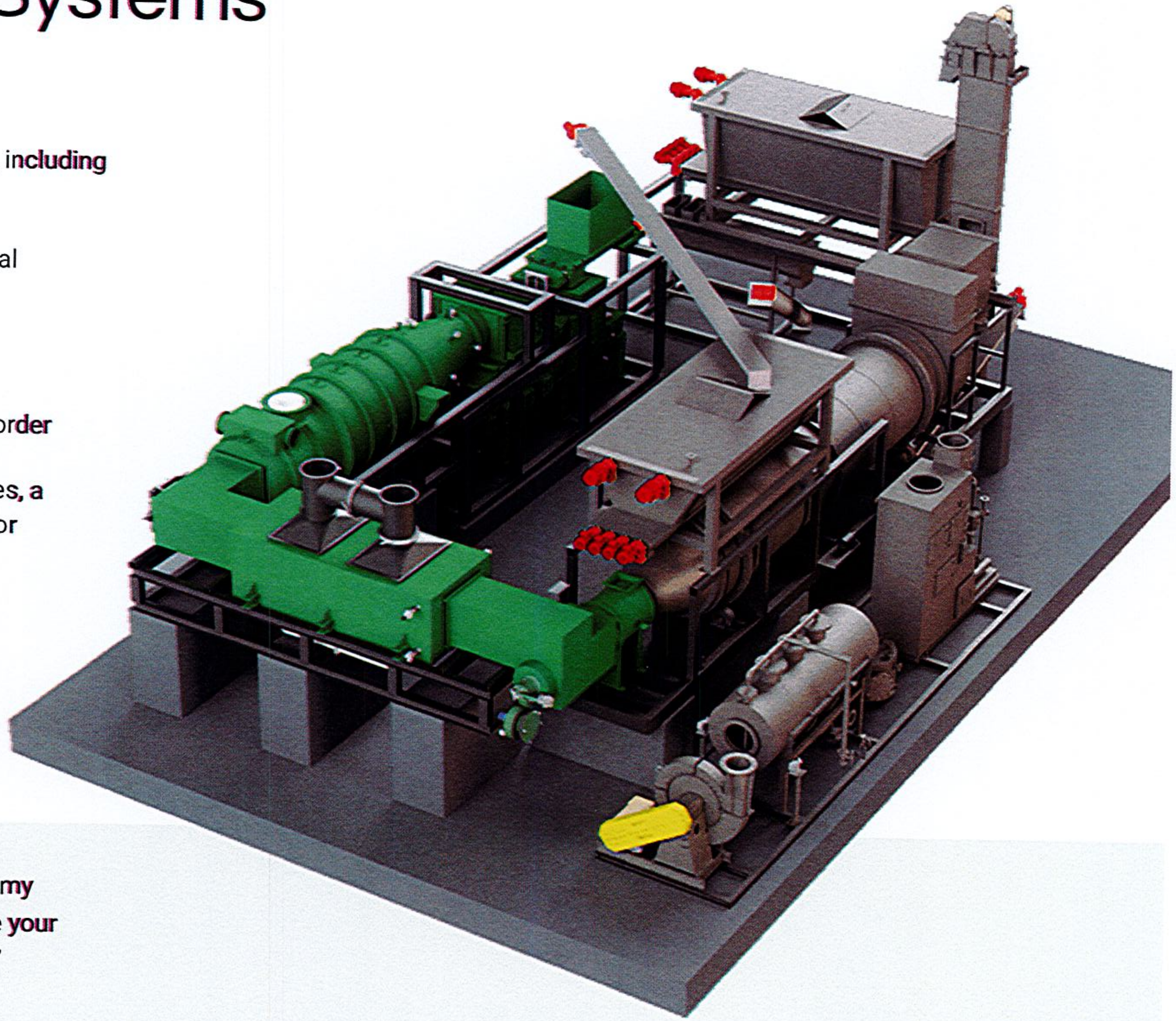


960 Penn Ave, Suite 400
Pittsburgh, PA 15222

info@ecoremedyllc.com

ECR-432

Pre-Fabricated Systems



Up to 10,000 wet tons per year design capacity, including grit and screenings

Pre-engineered, pre-wired modules with minimal construction cost

40' wide x 60' long x 25' tall standard footprint

Operational on-site within a year of a purchase order

Turnkey delivery with all critical parts and spares, a control room, laboratory, and all tools needed for O&M

De minimis air permit in many states

Fully equipped tool room, laboratory, and critical spares provided with all Ecoremedy® offerings

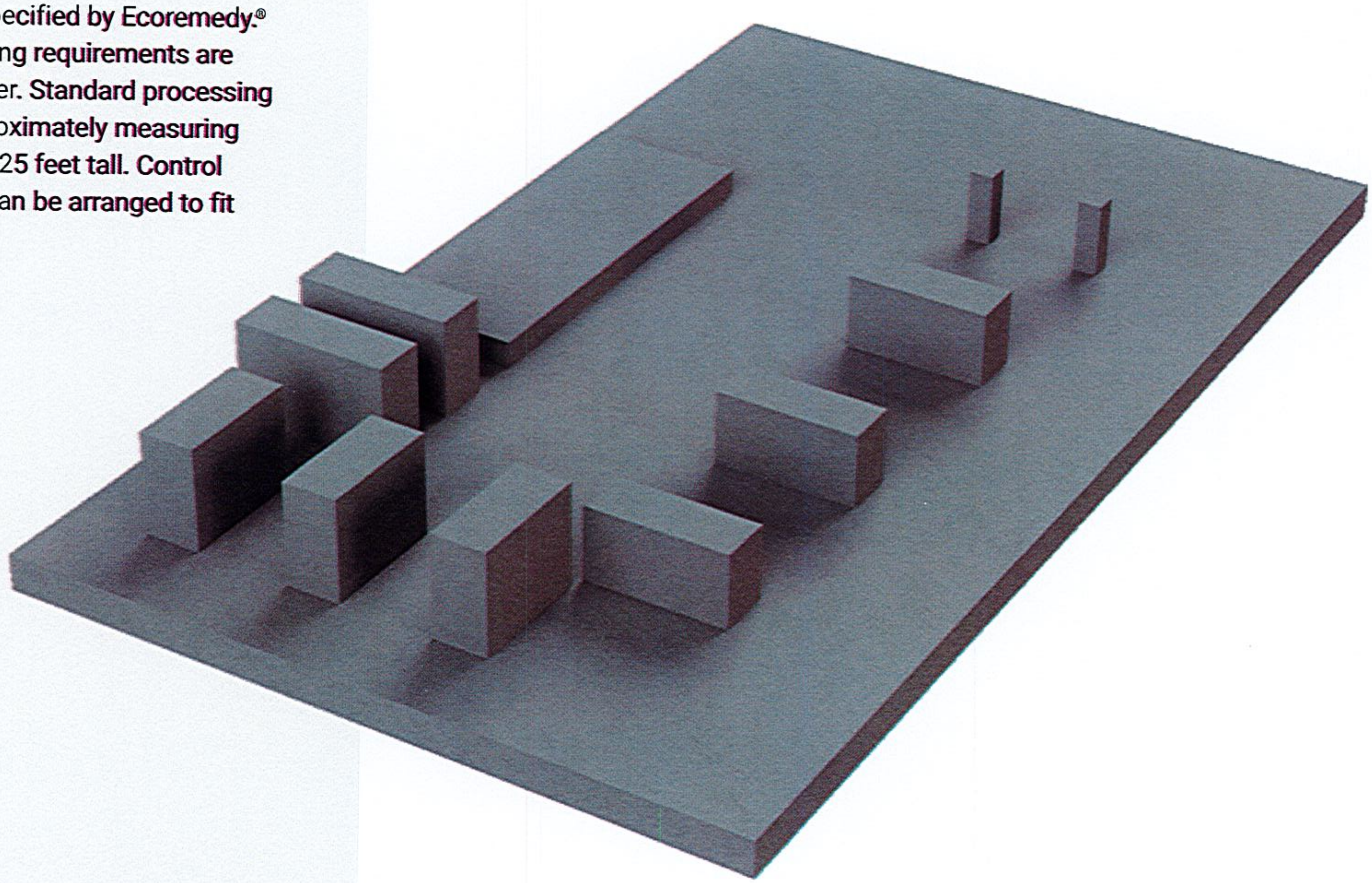
"I have experienced many pyrolysis processes in my 50 years of professional experience, and I believe your Ecoremedy technology has the best handle on it."

WALTER S. SMITH
Author of EPA methods 1-8 and the F-factors, industry consultant

ECR-432

Site

Prior to equipment arrival, the site is prepared with concrete support piers and equipment anchors with dimensions and locations specified by Ecoremedy.® Civil and structural engineering requirements are the responsibility of the owner. Standard processing layout requires a space approximately measuring 40 feet wide x 60 feet long x 25 feet tall. Control room and support services can be arranged to fit the space available.



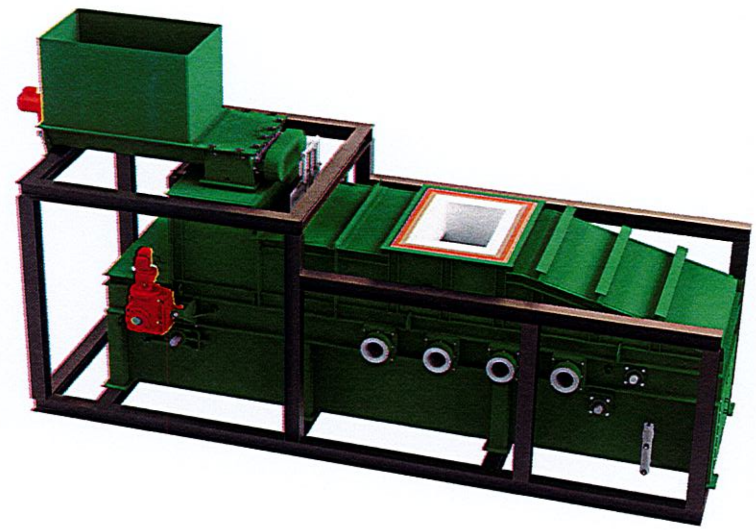
ECR-432

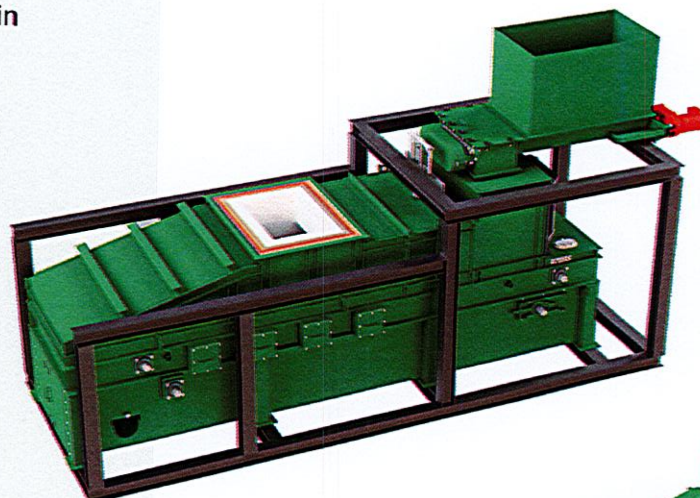
Gasifier Base Assembly

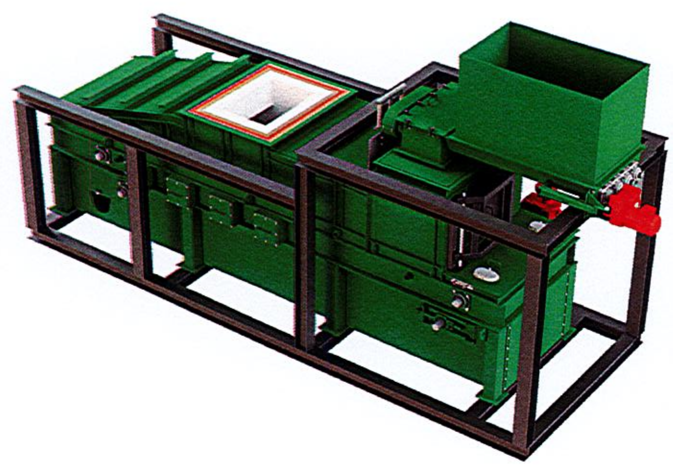
The base assembly is placed on its foundation pedestal and anchored in place.

The gasifier converts the energy trapped within the biosolids to volatile syngas to drive the evaporative process and creates a valuable byproduct called FlexChar.™ With unparalleled operating flexibility the Ecoremedy® operator can customize the carbon content of the byproduct, ranging from low carbon concentrated minerals to high carbon biochar.

The time and temperature within the gasifier destroy contaminants and perfluoroalkyl substances (PFAS) to non-detectable levels below two parts per billion.

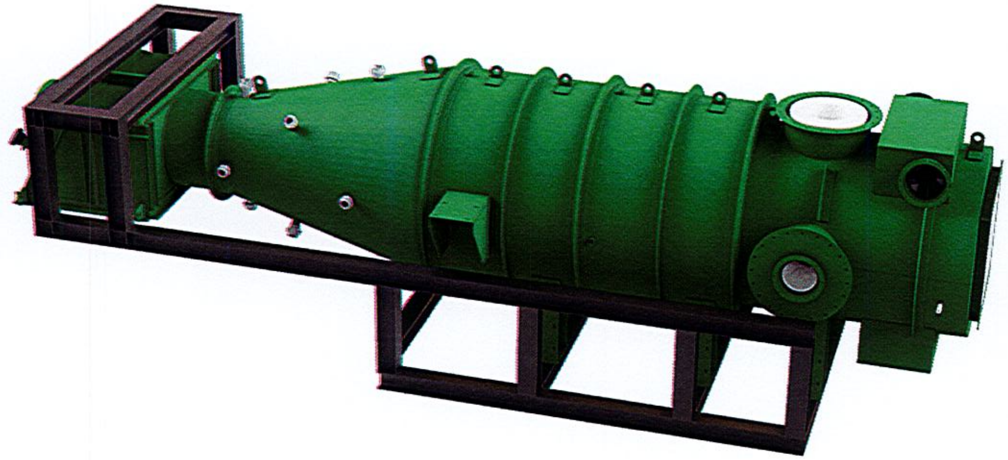






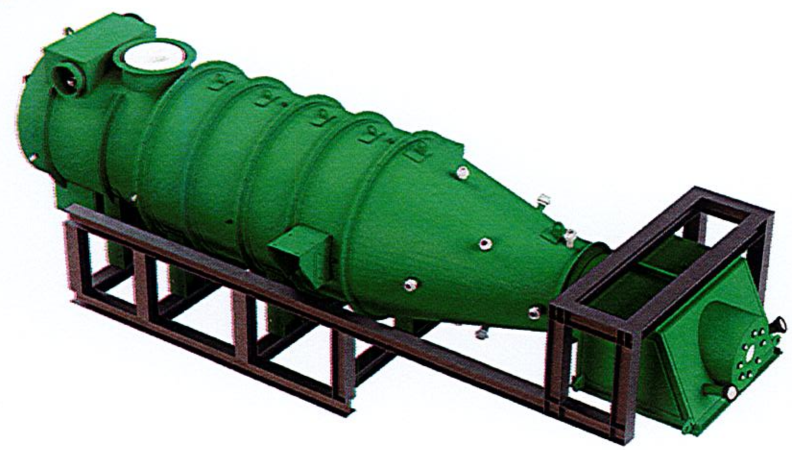
ECR-432

Oxidizer & Blend Box Assembly



The oxidizer and blend box assembly is placed atop the gasifier structure and bolted in together. Once connected, all flanges and interconnection points between gasifier and oxidizer are aligned.

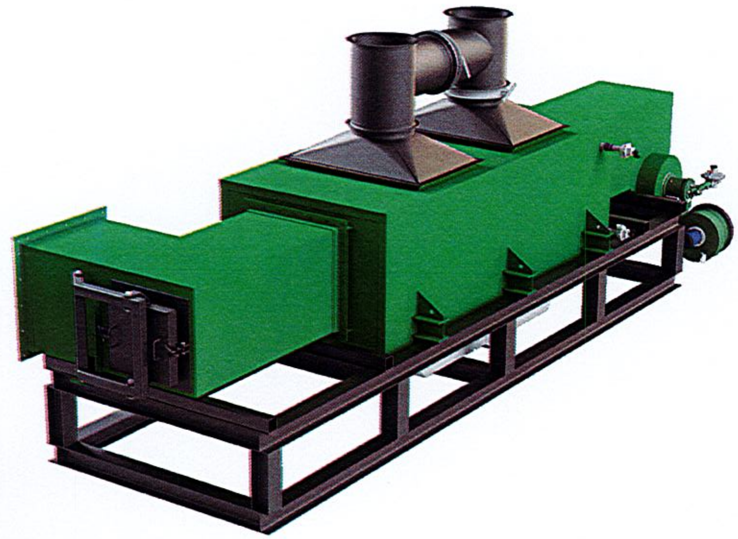
In the oxidizer, ambient air is injected into the flow of hot volatile syngas from the gasifier resulting in spontaneous combustion of the syngas achieving temperature exceeding 2000°F. A two second dwell time within the oxidizer ensures complete combustion resulting in clean air emissions and destruction of vapor phase PFAS. The hot flue gas now enters the blend box.

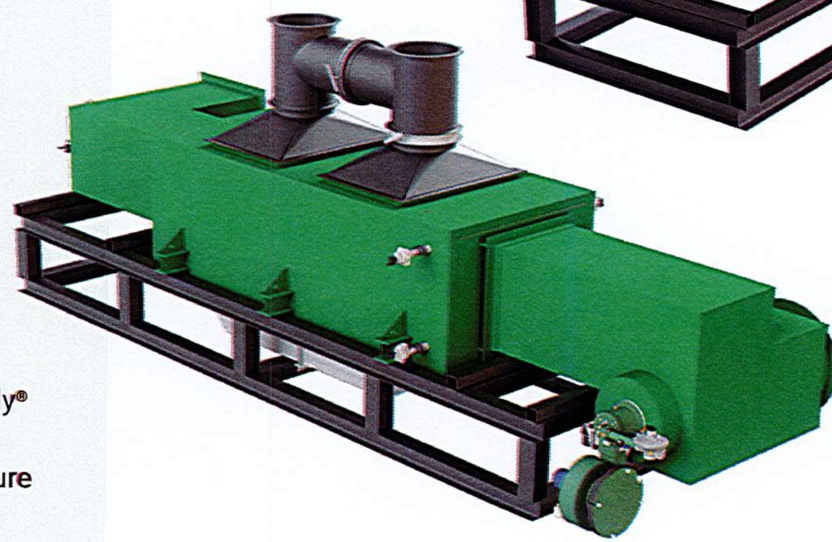


In the blend box, the hot flue gas is automatically tempered to an operator controlled setpoint before entering the process heat exchanger. This automated control point affects energy transfer throughout all subsequent process components.

ECR-432

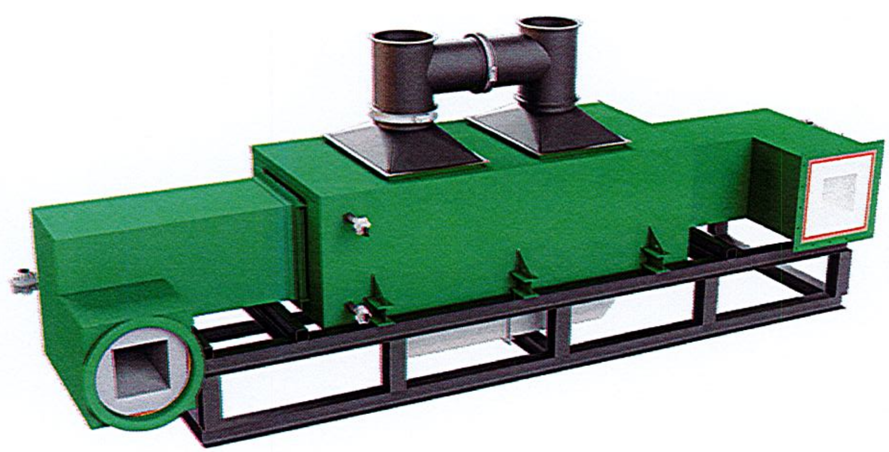
Process Heat Exchanger Assembly





The process heat exchanger assembly is placed on the prepared piers and anchored in place, perfectly aligning with all interconnecting bolt holes to attach the heat exchanger ductwork to the blend box discharge flange.

Typically, the energy balance within the Ecoremedy® process is energy positive, meaning there is more energy available than is needed to perform moisture evaporation in the dryer. This “excess” energy is converted to beneficial use within the process heat exchanger.



The standard use is to return the dryer vent to the heat exchanger prior to atmospheric discharge, heating the system exhaust and abating plume visibility. The heat transferred to the exhaust stream reduces the flue gas temperature entering the dryer to a target temperature set by the operator. This is an automated control loop.

The heat exchanger assembly is complete with supplemental burner for dryer operation during gasifier outages.

ECR-432

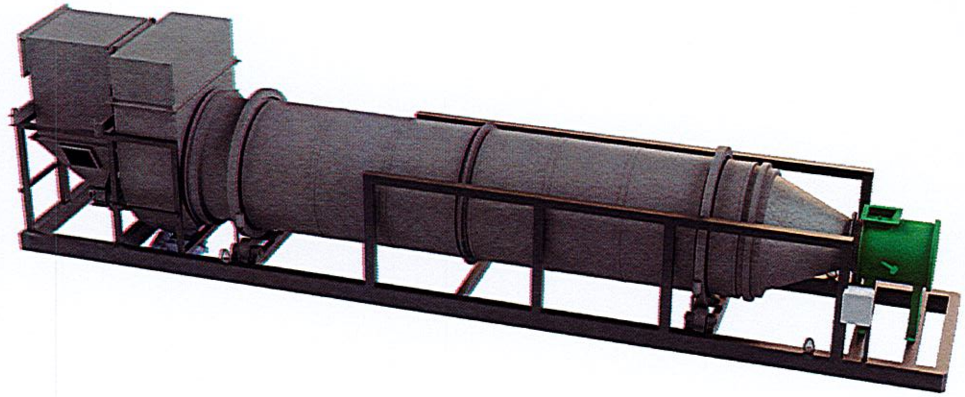
Dryer Assembly

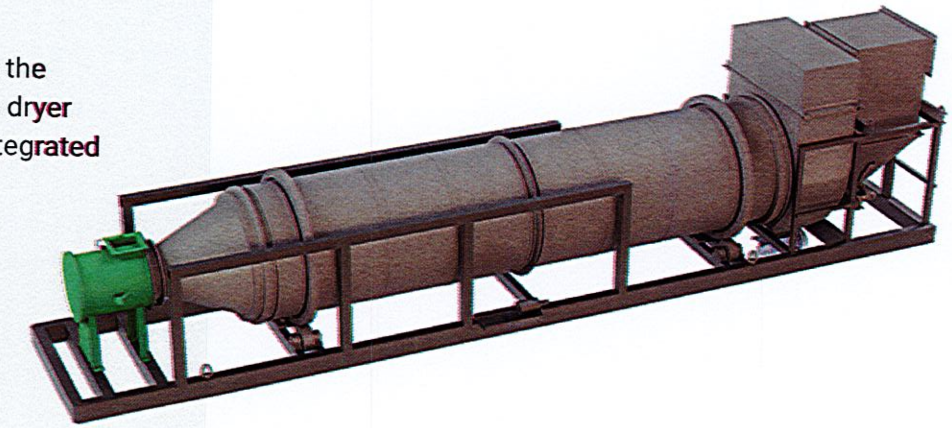
The dryer assembly is placed on the prepared piers and anchored in place, perfectly aligning with all interconnecting bolt holes to attach the heat exchanger ductwork.

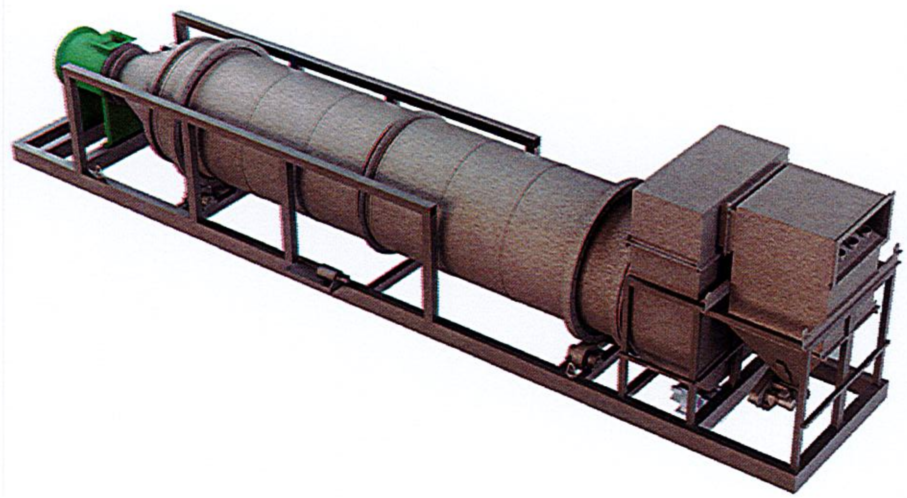
The frame for the dryer is built to support the material metering bin mounted above the dryer inlet. The motor drive assembly is fully integrated into the mounting skid.

Moisture from the incoming dewatered biosolids is evaporated within the dryer targeting a final product that is 92% total solids and meeting Class A requirements. The dried product is also recognized by the US EPA as an "Alternative Fuel" and agricultural amendment offering other salable products.

At the dryer discharge is a product dropout box with rotary airlock. Close coupled to the dropout box is a high efficiency multi-clone dust collector to capture and return particles larger than 10 microns to the process. Both collection devices discharge the product to a common conveyor feeding the product recycle bin.







ECR-432

Product Recycle Assembly

The product recycle assembly is a stand-alone component that sits on grade without the need for a supporting pier. The assembly is connected to the system via a product discharge conveyor and bucket elevator.

Total retention time within the recycle bin is typically two to four hours and the stored material depth is only four feet deep and constantly moving thereby preventing the possibility of spontaneous combustion of stored material.

Mounted beneath the recycle bin is a twin shafted pugmill where wet dewatered cake and dried recycled Class A material are blended to achieve an operator determined quality for fuel to the gasifier and feedstock to the dryer. The process is fully automated to adjust the rate of wet and dry material flow to achieve the desired blended ratio. Periodic moisture measurements must be made manually by the operator.

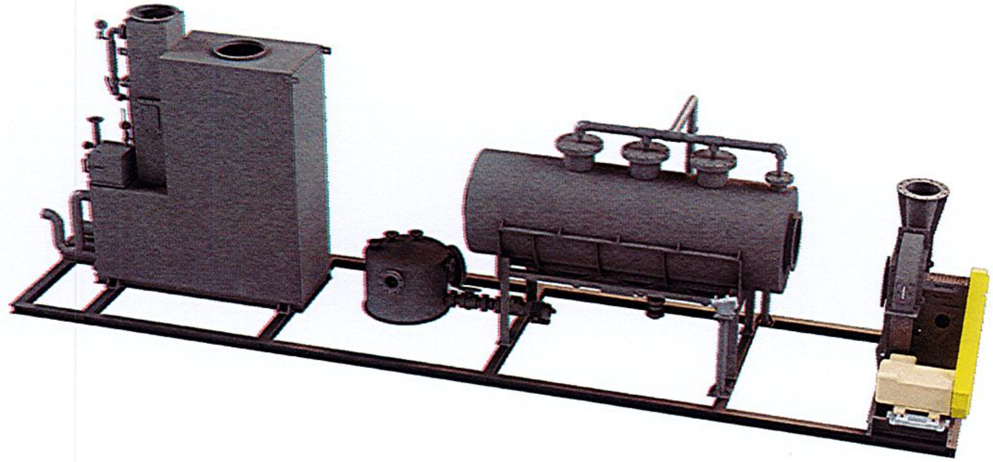
ECR-432

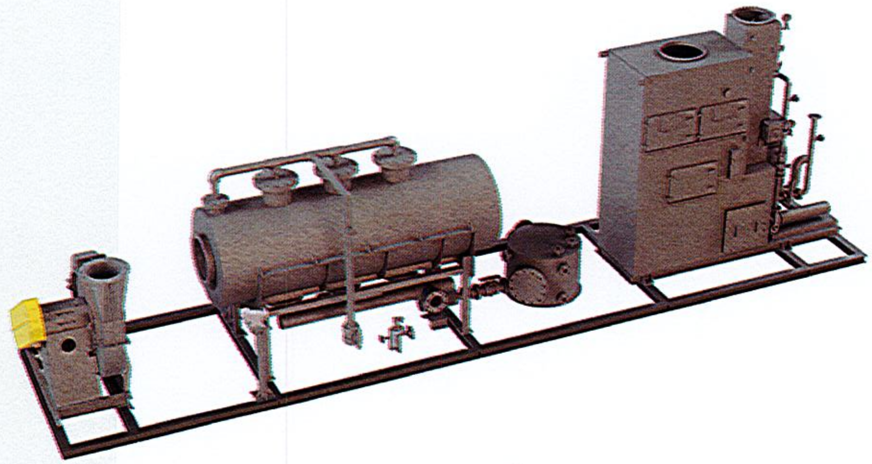
Flue Gas Conditioning Assembly

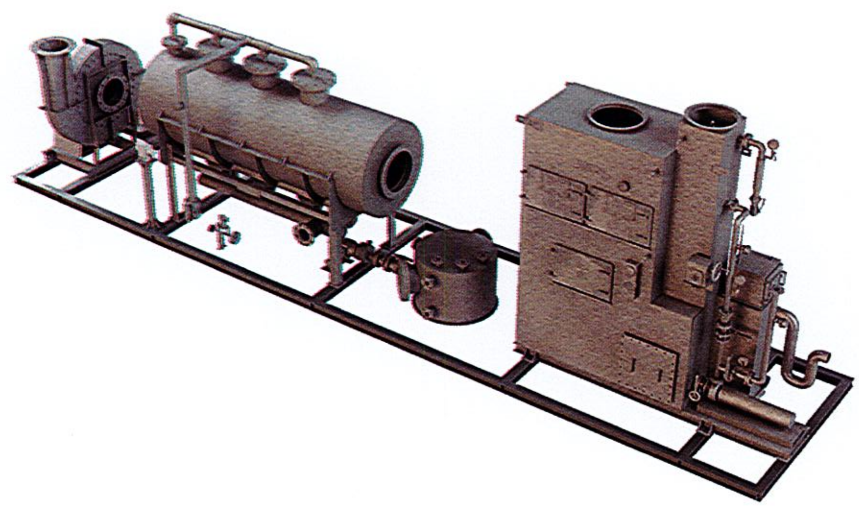
The flue gas conditioning equipment consists of a venturi scrubber, packed bed scrubber, and induced draft fan fully assembled as a stand-alone component that sits on grade. Located adjacent to the dryer assembly, the product dropout box is connected to the venturi scrubber inlet via stainless steel ductwork.

The venturi scrubber removes 99% of particles that are 5 microns and larger. This removal is critical to ensuring the performance of the downstream packed bed scrubber.

With a particulate free flow entering the packed bed scrubber, sulfur removal is achieved using bleach and baking soda. Removing sulfuric acid (H_2SO_4) and hydrogen sulfide (H_2S) from the flue gas is a critical process step to protect the metallurgy of the downstream induced draft fan and process heat exchanger. The two scrubbers are required process components to fully convert biosolids to renewable energy and purified byproducts.





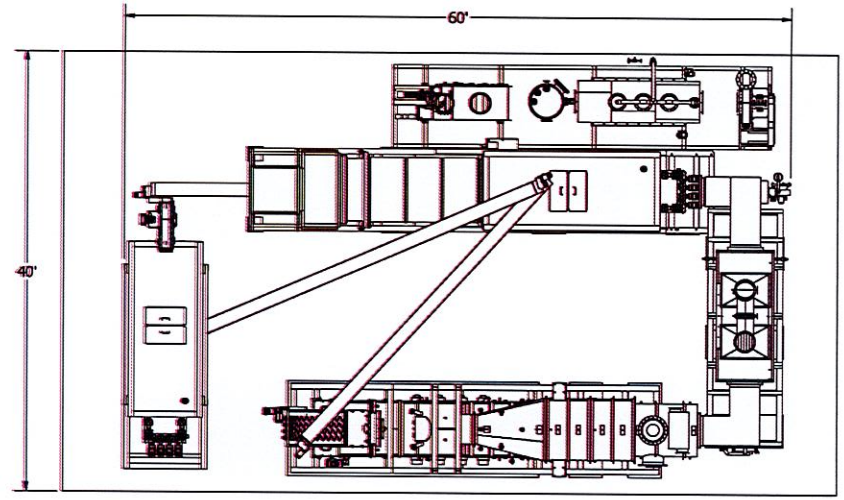


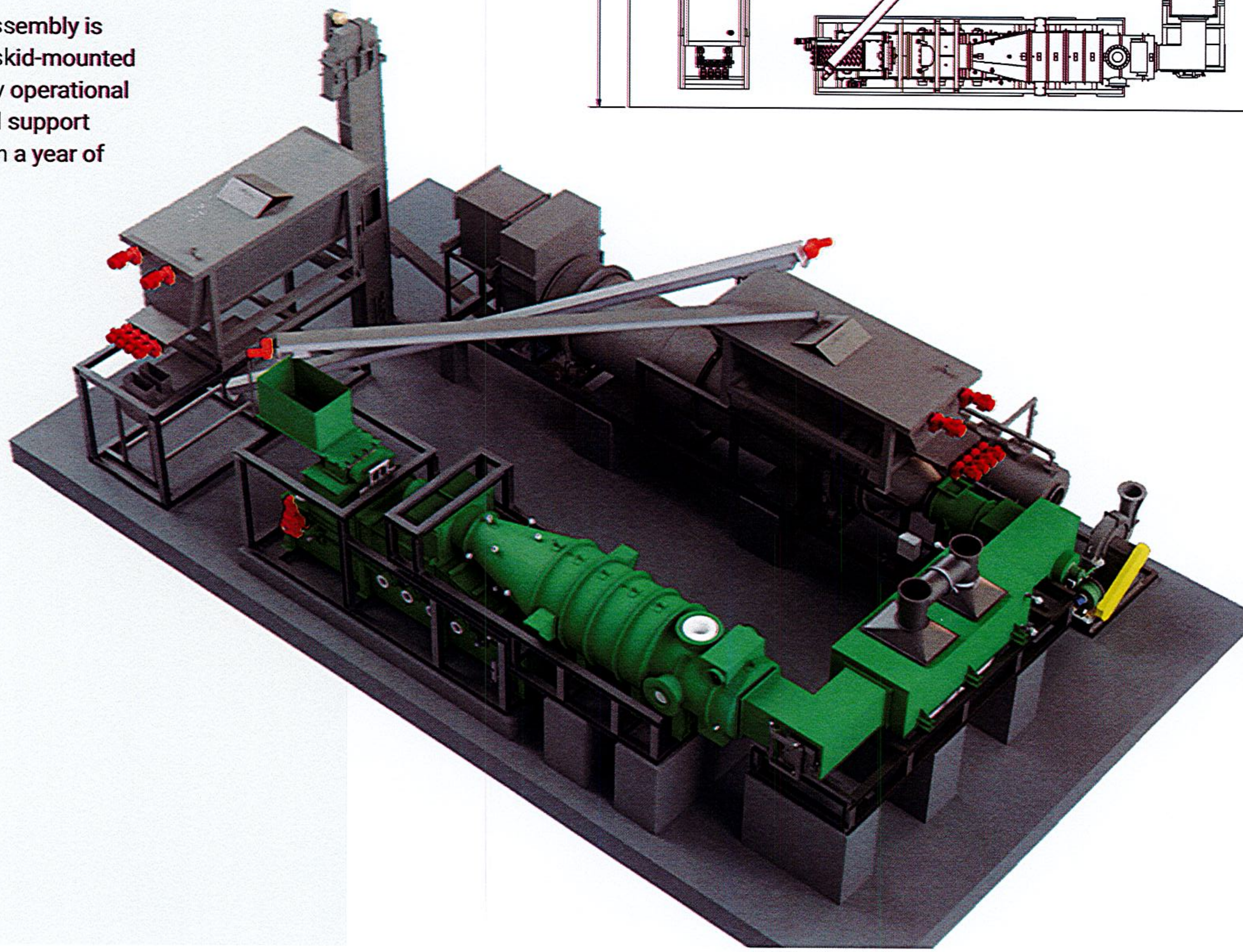
ECR-432

Modular Layout

The ECR-432 modular assembly is part of the Ecoremedy® skid-mounted solution delivering a fully operational facility, complete with all support tools and services, within a year of a purchase order.

Unprecedented.

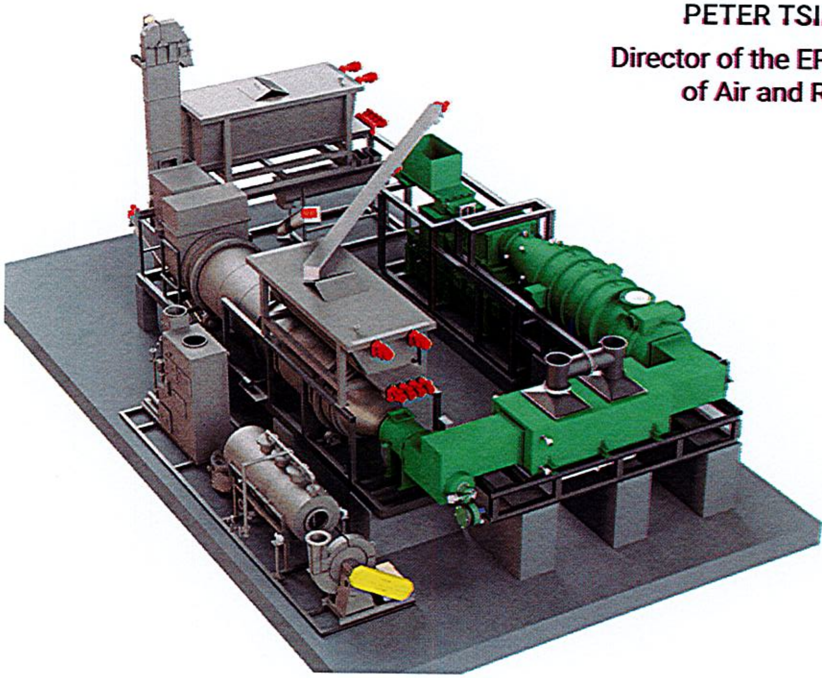




EPA Rules Ecoremedy® Fluid Lift™ Gasification is Not Incineration

"EPA concluded that the Ecoremedy gasifier unit as proposed would not combust sewage sludge as defined in the pertinent regulations and that the SSI NSPS would not apply to the biosolids gasification unit that is proposed for construction at the wastewater treatment facility of the City of Edmonds."

PETER TSIRIGOTIS
Director of the EPA Office of Air and Radiation



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One of the top 4 sludge gasifier companies in the world

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