COMPREHENSIVE ENGINEERING REPORT FOR PHOSPHORUS REMOVAL

City of Waterbury, Connecticut

Water Pollution Control Facility

September 1, 2015

CDM Smith

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Section 1

Project Overview

1.1 Introduction

The City of Waterbury Water Pollution Control Department (City) is undertaking a comprehensive analysis of current operations at the Waterbury Water Pollution Control Facility (WPCF) to determine an overall roadmap for a long term plan to address the operational upgrades required to meet new NPDES permit limits on phosphorus and metals, long term wet weather capacity, new Title V permits that would require capital improvements to the sludge incinerator, limitations on landfilling ash at the current location, and a desire to have a more sustainable operation with improved energy efficiency and potentially on-site energy generation, while addressing public concerns associated with the operation of a merchant incinerator in the most economically, socially and environmentally sound manner.

1.2 Plant Description

The WPCF is a conventional activated sludge wastewater treatment plant that provides primary and secondary treatment for the removal of Biochemical Oxygen Demand (BOD), Suspended Solids (SS), Total Nitrogen (TN) and Total Phosphorus (TP) in wastewater flow. The present average day dry weather flow is approximately 22 million gallons per day (MGD). Primary treatment consists of influent screening, grit removal, influent pumping and primary sedimentation. Secondary treatment consists of an activated sludge process followed by secondary sedimentation, and disinfection with ultraviolet light. Solids processing at the plant consists of sludge thickening and dewatering. The dewatered cake is currently burned in the on-site fluidized bed incinerator, which is currently operated by a third party.

The WPCF currently processes waste activated sludge (WAS) that is collected from the final settling tanks and returned to the head of the primary settling tanks where it is co-settled with the primary sludge. These co-settled solids are collected from the primary settling tanks are then co-thickened in gravity thickeners (GTs). The WPCF has gravity belt thickeners (GBTs) that are set up to thicken WAS, but they are not in service at this time due to the success of the co-settling/thickening scheme described above. After gravity thickening, the thickened sludge is transferred to the thickened sludge holding/blending tanks. From there, the thickened sludge is pumped to the belt filter presses (BFPs) where it is dewatered to approximately 22 percent solids before incineration in a fluidized bed incinerator. The solids incinerator at the Waterbury WPCF is operated by Synagro, who also accepts and processes sludge from outside facilities. The filtrate from the solids processing operations (gravity thickeners, GBTs, and BFPs) and the water from the incinerator scrubber are returned to the liquid wastewater process train at the primary pump station, upstream of the primary settling tanks.

1.2.1 Biosolids Quantities

The sludge quantities produced at the WPCF are summarized in Table 1.2-1 below. The quantities presented represent the "design year" conditions which are approximately 1.4 times the present day quantities.

Table 1.2-1. Sludge Feed Characteristics

	Present Day Average	Design Year Average
Sludge Volume (gallons/day)	176,000	**246,000**
Dry Solids (pounds/day)	28,600	**40,000**
Primary Percent Solids	1.8%	**1.8%**
GT Percent Solids*	5.0%	**5.0%**
BFP Percent Solids*	22.0%	**22.0%**

*GT and BFP Solids are based on historical plant records

Section 2

Phosphorus and Metals Limitations

2.1 Introduction

The Connecticut Department of Energy and Environmental Protection (DEEP) is in the process of implementing a state wide phosphorus reduction program. The program targets many WPCFs discharging to inland watercourse such as the Waterbury WPCF, which discharges to the Naugatuck River. The program began in 2009 when DEEP issued its initial program. Recognizing the potential impact to the WPCF, the City retained CDM Smith to complete a feasibility study evaluating potential options for compliance with the proposed limits.

2.1.1 Previous Report Findings

CDM Smith issued the final report, titled "Water Pollution Control Facility Phosphorus Removal Study and Preliminary Metals Investigation", in August 2011. The study evaluated treatment technologies capable of consistently meeting an average monthly performance limit of 0.2 mg/L during the period of April through October. The study also evaluated the impact of the proposed seasonal load cap of 34.26 lbs/day which translates to a concentration of 0.15 mg/L at the design flow of the facility.

CDM Smith considered three possible alternatives to address a range of limits. They included: 1) enhanced biological phosphorus removal, 2) chemical phosphorus removal, and 3) effluent filtration. The following design assumptions were carried through the analysis:

- Seasonal phosphorus removal, April 1 through October 31. O&M costs were based on 7 months of operation.
- New Treatment facilities will be able to pass peak daily flow with the largest operating unit out of service (pump, tank, train, etc.).
- New treatment systems will be able to maintain treatment with the largest unit out of service.
- Primary settling tanks, aeration tanks, and final settling tanks are available for phosphorus removal.

The report recommended upgrades for low level phosphorus removal focused on a final effluent concentration of 0.2 mg/L (and lower). To reach that limit a chemical feed system followed by effluent filtration was recommended. The chemical feed system would provide for the dosing of metal salt coagulants in the liquid treatment process train upstream of the filtration facility. The system would consist of a centralized chemical bulk storage building to house the liquid storage tanks along with multiple smaller chemical feed stations equipped with day tanks and chemical dosing equipment. The filtration equipment would consist of an Aqua Diamond cloth-media filter with four (4) trains each containing eight (8) diamond sections. A small backwash lift station was included along with an intermediate lift station to convey the flow from the lower final clarifiers to the filter facility. Following filtration the flow would be conveyed to the existing ultraviolet light disinfection system.

Additionally, the study noted that gravity thickener overflow, the gravity belt thickener filtrate (if used), and the belt filter press filtrate are combined and returned to the primary pump station upstream of the primary clarifiers, returning phosphorus to the liquid process train. The process water utilized by Synagro for the incinerator and associated scrubbers is also returned to the primary pump station. The WPCF staff regularly sample and record flow in this combined stream for phosphorus. At the time of the report, the recent average flow of the combined stream was 2.7 million gallons per day and the average phosphorus concentration was 15.9 mg/L. This equated to approximately 350 lbs/day of phosphorus.

The 2011 study also included a preliminary metals investigation. In terms of metals, DEEPs individual and general permits for industries in Waterbury were reviewed. Nine industries, tributary to the WPCF, were identified as significant industrial users (SIUs). These users all fell into either the electroplating or metal finishing categorical classification and collectively contribute approximately 400,000 gallons per day of industrial wastewater. In addition to the nine SIUs, over 209 general industrial permits have been issued to businesses, industries and municipal facilities that discharge to the wastewater collection system. Due to the typically low removal efficiency for metals through the WPCF, source controls were recommended as the initial means of ensuring compliance.

2.1.2 Current Permit Limits

The most recent National Pollution Discharge Elimination System (NPDES) permit, issued to Waterbury in November 2013, includes phased limits for metals and phosphorus. For metals, there is an interim limit in effect for a four-year time period after NPDES issuance with the final limit going into effect 1,460 days after that. Likewise, a staged phosphorus limit is included requiring a moderate reduction in the short term and significant reduction by 2020. The metals and phosphorus limits are summarized below:

- Copper (interim) - 3.11 kg/day average monthly; 5.74 kg/day maximum daily
- Copper (final) - 2.48 kg/day average monthly; 4.58 kg/day maximum daily
- Nickel (interim) – 4.06 kg/day average monthly; 7.50 kg/day maximum daily
- Nickel (final) - 3.35 kg/day average monthly; 6.18 kg/day maximum daily
- Zinc (interim) – 9.24 kg/day average monthly; 12.24 kg/day maximum daily
- Zinc (final) - 6.72 kg/day average monthly; 8.91 kg/day maximum daily
- Phosphorus (interim) – 0.7 mg/L seasonal average April 1 to October 31; no two consecutive months shall exceed 0.7 mg/L. This limit went into effect April 1, 2014

- Phosphorus (final) – 0.28 mg/L day average monthly; 0.62 mg/L maximum daily; seasonal cap of 34.26 lb/day (April 1 to October 31) This limit goes into effect April 1, 2020.

It should be noted that the seasonal load cap equates to a treatment level of 0.2 mg/L at present day flows and 0.15 mg/L at the facilities full design flow of 27 million gallons per day.

2.2 Mass Balance

As part of the NPDES permit requirements, the WPCF is required to perform a mass balance. CDM Smith prepared a mass balance in early 2015 to comply with this requirement. Plant operating data for calendar year 2014 was reviewed and tabulated to account for the reduction in pollutants from the influent to effluent as well as side streams and biosolids removal. Table 2.2-1 at the end of this section summarizes this data. The following sub-sections present key excerpts of the data graphically.

2.2.1 Metals

Table 2.2-2 summarizes the metals influent and effluent mass on a monthly basis.

Table 2.2-2 – 2014 Monthly Average Metals Loads (kg/d)

Month	Lead(1)		Zinc(2)		Copper(3)		Nickel(4)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
January	0.5	0.5	8.0	8.6(6)	4.5	6.7(5) (6)	4.7	5.6(5) (6)
February	0.4	0.3	8.2	5.8	3.6	0.9	2.3	3.7(6)
March	0.6	0.4	6.3	8.1(6)	2.9	1.4	5.1	7.3(5) (6)
April	0.6	0.5	9.0	5.1	5.3	1.6	24.9	1.6
May	0.6	0.6	9.9	6.3	2.4	2.0	1.2	1.4(6)
June	0.5	0.4	10.4	4.4	5.0	1.0	1.9	1.2
July	0.8	0.3	11.3	2.6	5.4	1.0	2.1	0.7
August	0.4	0.2	6.9	2.4	3.7	1.3	2.7	8.2(5) (6)
September	1.2	0.2	10.1	2.2	7.8	1.0	1.8	0.9
October	0.4	0.2	9.3	3.3	6.5	0.7	8.9	1.6
November	0.6	0.3	10.5	2.9	6.8	1.7	3.2	2.2
December	0.4	0.4	9.6	5.1	4.9	2.0	11.9	2.7

(1) Currently no limit
(2) Interim limit = 9.24 kg/d; Final limit = 6.72 kg/d
(3) Interim limit = 3.11 kg/d; Final limit = 2.48 kg/d
(4) Interim limit = 4.06 kg/d; Final limit = 3.35 kg/d
(5) Exceedance of interim limit
(6) Effluent greater than influent

Table 2.2-3 located at the end of this section summarizes the metals influent and effluent mass on a daily basis. The percent removal for each metal is calculated. A positive value for the percent removal (i.e. 55%) represents a reduction in the mass of metals in the effluent relative to the influent. Metals are a conservative pollutant (i.e., not subject to volatility and biodegradation in the WPCF) so the mass of metals associated with positive removal efficiencies can be directly applied to the plant's sludge stream. Conversely, a negative value for the percent removal (i.e., -55%) represents an increase in the mass of metals in the effluent relative to the influent. An occasional negative removal efficiency could be attributed to a time delay in the metals traveling through the treatment plant, but a frequent occurrence suggests a source of metals through a side stream such as the incinerator scrubber water.

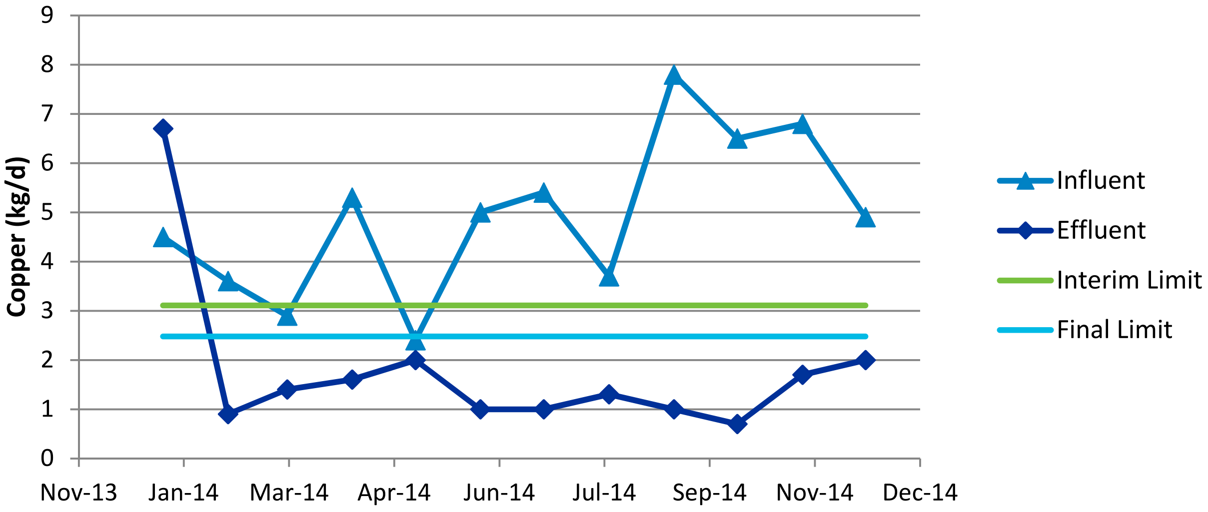
During the days when the influent mass was greater than the effluent mass the average removal efficiency for copper was 75%, nickel was 48% and zinc was 61%. On the days when the effluent mass was greater than the influent, the average additional pounds of copper were 5.0 kilograms, nickel 4.0 kilograms, and zinc 2.5 kilogram. Assuming the incinerator side stream is 2.5 mgd, on average the concentration of these metals in that stream would be on the order of 240 - 960 µg/L, 190 - 370 µg/L, 120 - 310 µg/L respectively.

The influent and effluent copper, nickel and zinc levels were graphed and presented below. Each graph also shows the respective interim and final permit limits.

Copper

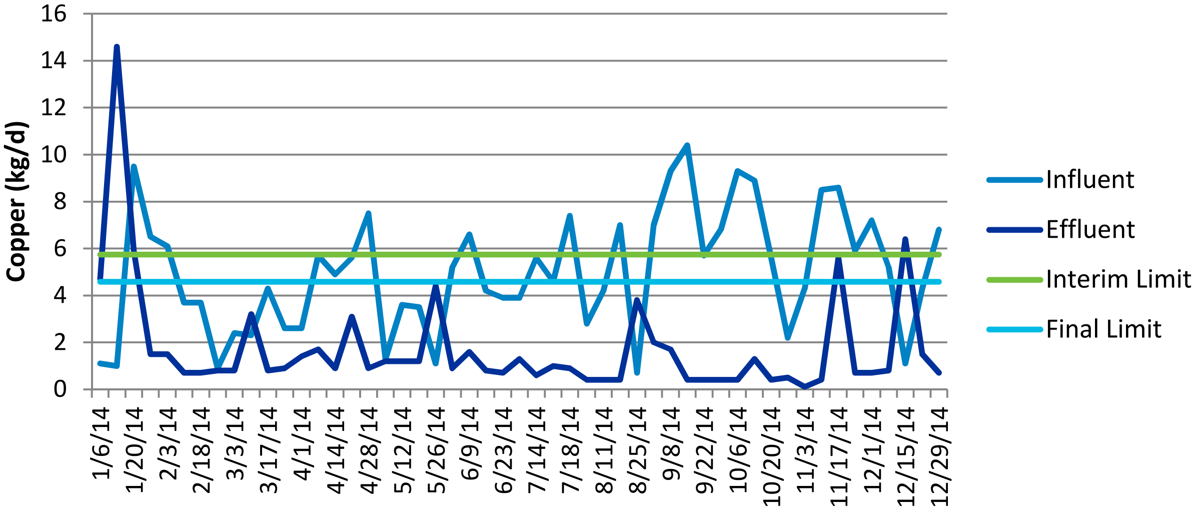
Monthly average effluent copper was consistently below both the interim and final limits with the exception of January. The data for January is noteworthy because it indicates that the effluent copper levels were higher than the influent levels; a potential indication of a temporary elevated copper component in the incinerator side stream.

Figure 2.2-1. Monthly Copper Mass



Daily effluent copper levels exceeded the interim limit three times and exceeded the final limits four times. The data for six days indicated that the effluent copper levels were higher than the influent levels.

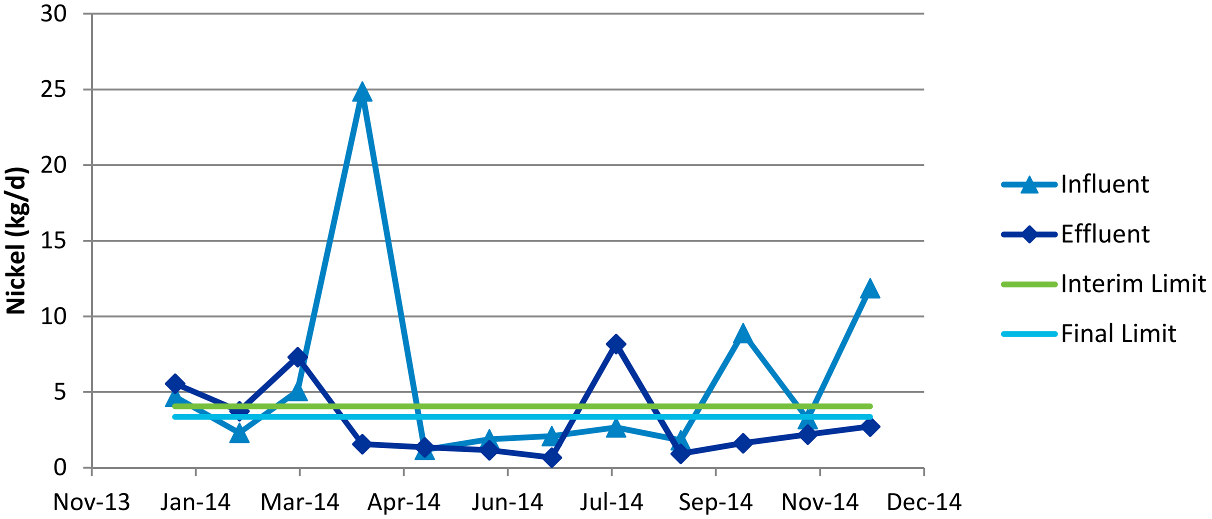
Figure 2.1-2. Daily Copper Mass



Nickel

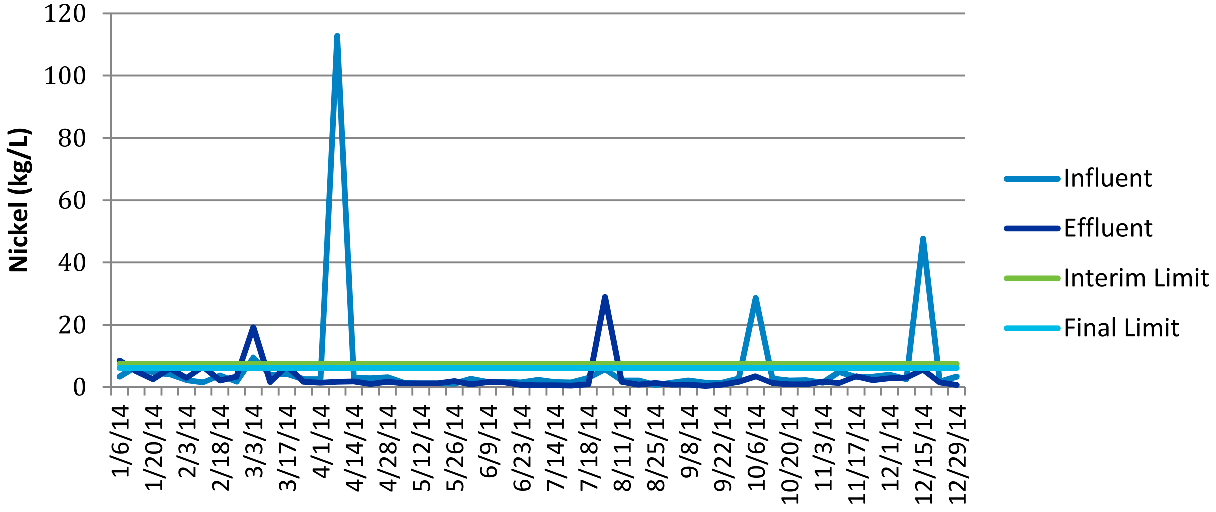
Monthly average effluent nickel was below the interim limit for nine months and below final limits for eight months. The data for February, March, May and August are noteworthy because it indicates that the effluent nickel levels were higher than the influent levels; a potential indication of a temporary elevated nickel component in the incinerator side stream.

Figure 2.2-3. Monthly Nickel Mass



Daily effluent Nickel levels exceeded the interim limit three times and exceeded the final limits five times. The data for thirteen days indicated that the effluent nickel levels were higher than the influent levels.

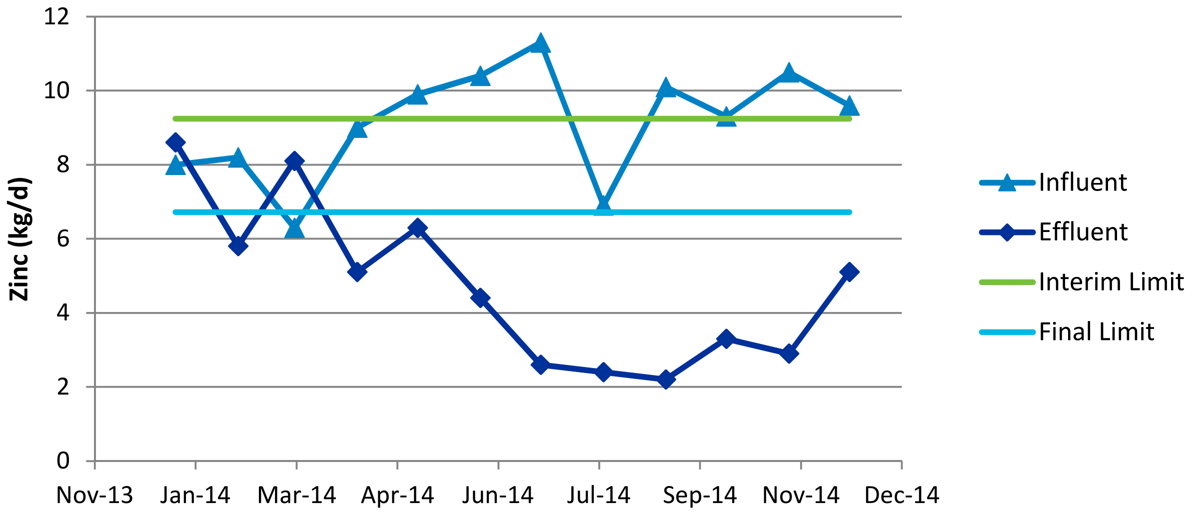
Figure 2.2-4. Daily Nickel Mass



Zinc

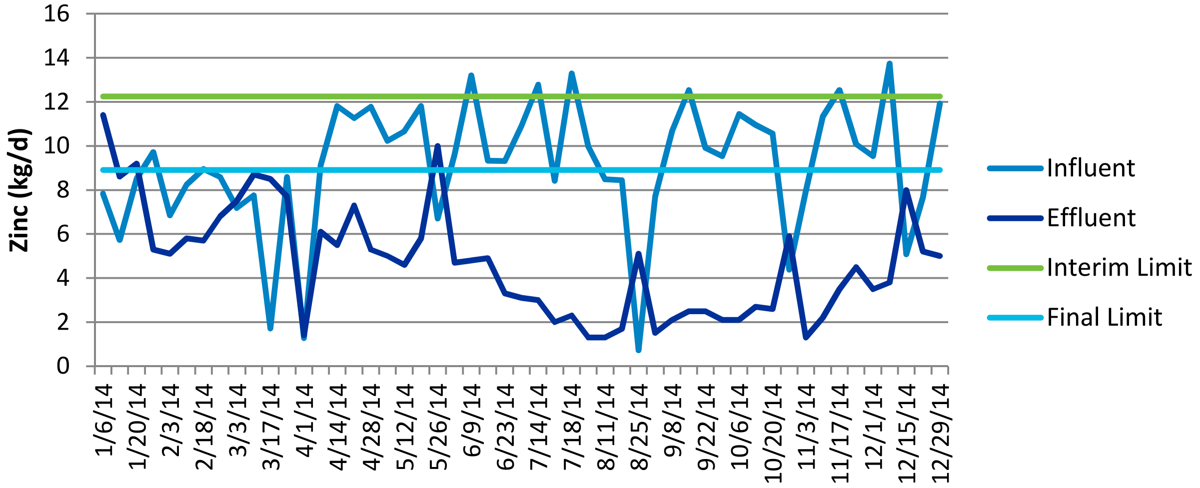
Monthly average effluent zinc was consistently below the interim limit and below final limits in ten months. The data for January and March are noteworthy because it indicates that the effluent zinc levels were higher than the influent levels; a potential indication of a temporary elevated zinc component in the incinerator side stream.

Figure 2.2-5. Monthly Zinc Mass



Daily effluent zinc levels did not exceed the interim limit and exceeded the final limits three times. The data for eleven days indicated that the effluent zinc levels were higher than the influent levels.

Figure 2.2-6. Daily Zinc Mass

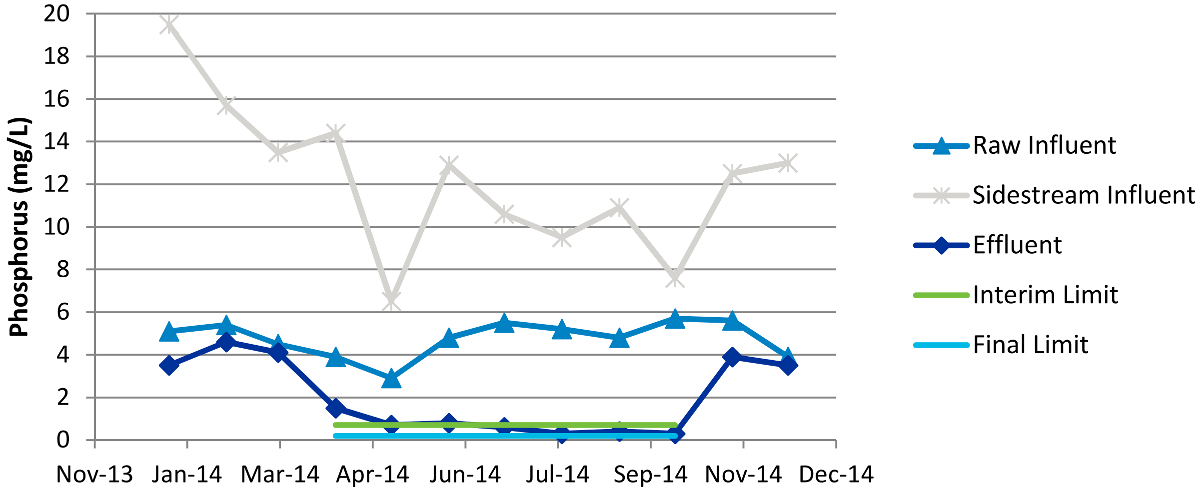


2.2.2 Phosphorus

The influent and effluent phosphorus levels were graphed and presented below. The seasonal limit for phosphorus is in effect from April 1 to October 31 annually.

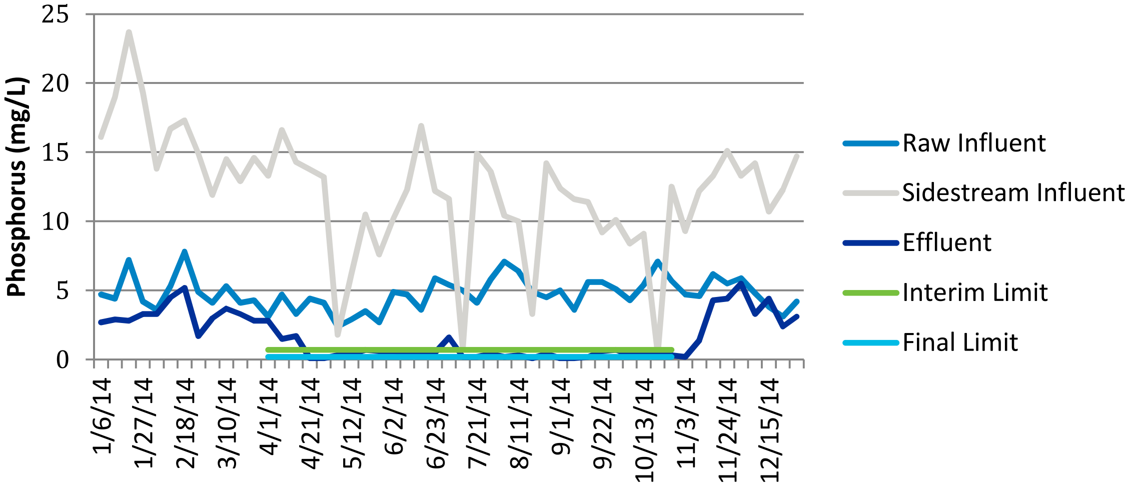
From April 1, 2014 to October 31, 2014, the WPCF was able to achieve the interim seasonal average of 0.7 mg/L using alum addition upstream of the primary tanks and downstream of the aeration tanks. Initial performance was sluggish but the months toward the end of the season brought the seasonal average down well below the limit. No consecutive months exceeded 0.7 mg/L during the season. The elevated effluent phosphorus levels during the remainder of the year illustrate the profound impact alum addition has on removing phosphorus.

Figure 2.2-7. Monthly Phosphorus Concentration



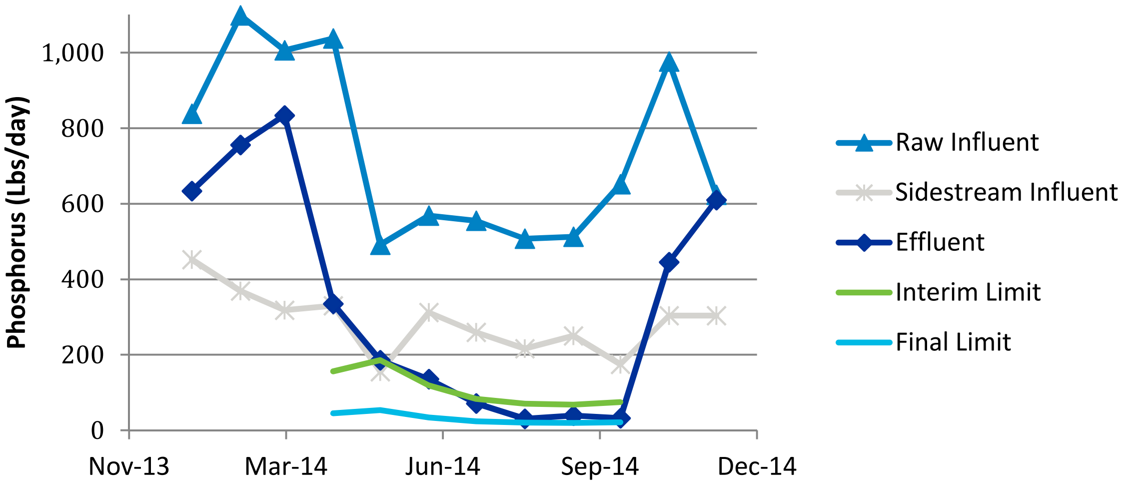
The interim limit does not include a daily limit; however the graph below indicates the effluent was consistently below the interim limit on a daily basis.

Figure 2.2-8. Daily Phosphorus Concentration



As shown on the table above there is a side stream phosphorus load from the incinerator that contributes to the overall phosphorus load on the facility. The phosphorus mass of this side stream represents roughly 30 percent of the total influent phosphorus load. The graph below shows each stream and the effluent limits on a mass basis.

Figure 2.2-9. Monthly Phosphorus Mass



Additionally, the following table shows the plant performance, in terms of monthly average effluent phosphorus, for 2014 and 2015 to date.

Table 2.2-4 – Monthly Average Phosphorus Performance

	2014 Monthly Total P			2015 Monthly Total P		
Month	Effluent Conc. (mg/l)	Average Flow (MGD)	Effluent Total P (ppd)	Effluent Conc. (mg/l)	Average Flow (MGD)	Effluent Total P (ppd)
April	1.5	26.8	335.5	0.6	23.1	115.7
May	0.7	31.9	186.4	0.5	17.8	80.6
June	0.8	20.3	135.5	0.4	18.7	59.0
July	0.6	14.2	71.1	0.1	16.8	19.4
Aug	0.3	12.1	30.3	-	-	-
September	0.4	11.7	39.1	-	-	-
October	0.3	12.8	32.0	-	-	-
Seasonal Average	0.7	18.5	118.6	0.4	19.1	68.7

The future seasonal average concentration of 0.28 mg/l per day was achieved using chemical addition in July 2015. The performance trend has continually improved as the plant personnel have become more familiar with the phosphorus removal process and the system has potential to be further optimized for better chemical phosphorus removal. The future daily maximum limit of 0.62 mg/l was exceeded 23 times in 2014, but only 4 times from March 2015-July2015. With the recent success of meeting the future phosphorus limit in July 2015, coupled with further process optimization and the potential removal of the incinerator side stream loads (which account for approximately 30% of the total phosphorus load to the plant), it is possible that the WPCF could meet the future permit limits with chemical addition alone. Impending air regulations may require the incinerator be shutdown in March of 2016, and at that time the WPCF could take the opportunity to optimize the existing chemical phosphorus removal system in an effort to try and meet future permit limits with chemical addition alone. The results of the 2016 phosphorus removal season (April –October 2016) would then be used to determine if additional treatment is required to meet future phosphorus limits. This would also provide an excellent opportunity to monitor metals to quantify the potential impact of shutting down the incinerator on the effluent metals levels.

2.3 Additional Data Collection

The mass balance of metals indicates the likelihood of a metals load on the facility that is not being captured in the raw influent samples. To determine if the source of the load is the incinerator side stream, samples from that stream should be analyzed for metals for an extended period of time. These samples should be analyzed concurrent with the ongoing phosphorous analysis that is conducted. If the results of this effort indicate that metals are not present in the side stream, it may be an indication of a hydraulic delay in the time interval between influent and effluent samples. If that is the case, daily influent and effluent samples may be required for an extended period of time.

The mass balance indicates that the side stream phosphorus load represents roughly 30-pecent of the total phosphorus load to the facility. Despite that fact, the WPCF has been able to consistently meet the interim limit for phosphorus. A reduction in the side stream load would likely reduce the quantity of chemicals required to achieve the permit limits, and thus the quantity of dewatered cake. Elimination of the side stream could also potentially change the technology selected for low level phosphorus removal.

If extenuating circumstances, such as the impending air permit regulations, require that the incineration system be shut down for an extended period of time, the City would benefit from the full-scale data that could be obtained, as discussed in Section 2.2.2. Several recent short-duration shutdowns did not provide definitive data on the impact of the side stream on the treatment process. However, if the incinerator were offline for an entire phosphorus removal season, a full-scale pilot could be conducted to demonstrate the maximum potential of chemical addition. Additionally, during this period small scale pilots for other treatment technologies, such as effluent filters, could also be implemented. The results of these piloting efforts can then be utilized to support a recommendation on the type of technology that can consistently meet the proposed permit limits, and the data can be used as part of the design effort to appropriately size the needed equipment.

2.4 Capital Costs

Capital costs for the full Phosphorus Upgrade (with effluent filtration) are presented in Table 2.4-1 below. If the piloting efforts yield favorable results with chemical addition only (no filtration) the capital cost would be reduced to $4,300,000.

Table 2.4-1 Capital Costs for Phosphorus Upgrade

Phosphorus Removal	Capital Cost
Civil / Site Work	$2,900,000
Filtration Facility	$4,300,000
Filtration Equipment	$13,300,000
Pump Station(s)	$2,400,000
Electrical, I&C, Misc Mechanical	$5,800,000
Chemical Feed Systems	$4,300,000
TOTAL	$33,000,000

Notes: Costs include escalation to 2019 midpoint of construction.
Costs include allowances for engineering and contingency.

2.5 Conclusion

The recommendation for effluent filters included in the 2011 report is still a viable alternative for compliance. In the time that has passed since that report was issued, technology has improved and the five micron media has gone into full scale production for the diamond filter configuration and is installed in many facilities consistently meeting 0.2 mg/L or lower phosphorus levels. Another development in the cloth media filter technology is the “mega-disk” technology that uses the disk filter configuration with significantly larger disks than were previously available. This advancement makes disk filter technology worthy of consideration at a larger plant like Waterbury’s, potentially saving approximately $2,500,000 in the projected capital cost shown in table 2.4-1 when compared to the diamond filter technology.

With the operation of the chemical treatment system installed to meet the interim phosphorus limits, the WPCF has been able to consistently meet the interim phosphorus limits and has had an instance where they have met the future limits. The presence (or lack of) an untreated side stream from the incineration process will have a significant impact on the phosphorus removal process given the significant phosphorus load from this side stream. However, it is uncertain whether chemical addition alone can consistently meet the future phosphorus limits, whereas effluent filtration has a proven track record of meeting these treatment levels. Given the uncertainty in whether chemical addition can consistently meet the future limits, particularly if the side stream load is eliminated through shutting down the incinerator or from the provision of side stream treatment, a full scale chemical addition pilot is recommended. This full scale pilot would operate for a complete season where the incinerator is taken off line and where the chemical treatment system is optimized and operated in a manner that attempts to consistently meet the future phosphorus limits. The results of such a pilot can then be used to support a recommendation for a final phosphorus treatment technology to meet the future effluent limits.

Table 2.2-1 Summary of 2014 Plant Operating Data

INFLUENT CHARACTERISTICS

Month	Av Flow	Max Day	Pk hr	Septage	Influent BOD		Influent TSS	
	mgd	mgd	mgd	gal/mo	mg/l	lbs/day	mg/l	lbs/day
Jan-14	21.7	26.8	38.2	2,700	118	21,355	91	16,469
Feb-14	19.7	22.3	30.0	3,200	132	21,687	123	20,209
Mar-14	24.4	41.5	50.7	3,600	111	22,588	108	21,978
Apr-14	26.8	37.1	50.8	4,100	89	19,893	88	19,669
May-14	31.9	47.7	55.4	8,100	72	19,155	82	21,816
Jun-14	20.3	28.7	41.7	8,700	95	16,084	129	21,840
Jul-14	14.2	18.3	38.5	6,400	130	15,396	162	19,185
Aug-14	12.1	16.7	32.5	4,200	118	11,908	162	16,348
Sep-14	11.7	14.0	31.2	2,100	139	13,563	167	16,296
Oct-14	12.8	21.7	33.4	5,100	135	14,412	160	17,080
Nov-14	13.7	19.8	34.4	2,800	117	13,368	153	17,481
Dec-14	20.9	32.9	52.6	0	86	14,990	105	18,302
Jan 2014 - December 2014	19.2			4,250	112	17,033	128	18,889

INFLUENT CHARACTERISTICS NUTRIENTS AND METALS

Month	Influent TKN		Influent TP		Synagro Eff TP		Infl Copper	Infl Nickel	Infl Zinc
	mg/l	lbs/day	mg/l	lbs/day	mg/l	lbs/day	kg/day	kg/day	kg/day
Jan-14	27.0	4,436	5.1	838	19.5	452	4.5	4.7	8.0
Feb-14	27.7	5,637	5.4	1,099	15.7	369	3.6	2.3	8.2
Mar-14	25.2	5,633	4.5	1,006	13.5	318	2.9	5.1	6.3
Apr-14	18.5	4,922	3.9	1,038	14.4	330	5.3	24.9	9.0
May-14	17.7	2,997	2.9	491	6.5	155	2.4	1.2	9.9
Jun-14	29.3	3,470	4.8	568	12.9	312	5.0	1.9	10.4
Jul-14	29.5	2,977	5.5	555	10.6	260	5.4	2.1	11.3
Aug-14	30.9	3,015	5.2	507	9.5	216	3.7	2.7	6.9
Sep-14	40.6	4,334	4.8	512	10.9	250	7.8	1.8	10.1
Oct-14	38.0	4,342	5.7	651	7.6	175	6.5	8.9	9.3
Nov-14	26.2	4,567	5.6	976	12.5	304	6.8	3.2	10.5
Dec-14	17.7	2,832	3.9	624	13.0	304	4.9	11.9	9.6
Jan 2014 - December 2014	27.4	4,097	4.8	739	12.2	287	4.9	5.9	9.1

Table 2.2-1 Summary of 2014 Plant Operating Data (continued)

PRIMARY EFFLUENT CHARACTERISTICS								
Month	Primary Eff BOD		Primary Eff TSS		Primary Eff TKN		Primary Eff TP	
	mg/l	lbs/day	mg/l	lbs/day	mg/l	lbs/day	mg/l	lbs/day
Jan-14	84	15,202	51	9,230	23.2	4,199	5.70	1,032
Feb-14	94	15,444	60	9,858	25.0	4,107	6.33	1,040
Mar-14	94	19,129	62	12,617	24.4	4,965	5.81	1,182
Apr-14	89	19,893	55	12,293	18.0	4,023	4.70	1,051
May-14	57	15,165	51	13,568	13.9	3,698	3.60	958
Jun-14	59	9,989	50	8,465	18.7	3,166	4.37	740
Jul-14	62	7,343	54	6,395	20.3	2,404	5.20	616
Aug-14	68	6,862	59	5,954	19.7	1,988	4.54	458
Sep-14	82	8,001	60	5,855	28.0	2,732	5.08	496
Oct-14	83	8,860	61	6,512	25.1	2,679	5.35	571
Nov-14	85	9,712	62	7,084	22.0	2,514	7.58	866
Dec-14	72	12,550	53	9,238	15.7	2,737	5.90	1,028
Jan 2014 - December 2014	77	12,346	57	8,922	21	3,268	5.35	836

EFFLUENT CHARACTERISTICS				
Month	Effluent BOD		Effluent TSS	
	mg/l	lbs/day	mg/l	lbs/day
Jan-14	8	1448	8	1,448
Feb-14	8	1314	8	1,314
Mar-14	9	1831	11	2,238
Apr-14	7	1565	8	1,788
May-14	2	532	8	2,128
Jun-14	2	339	3	508
Jul-14	1	118	3	355
Aug-14	1	101	2	202
Sep-14	2	195	2	195
Oct-14	3	320	3	320
Nov-14	9	1028	9	1,028
Dec-14	9	1569	9	1,569
Jan 2014 - December 2014	5	863	6	1,091

Table 2.2-1 Summary of 2014 Plant Operating Data (continued)

EFFLUENT CHARACTERISTICS NUTRIENTS AND METALS							
Month	Effluent Total N		Effluent TP		Eff Copper	Eff Nickel	Eff Zinc
	mg/l	lbs/day	mg/l	lbs/day	kg/day	kg/day	kg/day
Jan-14	5.9	829	3.5	633	6.7	5.6	8.6
Feb-14	4.3	832	4.6	756	0.9	3.7	5.8
Mar-14	4.5	788	4.1	834	1.4	7.3	8.1
Apr-14	4.5	1,020	1.5	335	1.6	1.6	5.1
May-14	5.1	718	0.7	186	2.0	1.4	6.3
Jun-14	3.4	600	0.8	135	1.0	1.2	4.4
Jul-14	2.9	643	0.6	71	1.0	0.7	2.6
Aug-14	2.3	677	0.3	30	1.3	8.2	2.4
Sep-14	2.5	1,635	0.4	39	1.0	0.9	2.2
Oct-14	2.9	1,391	0.3	32	0.7	1.6	3.3
Nov-14	4.4	779	3.9	446	1.7	2.2	2.9
Dec-14	4.4	1,672	3.5	610	2.0	2.7	5.1
Jan 2014 - December 2014	3.9	965	2.02	342	1.8	3.1	4.7

SOLIDS					
Month	Primary	WAS	Dewatering		
	dry lb/month	dry lb/month	dry lb/month	% solids	dry tons / day
Jan-14	779,790	219,000	781,800	22.3	12.6
Feb-14	750,600	233,800	773,800	21.5	13.8
Mar-14	825,660	263,800	816,000	21.9	13.2
Apr-14	663,030	263,000	692,200	22.4	11.5
May-14	1,050,840	403,400	1,141,200	20.5	18.4
Jun-14	984,120	346,000	1,109,600	21.5	18.5
Jul-14	930,744	277,800	1,037,200	21.6	16.7
Aug-14	928,242	226,600	990,200	21.6	16.0
Sep-14	817,320	235,600	854,400	21.2	14.2
Oct-14	808,146	280,000	886,000	20.8	14.3
Nov-14	666,366	236,600	748,400	21.3	12.5
Dec-14	431,178	129,000	608,200	23.4	9.8
Jan 2014 - December 2014	803,003	259,550	869,917	21.7	14

Table 2.2-3 Daily Influent and Effluent Metals Loads (kg/d)

	Copper(1)			Nickel(2)			Zinc(3)		
Date	Influent Mass	Effluent Mass	Percent Removal	Influent Mass	Effluent Mass	Percent Removal	Influent Mass	Effluent Mass	Percent Removal
1/6/14	1.1	4.7(5)	-327%	3.36	8.52(4)	-154%	7.8	11.4(5)	-45%
1/13/14	1.0	14.6(4)	-1360%	6.68	5.16	23%	5.7	8.6	-50%
1/20/14	9.5	5.9(4)	38%	4.73	2.51	47%	8.5	9.2(5)	-8%
1/27/14	6.5	1.5	77%	4.05	6.05	-49%	9.7	5.3	45%
2/3/14	6.1	1.5	75%	2.28	2.93	-29%	6.8	5.1	26%
2/10/14	3.7	0.7	81%	1.50	6.54(5)	-336%	8.2	5.8	30%
2/18/14	3.7	0.7	81%	3.73	2.13	43%	8.9	5.7	36%
2/24/14	0.9	0.8	11%	1.72	3.38	-97%	8.6	6.8	21%
3/3/14	2.4	0.8	67%	9.58	19.2(4)	-100%	7.2	7.5	-4%
3/10/14	2.3	3.2	-39%	3.88	1.58	59%	7.8	8.7	-12%
3/17/14	4.3	0.8	81%	4.28	6.80(5)	-59%	1.7	8.5	-397%
3/24/14	2.6	0.9	65%	2.58	1.71	34%	8.6	7.7	10%
4/1/14	2.6	1.4	46%	2.56	1.41	45%	1.3	1.4	-9%
4/7/14	5.7	1.7	70%	112.79	1.74	98%	9.1	6.1	33%
4/14/14	4.9	0.9	82%	2.95	1.84	38%	11.8	5.5	53%
4/21/14	5.6	3.1	45%	2.82	1.04	63%	11.3	7.3	35%
4/28/14	7.5	0.9	88%	3.21	1.76	45%	11.8	5.3	55%
5/5/14	1.3	1.2	8%	1.28	1.24	3%	10.2	5.0	51%
5/12/14	3.6	1.2	67%	1.18	1.16	2%	10.7	4.6	57%
5/19/14	3.5	1.2	66%	1.18	1.16	2%	11.8	5.8	51%
5/26/14	1.1	4.4	-300%	1.12	1.89	-69%	6.7	10.0(5)	-49%
6/2/14	5.2	0.9	83%	2.62	0.93	65%	9.6	4.7	51%
6/9/14	6.6	1.6	76%	1.65	1.61	2%	13.2	4.8	64%
6/16/14	4.2	0.8	81%	1.70	1.47	14%	9.3	4.9	47%
6/23/14	3.9	0.7	82%	1.55	0.65	58%	9.3	3.3	65%
7/7/14	3.9	1.3	67%	2.34	0.63	73%	10.9	3.1	72%
7/14/14	5.6	0.6	89%	1.60	0.61	62%	12.8	3.0	77%
7/21/14	4.6	1.0	78%	1.53	0.50	67%	8.4	2.0	76%
7/18/14	7.4	0.9	88%	2.95	0.93	68%	13.3	2.3	83%
8/4/14	2.8	0.4	86%	5.69	28.91(4)	-408%	10.0	1.3	87%
8/11/14	4.2	0.4	90%	2.12	1.71	19%	8.5	1.3	85%
8/18/14	7.0	0.4	94%	2.11	0.85	60%	8.4	1.7	80%
8/25/14	0.7	3.8	-443%	0.72	1.28	-78%	0.7	5.1	-605%
9/1/14	7.0	2.0	71%	1.40	0.84	40%	7.7	1.5	81%
9/8/14	9.3	1.7	82%	2.13	0.85	60%	10.7	2.1	80%
9/15/14	10.4	0.4	96%	1.39	0.42	70%	12.5	2.5	80%
9/22/14	5.7	0.4	93%	1.42	0.85	40%	9.9	2.5	75%
9/29/14	6.8	0.4	94%	2.73	1.70	38%	9.5	2.1	78%
10/6/14	9.3	0.4	96%	28.6	3.42	88%	11.4	2.1	82%
10/13/14	8.9	1.3	85%	2.74	1.33	51%	11.0	2.7	75%
10/20/14	5.6	0.4	93%	2.11	0.88	58%	10.6	2.6	75%
10/27/14	2.2	0.5	77%	2.19	0.91	58%	4.4	5.9	-35%

Table 2.2-3 Daily Influent and Effluent Metals Loads (kg/d)

	Copper(1)			Nickel(2)			Zinc(3)		
Date	Influent Mass	Effluent Mass	Percent Removal	Influent Mass	Effluent Mass	Percent Removal	Influent Mass	Effluent Mass	Percent Removal
11/3/14	4.3	0.1	98%	1.45	1.77	-22%	8.0	1.3	84%
11/11/14	8.5	0.4	95%	4.95	1.32	73%	11.3	2.2	81%
11/17/14	8.6	5.6	35%	3.13	3.48	-11%	12.5	3.5	72%
11/24/14	5.9	0.7	88%	3.36	2.25	33%	10.1	4.5	55%
12/1/14	7.2	0.7	90%	3.97	2.83	29%	9.5	3.5	63%
12/8/14	5.2	0.8	85%	2.58	3.04	-18%	13.7	3.8	72%
12/15/14	1.1	6.4(4)	-482%	47.68	5.59	88%	5.1	8.0	-58%
12/22/14	4.3	1.5	65%	1.70	1.48	13%	7.7	5.2	32%
12/29/14	6.8	0.7	90%	3.41	0.72	79%	11.9	5.0	58%

(1) Interim limit = 5.74 kg/d; Final limit = 4.58 kg/d

(2) Interim limit = 7.50 kg/d; Final limit = 6.18 kg/d

(3) Interim limit = 12.24 kg/d; Final limit = 8.91 kg/d

(4) Denotes exceedance of interim limit.

(5) Denotes exceedance of final limit.

Section 3

Biosolids Alternatives Evaluation

3.1 Introduction

With the upcoming expiration of the incinerator operations contract with Synagro at the end of 2016, the City sought to perform an evaluation of sludge processing alternatives that may be viable for WPCF. As part of this analysis a comprehensive screening program was implemented to evaluate all sludge processing technologies including maintaining incineration. The critical steps in the decision making process included:

- Defining all of the sludge processing alternatives to be considered
- Defining the criteria and weighing factors for each round of the decision making process
- Understanding EVAMIX, the decision support tool

3.2 EVAMIX

EVAMIX is a matrix based tool that has been used successfully on a number of projects to assist clients in their selection process. Matrix-based methods of evaluation have been available since the early 1960s. Their development was specifically targeted for planners and engineers to evaluate alternative plans, sites, or technologies, with the objective of selecting the best one, or ranking the alternatives for presentation to decision makers.

EVAMIX was originally developed during the 1980s in The Netherlands. It was designed to make use of the best aspects of both concordance/discordance analysis and the goals achievement matrix to handle both quantitative and qualitative data in a mathematically rigorous manner. It is a multi-criteria evaluation program that makes use of both quantitative and qualitative criteria within the same evaluation, regardless of the units of measure. The algorithm behind EVAMIX maintains the essential characteristics of quantitative and qualitative criteria, yet is designed to ultimately combine the results into a single appraisal score. This unique feature gives the program much greater flexibility than most other matrix-based evaluation programs, and allows the evaluation team to make use of all data available to them in its original form.

A consensus or agreement of the results from the decision support tool was obtained and the selected alternative(s) to be considered further are presented herein.

3.3 Initial Alternative Screening

A matrix of 68 potential sludge processing alternatives was developed and is presented in Table 3.3-1 located at the end of this section. These alternatives were screened based on two criteria: development status and typical scale, as follows:

Developmental Status – established (proven operating systems), innovative (permanent demonstration plant or one or two full scale plants), embryonic (no full scale operating systems)

Typical Scale – Large (>50 TPD), Medium (10 to 50 TPD), Small (less than 10 TPD)

In addition, general information on the type of system it is and potential venders were provided. It should be noted that the system to be constructed for the Waterbury WPCF is a large system and that if a system is not manufactured or currently proven to handle large volumes of sludge, it was eliminated from further consideration. In addition, emerging systems with no proven operational data or full scale facilities were also eliminated.

Based on this initial screening criteria of scale and developmental status, the following processes were eliminated. It should be noted that the composting alternatives were eliminated based on additional concerns of heavy odor generation and additional land requirements.

Pre-Digestion

- High Voltage Lysis
- Ozonation
- Sludge Minimization using Anaerobic sides tream reactor
- Enzyme treatment
- Ultrasonic lysis
- Mechanical lysis
- Chemical/Mechanical lysis

Digestion

- Aerobic Digestion
- Autothermal Thermophilic Aerobic Digestion
- Recuperative Thickening

Chemical Stabilization

- Ferrate Treatment
- Neutralizer Chemical Stabilization
- Clean B Chemical Stabilization

Composting

- Aerated Static Pile
- Windrow
- Chemically-enhanced windrow composting
- In-vessel/agitated bed
- In-vessel/tunnel
- In-vessel cage system
- Vermiculture

Heat Drying

- Solar Drying
- Microwave Drying

Other Thermal Processes

- Wet Pyrolysis
- Pyrolysis
- Thermal/Chemical Processing
- Plasma Assisted Sludge Oxidation

Other Processes

- Struvite Reduction
- Supercritical Water Oxidation
- High Nutrient Content Fertilizer Production
- Pyrobiomethane
- High Energy E-beam
- Deep well injection
- Extended recirculation
- FOG to biodiesel
- Sludge Degritting

The following processes are variations of Anaerobic Digestion and/or enhancements to Anaerobic Digestion that can be utilized in conjunction with a digestion process. These will be considered further if digestion is deemed a viable process.

- Electrical lysis
- Thermal hydrolysis (CAMBI)
- Pasteurization

3.4 Second Alternative Screening

The goal of the second alternative screening was to develop a listing of criteria to evaluate the remaining alternatives to select 4 to 6 alternatives to be evaluated in detail. It should be noted that 'Haul Dewatered Biosolids' was added after the initial round of screening. Although this is not an on-site treatment alternative, this is a viable option to ensure proper disposal of the dewatered biosolids. The dewatered biosolids without further on-site treatment would be landfilled, incinerated or otherwise properly disposed of off-site.

3.4.1 Evaluation Methodology

The second evaluation was conducted as follows:

- Define screening criteria and weighing factors with input from the City for the decision making process

- Review and provide technical information on each remaining alternative as related to the evaluation criteria

- Run EVAMIX, the decision support tool, to select 4 to 6 alternatives for further evaluation.

3.4.2 Evaluation Criteria

The matrix of 27 potential alternatives was evaluated against the following criteria:

- Liquid Side stream

- Sludge Dewaterability
- Complexity of Operation
- Emission Generation
- End Product Use
- Land Requirements
- Odor Generation
- Process Reliability
- Relative Capital Cost
- Relative Operating Cost
- Relative Energy Consumption

Table 3.4-1 provides a definition and a rating scale of each evaluation criteria and Table 3.4-2 lists the criteria rating on each of the alternatives.

3.5 EVAMIX Results

Following the second round of screening, the decision support tool was utilized to rank the 27 alternatives based on the ratings that the City assigned to the 11 criteria above. The alternatives that were selected for detailed engineering analysis were the following:

- Haul Dewatered Biosolids
- Fluid Bed Incineration
- Mesophilic Anaerobic Digestion
- High Solids Mesophilic Anaerobic Digestion
- Lime Stabilization
- Advanced Lime Stabilization

This engineering report includes detailed information on each of the above sludge disposal alternatives including potential site plans and process schematics, as well as cost benefit analysis to provide the stakeholders with the information they need to further analyze the disposal alternatives and be able to make informed decisions in the final evaluation of the alternatives.

3.6 Hauling Dewatered Biosolids for Off-Site Disposal

The alternative to haul dewatered biosolids off-site for final processing and disposal is a viable option that eliminates the need for O&M investment from City staff or contract operations staff. For the Waterbury WPCF there would be a minimum capital investment to modify the existing conveyor system, but the overall cost for this option will be market dependent on a $/wet ton disposed.

The capital investment includes design and construction of a sidewall sludge belt conveyor to pick up the dewatered biosolids off the existing belt filter presses and discharge into sludge hauling trucks. An enclosure would be built over the truck loading bay for weather protection and to mitigate some of the potential odors. Also, since the cost to haul is weight based unit pricing, the enclosure prevents additional water accumulation in the truck(s) during rain events.

As part of this study, CDM Smith worked with the City of Waterbury to issue an Invitation to Bid (ITB) seeking a Contractor(s) to provide long-term (2 years) and/or on-call loading, transportation and disposal services of the dewatered biosolids, scum and/or ash generated at the WPCF. The intent of the ITB was to obtain a Contractor to provide all labor, materials, equipment, supplies, permits, licenses, fees, tolls, facilities, and all other things necessary and required for the loading, transportation, and off-site disposal services for the biosolids, scum and/or ash generated at the WPCF.

This ITB was initially developed as a temporary solution due to the impending conclusion of the incinerator operations contract at the end of 2016, as well as the impending air permit regulation changes scheduled to take place in March 2016. The ITB issued also included the labor, material and all incidentals associated with the construction of a temporary conveyor to convey the dewatering biosolids from the end of the existing belt filter presses to a truck loading point. The ITB is included in Appendix A.

3.6.1 Results of the Invitation to Bid

Only one bid was received, therefore, the ITB has been reissued. It is understood that a major factor that prohibited Bidders from submitting on this ITB was the requirement to man the truck loading operation continuously. Because only one bid was received, a 2nd ITB was issued, addressing concerns raised during the 1st ITB process. The results of the 2nd bid will not be available until after this study is submitted. It is recommended that the results of the 2nd bid be considered prior to moving forward with a biosolids alternative decision.

3.6.2 Permanent Conveyor and Truck Loading Bay

To facilitate hauling of the dewatering biosolids, a sludge belt conveyor system would be required to convey the final product from the end of the existing belt filter press conveyor out to a truck loading bay. The sidewall belt sludge conveyors would be designed to run horizontal and transition to inclined, run outside the Dewatering Building and be configured to discharge at a minimum of three (3) locations along the length of the sludge hauling truck. The ITB included the provision of a temporary enclosure, however, should hauling be selected for the long term a more permanent pre-fabricated metal building would be built around the truck loading bay and appropriate heating, ventilating and odor control equipment provided.

3.6.3 Estimated Construction Costs for Hauling Off-Site

The capital cost to construct a permanent truck loading bay and sludge belt conveyor system is estimated to be $3,100,000. A breakdown of the capital costs is shown below in Table 3.6-1.

Table 3.6-1 Capital Cost of Cake Hauling Facility

Haul Cake	Capital Cost
Sitework	$ 200,000
Buildings	$ 1,100,000
Equipment	$ 1,200,000
Electrical	$ 400,000
I&C	$ 200,000
TOTAL	$ 3,100,000

Notes: Costs include escalation to 2019 midpoint of construction.
Costs include allowances for engineering and contingency.

3.7 Assessment of Fluidized Bed Incineration System

The City of Waterbury disposes of its residual water pollution control facility (WPCF) sludge in a Fluidized Bed Incineration System (FBIS). The FBIS thermally reduces the carbonaceous portion of the sludge to carbon dioxide and water vapor which are emitted as gases while the inert portion of the sludge is converted to ash. The gases from the incinerator, collectively called flue gas, contains pollutants which are sent to air pollution control (APC) systems for cleansing. The ash which exits the APC systems as a slurry is dewatered to a cake-like consistency and then hauled to a landfill for final disposal. The FBIS was supplied by Dorr-Oliver and was installed in 1995.

The FBIS is operated by Synagro which utilizes the incinerator to process Waterbury's sludge and also residual sludges from approximately 60 cities and towns in Connecticut, Rhode Island and Massachusetts. The incinerator is permitted to burn 3 dry tons of sludge per hour or 62 dry tons per day (DTPD). Approximately 20% of the sludge feed is from the Waterbury WPCF while the remaining 80% is from sludge generators outside the WPCF. Synagro operates a fleet of trucks which, along with independent haulers, transport dewatered sludge at approximately 15% solids concentration, or greater, to the incinerator facility. Waterbury's dewatered sludge is conveyed to the incinerator facility via a V-Ram and pipeline. All dewatered cake is discharged to a blending pit. The combined sludges are then transferred via a clam shell bucket system to a sludge strainer to remove scrap metal and other items which damage the downstream pumping equipment. Lime and Kaolin clay are then metered into the dewatered sludge. These additives are used to prevent clinker formation and fusing and solidification of the fluid bed. The dewatered sludge is then conveyed to a Komline Sanderson (K-S) indirect sludge dryer. The K-S sludge dryer dries the sludge to approximately 26% to 27% solids concentration. The dried sludge is then pumped to the Fluidized Bed Incinerator (FBI).

3.7.1 Process Description

A simplified process flow diagram of the fluidized bed incineration system (FBIS) is shown in Figure 3.7-1 located at the end of this section. The primary components of the FBIS consist of the following:

- Fluidized bed incinerator and fluidizing air blower
- Primary heat exchanger or combustion air preheater

- Heat recovery boiler
- Air pollution control (APC) systems

The incinerator is a refractory-lined vessel containing three zones—the windbox, the sand bed, and the freeboard. Preheated combustion air supplied by the fluidizing air blower is blown into the windbox and distributed through nozzles or tuyeres to the bottom of the bed. The hot combustion air fluidizes the sand bed. Fuel oil and dewatered solids are pumped into the bottom of the bed to create a hot, turbulent suspension of sand, gases, and burning solids. The temperature in this zone is typically 1300°F to 1500°F, and the water in the solids is evaporated and the combustible matter oxidized in a matter of seconds. The combustion gases rise through the sand bed and enter the freeboard where the burnout of volatilized organics is completed. The freeboard is a large, open space above the bed which provides a 5- to 6-second gas residence time at temperatures of 1500°F to 1600°F. Hence, it acts like an afterburner.

The reactor flue gas then proceeds to the combustion air preheater in which the flue gas flows countercurrent to the combustion air. The combustion air is heated to approximately 1200°F while the flue gas is cooled to 1100°F. The combustion air preheater greatly improves the thermal efficiency of the FBIS by recovering a large portion of the thermal energy in the incineration flue gas and returning it to the reactor. The combustion air preheater makes it possible to burn sludges with low solids content or low heating value with minimal, or in some cases without any, auxiliary fuel. Following the combustion air preheater, the flue gas is sent to a heat recovery boiler which produces approximately 5,000 to 6,000 lbs/hr of steam at 100 psi. The steam is used in the K-S sludge dryer to raise the solids level from 21% to approximately 27% solids. At 27% solids the sludge can be burned in the FBI with minimal or without any fuel use, depending on the heating value of the sludge.

The flue gas then proceeds to the air pollution control (APC) system. The APC system consists of a venturi scrubber, an impingement tray scrubber, a packed bed scrubber and a wet electrostatic precipitator (WESP). In the venturi scrubber the flue gas is sent through a narrow section which is flooded with plant effluent water. The scrubber water is atomized into fine droplets which wet the particulate matter. The wetted particles agglomerate and coalesce into larger particles which are collected as wet slurry at the bottom of the scrubber. The impingement scrubber removes some of the acid gases and cools the flue gas to approximately 90°F. The packed bed scrubber is available for additional control of acid gases. The use of caustic in this scrubber can provide additional removal of the acid gases. The flue gas then proceeds through the WESP where additional removal of fine particulate is accomplished.

The cleansed flue gas is discharged to the atmosphere through a 120 foot tall stack.

3.7.2 Condition of FBIS

The existing FBIS is operated continuously 24 hours per day, 7 days per week at its design capacity. Hence the equipment is subject to demanding operating conditions. In the past, Synagro has kept the FBIS in good operating condition. However, with the end of the Synagro contract approaching, there are several pieces of equipment which need immediate attention and repair or replacement. Necessary repairs are estimated to cost $7.0 million and include the following items:

- Primary Heat Exchanger Replacement
- Waste Heat Boiler Replacement
- KS Sludge Dryer Rotor Replacement
- Rock Screw Replacement

3.7.3 Air Pollution Control Upgrades

The recent Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Sewage Sludge Incineration Units, 40 CFR Part 60 Subparts LLLL and MMMM, placed severe emission limits on all sludge incinerators. These standards, hereafter referred to as the Sewage Sludge Incinerator Rule (SSI Rule), were promulgated on March 21, 2011 and they require that all sewage sludge incinerators must be in compliance by March 16, 2016. The SSI Rule placed very restrictive emission limits on 9 pollutants, namely: cadmium, mercury, lead, particulate matter, hydrogen chloride, nitrogen oxides, carbon monoxide, sulfur dioxide, and dioxin/furans. Based on recent emission testing on the incinerator stack gas, additional control will be required for mercury and sulfur dioxide.

Mercury is a difficult and costly pollutant to control due to its high vapor pressure. The assured method of controlling mercury emissions from a sludge incinerator is to adsorb the mercury on activated carbon which has been impregnated with sulfur. The mercury is captured as mercuric sulfide and mercuric sulfate on the activated carbon. Prior to adsorption on the carbon, the mercury laden flue gas must first be conditioned (demisted) and then heated to approximately 150°F. The carbon adsorption would take place in a large vessel with approximate dimensions of 12 ft in diameter by 30 feet in height depending on the carbon system supplier. Also the required heat exchanger, gas conditioning unit and carbon adsorber would add approximately 24 inches of additional pressure drop to the flue gas train. To overcome this additional pressure drop an ID fan would be required.

To achieve additional control of sulfur dioxide, a caustic storage tank and chemical feed pumps would be required.

3.7.4 Ash Disposal

Ash generated by the incineration process has been landfilled at the City owned South End Disposal Area (SEDA). Since 1987, SEDA has been permitted to operate as a special waste landfill for specific materials generated by WPCF including grit, screenings and ash. These materials were originally placed in the Route 8 right-of-way (ROW) in accordance with an encroachment permit issued by the Connecticut Department of Transportation (DOT). The placement of special waste within the ROW ceased in 2004 due to concerns raised by DOT regarding the status of the issued encroachment permit. From 2004 through the present, the City has been working with DOT to re-establish the approvals needed to resume placement of materials in the ROW.

Presently, the City is pursuing other options to resume filling within SEDA (which is about at capacity) and use of the ROW. Until an agreement is reached regarding continued use of SEDA or use of the ROW, the future ability to use SEDA or the ROW for disposal of WPCF grit, screenings and ash is uncertain.

3.7.5 Incinerator Upgrade Capital Costs

Capital costs for the incinerator include both improvements to the existing FBIS, as well as new requirements for air pollution control. A summary of these costs is shown below in Table 3.7-1. Annual O&M costs associated with this option are estimated to be $2.0 million. A 20 year present worth evaluation is also included in Section 5 of this report.

Table 3.7-1 Incinerator Upgrade Capital Cost

Incineration Upgrade	Capital Cost
Sitework	$ 1,000,000
Equipment Repair	$ 7,000,000
Chemical Feed	$ 1,000,000
Mercury Removal System	$ 8,000,000
Misc Equipment	$ 4,000,000
Electrical	$ 1,000,000
I&C	$ 1,000,000
TOTAL	$ 23,000,000

Notes: Costs include escalation to 2019 midpoint of construction.
Costs include allowances for engineering and contingency.

3.7.5 Pros and Cons of Incinerator Contract Operations

The following section briefly discusses some of the pros and cons of contract operations of the incinerator. The pros of keeping the incinerator operating as a contract operations are as follows:

1. The City is not staffed to operate the incinerator. Presently, Synagro has a full time staff of 13 full time employees who handle the operation, maintenance and administration of the FBIS.

2. Significant capital costs will be required to perform extensive deferred maintenance and to upgrade the emission control systems to meet the SSI Rule. While these costs would most likely be passed on to the City, a private company could likely have these upgrades done more quickly and at lower cost.

3. Continued operation of the sludge incinerator provides assured sludge disposal to the City. The City would still have to provide a landfill for disposal of the incinerator ash, but landfill disposal of ash is considerably less problematic and cumbersome than landfill disposal of dewatered sludge. It is noted that the ash quantity is about 1/8 of the sludge quantity and the ash is non-odorous.

If operation of the Waterbury incinerator ceases, as appears to be the trend in the region, sludge disposal in Connecticut will become considerably more difficult and more costly. The cons of keeping the incinerator operating as a contract operations are as follows:

1. The side streams from the incinerator, principally the phosphorous and metals in the scrubber water returned to the WWTP, will require the City to provide additional control of phosphorous and metals on liquid side of the WWTP.

2. The City makes possible a regional sludge disposal service to many cities and towns which would otherwise have to find alternative means of disposing of their sludge. Given the lack of landfills suitable for sludge disposal in Connecticut, the question is, "Will the City be fairly compensated for this service?"

3. The negative view of incineration from the community. Although the incinerator would be upgraded to comply with the latest air emission requirements, there is a negative view of the incinerator from the public in terms of potential health impacts and general "pollution". This is further exasperated from the significant quantities of outside sludge being brought into the community for disposal, giving the residents the perception that they are taking on the "problem" of outside communities.

3.8 Description and Design of Digestion Systems

The following analysis presents the preliminary design and feasibility for Anaerobic Digestion installations for long-term biosolids management for Waterbury.

Anaerobic digestion involves the decomposition of organic matter in biosolids into methane gas and carbon dioxide by microorganisms in the absence of oxygen. There are several reasons for considering advanced or high-performance anaerobic digestion at a wastewater treatment plant, including the reduction of pathogen concentrations and the desire to reduce energy costs and greenhouse gas emissions by utilizing the digester gas as a fuel source. Methane produced in anaerobic digestion facilities can be utilized to reheat the digester and/or produce power thus replacing energy derived from fossil fuels, and hence reducing emissions of greenhouse gases. Mesophilic Anaerobic Digestion results in Class B stabilized biosolids as an end-product, which will ultimately be land-filled, since the Connecticut DEEP currently has strict regulations for the land-application of Class B biosolids. It should be noted that digested solids are harder to dewater, so although this process will reduce the volatile solids in the sludge, there may be a reduction in the percent solids content from the dewatering operation.

The following Anaerobic Digestion technologies are discussed in more detail below.

- **Mesophilic Anaerobic Digestion**: Non-proprietary technology, which incorporates dual stage anaerobic digestion of thickened sludge for the production of biogas for combined heat and power or co-generation.

- **High Solids Mesophilic Anaerobic Digestion**: Manufacturer provided design of a high solids anaerobic digestion technology through Infilco Degremont and branded as HiSAD. This technology uses a single digester, which accepts high solids sludge (20% solids) followed by a filter for the associated process water to be recycled back into the plant treatment process. This technology also incorporates co-generation with the bio gas produced through digestion.

3.8.1 Mesophilic Anaerobic Digestion

3.8.1.1 Design Criteria

Anaerobic digestion occurs as the result of a complicated set of chemical and biochemical reactions. These reactions occur as a result of the complex ecosystem involving many types of bacteria within the digester. The overall extent of sludge stabilization by anaerobic digestion is typically measured by the amount of volatile solids destruction that occurs within the digester.

There are two operational temperature levels for anaerobic digesters, which are determined by the species of methanogens in the digesters:

- Mesophilic digestion takes place optimally around 37°-41°C (98° to 105° F), where mesophiles are the primary microorganism present.
- Thermophilic digestion takes place optimally around 50°-52°C (122º to 126ºF) at elevated temperatures up to 70°C (158ºF), where thermophiles are the primary microorganisms present.

There are a greater number of species of mesophiles than thermophiles. These bacteria are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are therefore, considered to be more stable than thermophilic digestion systems.

In continuous digestion processes organic matter is added constantly or in consistent stages to the reactor, with the end products continuously or periodically removed; however, there is a constant production of biogas.

For this study the Mesophilic Digestion process is being considered for installation.

A simple schematic of a mesophilic anaerobic digestion system incorporated into the existing solids train at the plant is presented in the Figure 3.8-1 located at the end of this section. The sludge feed to the system would be thickened with the existing gravity thickeners (and/or gravity belt thickeners), sent through the dual stage mesophilic anaerobic digesters then be thickened through the existing gravity belt thickeners (GBTs) followed by dewatering with the existing belt filter presses (BFPs) before being shipped off site.

3.8.1.2 System Components

The following components were evaluated for the Waterbury WPCF in the Mesophilic Anaerobic Digestion System:

- Tank Volume (Volumetric Loading & Hydraulic Retention Time)
- Tank Covers
- Tank Mixing System
- Preliminary Footprint

3.8.1.3 System Volume

The required volume for digesting sludge in a digester is a function of the volume of fresh sludge added daily, the volume of digested sludge produced daily, and the required digestion time in days. Additional volume is added for the supernatant liquid, gas storage and the storage of digested sludge. Anaerobic digesters are primarily sized based upon solids retention time (SRT) and hydraulic retention time (HRT). In this case, for a high-rate digestion system that will not include provisions for supernatant decant, SRT is interchangeable with HRT. The recommended design HRT value used for Waterbury were determined based on the calculated volumetric loading criteria presented below.

The WEF MOP FD-9, for completely mixed and heated digesters recommends a volumetric loading between 0.1 and 0.2 lbs volatile suspended solids (VSS)/1,000 ft^3 of volume per day. Based on the 76% VSS in the solids, it was determined that the minimum HRT to achieve this volumetric loading is 15 days. The values are presented in the Table 3.8-1 below.

Table 3.8-1 Volumetric Loading & HRT

Hydraulic Retention Time (HRT) in days	Volumetric Loading (lbs VSS/1,000 ft^3 per day)
15	0.16
20	0.12

The recommended HRT based on WEF MOP FD-9 and the EPA "503" regulations require 15 to 20 days. The WEF MOP FD-9 also recommends a lower volumetric loading of 0.08 lbs VSS/1,000 ft^3 per day. Based on this, the 20 day HRT was selected to achieve a more conservative volumetric loading value while remaining in the recommended HRT range.

The sludge quantities were calculated using average sludge production data from 2014 with a plant capacity factor of 1.4. The resulting volume of 5% sludge that would feed the digesters was calculated to be 79,300 gallons per day (gpd).

The preliminary digester sizing for the Waterbury WWTP is based on a minimum HRT of 20 days, which produces a total volume of 1,586,000 gallons (~212,000 ft^3). This volume is split between two tanks providing a single dual stage system.

There are two potential styles of digester system that could be considered for installation, conventional and egg shaped. Conventional digesters are low vertical cylindrical reinforced concrete tanks, with vertical sidewall depths ranging from 20 to 45 feet and conical bottoms to aid in cleaning. The 'egg' shape facilitates liquid mixing, reducing the buildup of scum, grit and dead zones within the reactor vessel. The egg-shaped digesters result in a smaller footprint, but greater visual impact. Egg shaped digesters are typically constructed of steel and are insulated with aluminum cladding on the exterior. The material cost of the egg digesters may be significant due to the material and construction requirements, based on this, the conventional digesters were further analyzed.

Tank dimensions for conventional digesters have been developed based on the following guidelines:

- Digester diameter should be in even 5-foot increments to allow for standard fixed and floating cover sizes;
- Allow 3 to 5 feet for freeboard;
- Conical bottom side slope of 1:6.

Based on this criteria, the dimension were determined for two anaerobic digesters to provide the total required volume of 1,586,000 gallons. Table 3.8-2 summarizes the dimensions.

Table 3.8-2 Conventional Digester Dimensions

Dimension	Value
Total HRT	20 days
Total Volume Required	212,000 ft^3
Individual Tank Volume Required	106,000 ft^3
VSS Loading	0.12 lbs VSS/1,000 ft^3/day
Diameter per Tank	55 ft.
Sidewall Depth	49 ft. (45 ft. plus 4 ft. freeboard)
Cone Depth	4.5 ft.
Volume per Tank	120,000 ft^3
Total Volume	240,000 ft^3

3.8.1.4 Digester Mixing Systems

There are a number of different mixing systems that can be applied to a mesophilic anaerobic digestion system, such as a confined gas draft tube mixing system and an external pump and nozzle mixing system. Contents of the digester should be adequately mixed to avoid significant variations in temperature and solids concentration. Mixing the digesters maintains the process, increases gas production and avoids grit and sludge accumulation by keeping heavier solids entrained in the sludge rather than settling to the bottom.

The Confined Mixing System (Draft Tubes) provides sludge mixing by recirculating digester gas to a bubble generator, which intermittently discharges into a mixing tube that acts as a large diameter piston bubble. The bubble drives the sludge out of the mixing tube up through the digester creating turbulence and an updraft for proper mixing.

Olympus Technologies, Inc. (OTI) manufactures draft tube mixers that can either be installed inside the digester (mounted from the cover) or that can be located outside of the digester tank wall. The OTI system consists of a draft tube(s) that contains a mixer which forces the sludge to circulate in either a top-to-bottom or bottom-to-top flow pattern. The direction of the sludge flow is therefore reversible, with the draft tube behaving as a discharge or suction pipe. The draft tubes can also include a heat exchanger and can provide the required heating requirements for the digesters. WesTech manufactures the ExtremeDuty™ draft tube mixing system that can either be installed inside the digester (mounted from the cover) or that can be located outside of the digester tank wall. These draft tubes can also include a heat exchanger and can provide the required heating requirements for the digesters.

The confined mixing system, as manufactured by Infilco Degremont, consists of non-clog piston bubble generators, draft mixing tubes, floor support brackets, liquid ring rotary compressors, inlet sediment trap, inlet flame arrester, discharge moisture separator, and gas flow balancing system.

Mechanical mixing technologies located inside of the digester can also serve as efficient methods of mixing. The Linear MotionTM Mixer manufactured by Ovivo provides digester mixing by the continuous operation of a mechanical mixer. The mixer includes an oscillating, ring shaped disk, which moves up and down through the digester contents.

The external pump and nozzle mixing system utilizes floor and wall mounted sludge mixing nozzles fed by a chopper pump. The use of a chopper pump minimizes nozzle clogging, as the pumped solids are macerated by the pump. The mixing performance is developed using a dual rotational mixing field, providing efficient mixing of both uniform and vertical fields of flow. The system works by the use of jet mixing technology, which generates a high velocity stream at each nozzle discharge. This jet-like stream not only travels relatively inside the fluid volume to affect a large area of mixing, but also induces additional flow in the static field around it as the plume travels through the digester sludge. Potential manufacturers of these technologies include the Vaughan Rotamix, Global Bio-Fuels Technology mixing system, and MTSs Jet Mixing system. The external pump and nozzle mixing system have proven to be highly efficient and is recommended over a gas mixing system.

3.8.1.5 Sludge Heat Exchangers

Maintaining a constant temperature within the digester improves the performance of the process. Rapid changes in temperature can lead to process upset. External heat exchangers are the most commonly used and preferred method of sludge heating. In a spiral heat exchanger, sludge and hot water flow in alternate channels formed by concentric spirals, allowing for the transfer of heat from the hot water to the sludge. Tube-in-tube heat exchangers utilize a similar principle with the added benefit of being able to clean and maintain the individual tubes. In either the heat source (typically a boiler or cogeneration system) can be placed remotely.

3.8.1.6 Digester Covers

Anaerobic digester covers can be fixed or floating. Fixed covers are flat, conical, or dome-shaped and are constructed of reinforced concrete or steel. Floating covers can rest directly on the liquid surface or float on the gas and be supported by side skirts at the side of the tank. The appropriate type of cover for any given application depends on the design and size of the digester. Both fixed and floating covers have advantages and disadvantages. For example, floating covers rise and fall with the liquid level in the digester, therefore, prevent the formation of a vacuum, which could damage the vessel or the cover. Floating covers also prevent air from being drawn into the digester during solids removal. In contrast, a fixed cover is often easier to design, requires less maintenance, and is less prone to develop gas leaks. The type of cover system best suited for a digester depends on the operational conditions of the system. Fixed covers, for example, are best suited for primary digesters where the sludge level remains constant. Floating covers are best suited for secondary digesters, where operating flexibility is required.

Dual membrane fabric covers are designed to optimize gas storage, which is particularly important at facilities that have cogeneration systems. The outer membrane in these systems is maintained inflated by the continuous operation of blowers. The inner membrane moves as gas is stored and released. The two membranes are maintained at a fixed operating pressure. Compared to the conventional digester cover, these systems can provide up to three times more gas storage capacity.

3.8.1.7 Building Layout & Process Footprint

The estimated process footprint for the Anaerobic Digesters includes a process building to house the sludge feed pumps, digester mixing chopper pumps or digester gas recirculation compressors, hot water boilers for sludge heating, sludge heat exchangers, associated controls and piping, and two digester tanks on either side of the process building. The sludge will then be pumped from a digested sludge holding tank to the existing gravity belt thickeners and then dewatered with the existing and belt filter presses before being hauled off site. The preliminary dimensions for each structure are presented in Table 3.8-3.

Table 3.8-3 Mesophilic Anaerobic Digestion Process Dimensions

Building	Dimensions
Process Building	45 ft x 45 ft
Digester 1	55 ft diam, 49 ft SWD, 4.5 ft cone depth
Digester 2	55 ft diam, 49 ft SWD, 4.5 ft cone depth

NOTE: diam = diameter, SWD = side wall depth

Figure 3.8-2 located at the end of this section presents the preliminary layout proposed for Mesophilic Anaerobic Digestion process.

3.8.2 High Solids Anaerobic Digestion

3.8.2.1 Process Description

Infilco Degremont's HiSAD technology incorporates the principles of anaerobic digestion with the ability to process feed sludge with a significantly higher solids content, which can reduce the footprint of the system considerably. The HiSAD technology incorporates a primary digester for sludge volume reduction followed by a secondary vessel to reduce the organic content of the liquid in the process and recirculate it back to the primary digester to reduce the acidic content in the digester. This technology functions without mixing and produces heat through utilization of the biogas produced through the system. The system also has the ability to accept over 20% solids, which significantly reduces the footprint of the system.

Based on discussions with the manufacturer, the system sizing and sludge production is based on typical sludge created from an activated sludge system similar to Waterbury's WPCF. If this alternative is selected for further consideration, the vendor recommends conducting a pilot study to determine specific volumes and content of sludge and detailed design. The pilot study would require approximately six weeks to complete using the Infilco Degremont's mobile pilot unit.

It should be noted that conveyance of 20% solids to the proposed location of the digestion complex would require new or relocation of the existing belt filter presses, as pumping high solids is not recommended.

3.8.2.2 Design Criteria

Figure 3.8-3 located at the end of this section, presents the HiSAD process incorporated into the solids processing currently at the plant. The installation includes the utilization of the existing belt filter presses to produce the 20% solids sludge to feed the process.

3.8.2.3 System Components

The Manufacturer's Scope of Supply includes the following items:

- Solids digester
- Anaerobic Filter
- Filter Media
- Maceration Pumps (2)
- Liquid Recirculation Pumps (2) & appurtenances
- Control Panel (starter, circuit breaker, switches)
- Gas safety equipment
- Instrumentation
- Hot Water Boiler (for biogas or natural gas) – contains controls and safety devices (1)
- Waste Gas burner (1)
- Steel Tanks for storage of product

Components outside of the scope of supply through the manufacturer include the following.

- Biogas Storage
- Biogas Conditioning
- Cogeneration equipment
- Hauling of digested product
- Piping
- Buildings, Plumbing, HVAC, Mechanical, & Electrical Systems

3.8.2.4 Building Layout & Process Footprint

The estimated process footprint for the Infilco Degremont HiSAD process includes a process building to house the pumps, controls and boiler equipment, an Anaerobic Digester followed by a Filtration Vessel and a sludge storage building. The preliminary dimensions for each building are presented in the Table 3.8-4.

Table 3.8-4 HiSAD Process Dimensions

Building	Dimensions
Solids Digester	35 ft diam, 37 ft SWD, 8.8 ft cone depth
Anaerobic Filter	24 ft diam, 25 ft SWD, 6 ft cone depth
Process Building	50 ft x 30 ft

NOTE: diam = diameter, SWD = side wall depth

3.8.3 Cogeneration

Cogeneration through Combined Heat and Power (CHP) utilizes the digester gas created through anaerobic digestion to power an engine which generates electrical energy and the waste heat from the engine jacket and engine exhaust are reclaimed to off-set the heat demand on the sludge boilers. The Mesophilic Anaerobic Digestion and HiSAD process have the ability to produce bio-gas for cogeneration.

3.8.3.1 Bio Gas Production

Gas produced during the anaerobic digestion of organic solids is an energy source that can be collected and used as an alternative fuel. As the gas is produced, it rises through the sludge and is collected above the digester tank liquid level and is either burned in a waste gas flare and/or collected and distributed to a dual-fuel boiler to heat the digester contents and/or to an electrical generation system such as a microturbine or engine generator.

The following table presents the potential biogas calculations for the Waterbury WPCF.

Based upon the proposed design of the dual stage mesophilic anaerobic digestion process, including an average detention time of 20 days and a feed sludge volatile solid of approximately 76%, the estimated reduction in volatile solids is 50%. The HiSAD process manufacturers have determined that their proprietary process is able to achieve a 75% reduction in volatile solids through similar installations. A summary of the estimated biogas production is included on Table 3.8-5 below.

Table 3.8-5 Biogas Production

Parameter	Mesophilic Anaerobic Digestion	HiSAD
Influent Sludge & Water	800,800 lbs/day	
Heat Load	1,800,000 BTU/hr	
Heat Loss[1]	324,000 BTU/hr	
Total Heat Load	2,100,000 BTU/hr	
Estimated Volatile Solids Reduction	50%	75%
Digester Gas Production[2]	5,700,000 BTU/hr	8,600,000 BTU/hr

NOTES:

Influent sludge temperature is assumed to be 50°F and a mesophilic temperature of 104°F.

Based on 76% volatile solids & approximately 40,040 lbs/day sludge production, and a biogas production rate of 15 ft^3/lb VS destroyed and an energy value of 600 BTU/ft^3.

The available biogas was used to calculate the potential energy production using both microturbines and internal combustion engines for combined heat and power and for calculating the heat recovery to heat the digesters for both technologies. The calculations are presented in the following Tables 3.8-6 and 3.8-7 below.

Table 3.8-6 CHP Energy Production & Sizing

Parameter	Mesophilic Anaerobic Digestion		HiSAD	
Digester Gas Production[1]	5,700,000 BTU/hr		8,600,000 BTU/hr	
Generator Efficiency	Microturbine 27%	Internal Combustion 37%	Microturbine 27%	Internal Combustion 37%
Available Energy Through Generator	1,541,000 BTU/hr	2,111,000 BTU/hr	2,311,000 BTU/hr	3,167,000 BTU/hr
Generator Size[2]	450 kW	620 kW	680 kW	930 kW
Hours per Year[3]	7,884 hours/year		7,884 hours/year	
Annual Energy Production	3,200,000 kWh/yr	4,400,000 kWh/yr	4,800,000 kWh/yr	6,600,000 kWh/yr

NOTES:

Based on 76% volatile solids & approximately 40,040 lbs/day sludge production, and a biogas production rate of 15 ft^3/lb VS destroyed and an energy value of 600 BTU/ft^3.

Based on 3,413 BTU/kW-h.

Assumed to operate 90% of the year.

It should be noted that the average annual energy use at the Waterbury WWTP for 2013 and 2014 was approximately 13,800,000 kWh at a unit cost of $0.11 per kWh resulting in an annual cost of approximately $1,500,000. Based on the calculations presented in the tables above, the potential annual energy production for the Mesophilic Anaerobic Digestion technology is approximately 3,200,000 to 4,400,000 ($350,000-$484,000/yr) kWh. The digestion facility itself would require power to operate so the net savings translates to approximately $280,000 to $390,000 per year.

Table 3.8-7 Generator Heat Recovery

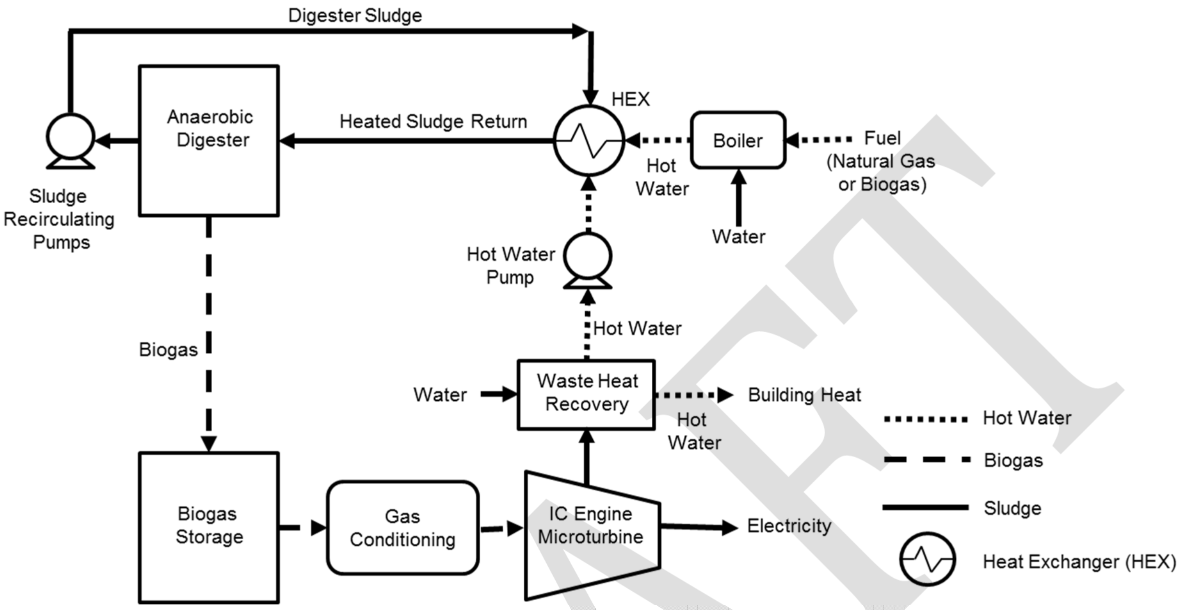
Parameter	Mesophilic Anaerobic Digestion		HiSAD	
Digester Gas Production[1]	5,700,000 BTU/hr		8,600,000 BTU/hr	
Heat Recovery Efficiency	Microturbine 30%	Internal Combustion 50%	Microturbine 30%	Internal Combustion 50%
Heat Recovered	1,700,000 BTU/hr	2,900,000 BTU/hr	2,600,000 BTU/hr	4,300,000 BTU/hr
Extra Heat	(400,000) BTU/hr	700,000 BTU/hr	400,000 BTU/hr	2,000,000 BTU/hr

NOTES:

Based on 76% volatile solids & approximately 40,040 lbs/day sludge production, and a biogas production rate of 15 ft^3/lb VS destroyed and an energy value of 600 BTU/ft^3.

3.8.3.2 Co-Generation Technologies

Microturbines and internal combustion engines are presented below as potential technologies to produce both electric and heat energy utilizing excess digester gas as fuel. A schematic of the digestion and combined heat-and-power process can be seen in Figure 3.8-3 below.



Microturbine Technology

Microturbines are small combustion turbines that produce between 30 and 1,000 kW of power. Micro turbines were derived from turbocharger technologies found in large trucks or the turbines in aircraft auxiliary power units and are composed of a compressor, combustor, turbine, alternator, recuperator, and generator. Most microturbines are single-stage, radial flow devices with high rotating speeds of 90,000 to 120,000 revolutions per minute.

Microturbines can also be classified as simple-cycle or recuperated. In simple-cycle, or unrecuperated turbines, compressed air is mixed with fuel and burned under constant pressure. The resulting hot gas is allowed to expand through a turbine to perform work. Simple-cycle microturbines have lower cost, higher reliability, and more heat available for co-generation applications than recuperated units. Recuperated units use a sheet metal heat exchanger that recovers some of the heat from an exhaust stream to transfer it to the incoming air stream. The preheated air is then used in the combustion process. If the air is preheated, less fuel is necessary to raise its temperature to the required level at the turbine inlet. Recuperated units have a higher thermal-to-electric ratio than unrecuperated units and can produce 30 percent to 40 percent fuel savings.

A microturbine system designed to use digester has three basic components: gas conditioning system, gas compressor, and microturbine.

- **Gas Conditioning System:** Microturbines are sensitive to the quality of digester gas that is used for fuel and consequently requires the digester gas to be conditioned for the removal of moisture, particulates (especially siloxanes) and hydrogen sulfide. The removal of siloxane is critical as siloxane is converted to silica (ash) during the combustion process and can erode engine parts. Therefore, conditioning the gas before use is a major factor in reliable microturbine operations.

- **Gas Compressor:** The digester gas should be compressed to at least 55 to 65 psig. This compression requirement becomes a significant electrical load based upon the volume of gas to be compressed and must be subtracted from the microturbine's gross electrical rating to determine the net electrical load transferred to the plant's electrical grid.
- **Microturbine**: Today's Microturbine has only one moving part (a shaft that rotates at 90,000 to 120,000 revolutions per minute) and uses electronics to maintain a high-quality power output.

Internal Combustion Engines

Internal combustions engines are diesel engines retrofitted to operate on digester gas. Like microturbines, the digester gas must be conditioned prior to being introduced into the engine. Typically, siloxane, hydrogen sulfide and moisture are removed from the incoming digester gas but not to a low level as required by microturbines. In addition, the gas pressure required at the engine's fuel train is approximately 1 psig as compared to 75 to 80 psig for microturbines thus requiring less electrical power to compress the gas. This allows a higher net electrical energy output to the plant's grid as compared to microturbines.

An advantage of internal combustion engines is that the engines can be operated at 60 percent of their full load capacity allowing operation of the internal combustion engines at varying digester gas production rates. As the internal combustion engines operate away from their full load capacity, the electrical and heat energy outputs vary linearly as a function of the operated load capacity.

3.8.3.3 Interconnection Requirements for CHP

Depending on the WPCF's electrical usage profile, it may be advantageous to "net meter". Net metering involves selling excess power to the utility company. Electricity for the Waterbury WPCF is supplied through Eversource. Connection to the existing power grid with a co-generation technology requires an Interconnection Agreement between the generator (owner of the power system) and the energy distribution company (EDC), Eversource, in this case. Certified inverter based generators larger than 10 kW qualify for the Fast Track Interconnection Process. Prior to submitting an Interconnection Application and prior to the purchase of any equipment associated with the generating system, it is recommended that the generator contact the EDC facilitator for an initial scoping meeting to discuss the proposed project and interconnection approach.

The application process involves a number of screening steps to determine the project's feasibility, safety, reliance and overall compliance with the EDC's interconnection design and legal requirements. In addition, there are fees associated with an interconnection application, which vary based on the energy generation size of the proposed system (less than 10 kW & up to 2 MW).

Key requirements of the Interconnection Application process include the following:

- The design of the proposed power generating system must comply with the EDC's technical requirements for the interconnection into the existing power system (per Eversource Exhibit B Generator Interconnection Technical Requirements);
- The generator must provide proof of site control (i.e. ownership of site, leasehold interest in, or developing rights for the purpose of building a generating facility);
- Site and/or Facility plans must be provided identifying the location of site structures, transformers, Eversource electrical metering and vicinity to the AC disconnect switch;
- One line electrical schematics with PE stamp must be provided including the utility voltage at the main panel, fuse symbol at the main panel, number and location of inverters with manufacturer name, model number and rating; circuit connectivity from the main switch including sub mains, metering and the main switch and rating of breakers; location of isolation device; generator electrical information; typical customer loads and operating voltages and additional formatting requirements. There are sample diagrams on the Eversource website for reference.
- Operating and/or Instruction Manual for the required relaying or inverter protection functions;
- Functional description of the proposed generation system including normal and abnormal functionality;
- Inverter based systems ranging in size between 0 kW to 10 kW must maintain general liability insurance of $300,000 and have an application fee of $100;
- Fast Track systems ranging in size between 0 kW and 2 MW must maintain general liability insurance of $500,000 to $2,000,000 and have an application fee of $500;
- Complicated systems requiring additional studies up to 2 MW must maintain general liability insurance of $2,000,000 to $5,000,000 and have an application fee of $1,000, which excludes the cost of the study;
- The generator must pay for any necessary upgrades to the existing power grid resulting from the proposed interconnection as identified by the EDC;
- The EDC may require an Interconnection Study that assesses the feasibility of the project and the impact of the proposed power system to the existing power system;
- The generator must provide municipal approval of the proposed system;
- Commissioning of the system must be witnessed by the EDC;
- Upon the successful completion of the commissioning tests, the EDC will issue the final approval for the interconnection.

3.8.3.4 Grants & Financing for Anaerobic Digestion and CHP

Several funding options are available for co-generation using anaerobic digestion through state and federal funding agencies. The two funding options discussed here are considered the most viable for this type of installation in the state.

- CT DEEP Clean Water State Revolving Fund (SRF) – Reserve for Green Infrastructure
- Eversource LREC/ZREC Program

CT DEEP Reserve for Low Impact & Green Infrastructure

The CT DEEP Reserve for Low Impact and Green Infrastructure provides grant funding at 20% of the project cost and 80% loan for improvement projects that incorporate cost-effective renewable energy components at waste water treatment plants and pump stations. The Connecticut Department of Energy & Environmental Protection (CT DEEPs) Clean Water Fund Priority List dated March, 2014 states that projects that qualify for the Green Infrastructure reserve fund are intended for a “Treatment plant, pump station, and/or collection system improvement projects that incorporate cost effective renewable energy components (20% grant/80% loan); and Community demonstration projects of green infrastructure technologies to promote infiltration of storm water into the ground in combined sewer overflow areas (50% grant/50% loan).”

Eversource LREC/ZREC Program

The Low and Zero Emission REC (LREC/ZREC) program became the primary incentive funding source for Class I renewable energy technologies, which includes solar arrays, wind turbines and hydro turbines and anaerobic digestion as defined in the Connecticut General Statutes (CGS) Section 16-1 (a)(26)(x). The LREC/ZREC program is managed by the electric distribution companies (EDCs) such as Eversource and United Illuminating (UI), and by the DEEP’s Public Utility Regulatory Authority (PURA). Under these regulations, the EDCs are required to allocate funding for the purchase of LREC/ZRECs from customers generating renewable energy.   The customers, once deemed to be qualified bidders, will be able to sell their LREC/ZRECs to the EDCs for a fifteen (15) year contract period. Each year, the EDCs will allocate $12M in these LEC/ZREC contracts. Overall, the program focuses on a market driven approach whereby generators enter a competitive, bidding process for the sale of the RECs they produce to the EDCs.

The power generating system program categories include the following:

- Small (1 to 100 kW);
- Medium (>100 kW and < 250 kW);
- Large (≥250 kW and ≤1,000 kW).

Generating systems are capped at 1,000 kW of ZRECs and at 2,000 kW for LRECs.

Systems that qualify must be in the proposal phase or if installed, must be behind electric meters and in operation after July 1, 2011. Projects which are in the proposal phase must be completed, permitted and in operation within one year after the contract award date.

The Year 1 request for proposals (RFP) was issued on May 1, 2012. Based on the Year 1 2012 request for proposals approved by PURA on February 1, 2013, the winning bids resulted in the following LREC/ZREC prices:

- LREC - $65.94
- Large ZREC - $101.36
- Medium ZREC - $149.29

The Year 2 RFP was issued on April 25, 2013 with bids due on June 13, 2013. On October, 2013 PURA approved 90 contracts. The winning bids approved on January 16, 2014 resulted in the following LREC/ZREC prices:

- LREC - $57.03
- Large ZREC - $76.67
- Medium ZREC - $93.65

The Year 3 RFP was issued in April 24, 2014. On January 14, 2015, PURA approved 151 contracts. The winning bids resulted in the following LREC/ZREC process:

- LREC - $56.29
- Large ZREC - $59.35
- Medium ZREC - $73.61

The LREC/ZREC program is based on a 15 year contract for the purchase of the number of RECs that the renewable energy project is expected to generate. If excess RECs are generated above the LREC/ZREC contract, the generator would have the ability to sell the excess RECs to the Wholesale Electric Market.

Based on the current PURA regulations, biogas derived from anaerobic digestion is considered a Class I renewable energy source, therefore, qualifying for the LREC/ZREC program. The current requirements for a ZREC include technologies for solar, wind, and hydroturbine while the LREC program is for fuel cells, methane, and biogas production technologies. Therefore, the biogas facility through anaerobic digestion is eligible for the LREC program.

3.8.4 Capital Costs for Digestion with Cogeneration

Capital costs for sludge digestion using Mesophilic Digestion and in combination with Cogeneration are summarized in Table 3.8-8 below.

Table 3.8-8 Sludge Digestion with Cogeneration Capital Costs

Digestion	Capital Cost
Sitework	$ 3,100,000
Buildings	$ 8,100,000
Digesters	$ 7,100,000
Cogen	$ 1,800,000
Electrical	$ 4,000,000
I&C	$ 2,500,000
TOTAL	$ 26,600,000

Notes: Costs include escalation to 2019 midpoint of construction.
Costs include allowances for engineering and contingency.

3.10 Thermal Drying System

3.10.1 Process Description

As has been typical for WPCFs in New England, the Waterbury WPCF has been operating on the premise that sludge is a waste by-product from the liquid treatment process and the goal of sludge management is to provide reliable disposal of this waste product. Industry trends have shifted towards a more sustainable approach to biosolids management, with an emphasis on biosolids beneficial reuse rather than sludge disposal. The thermal drying technology produces an end product that can be marketed for beneficial reuse.

There are essentially two (2) types of biosolids dryers: direct and indirect. In a direct dryer, the heating medium (usually hot gases) comes in direct contact with the solids. In an indirect dryer, the heating medium is separated from the solids by metal surfaces and the heat is transferred through a metal surface to the biosolids. Thus, the heating medium does not directly contact the solids. Most of the successful biosolids drying facilities in the USA use direct dryers. Direct dryers produce a high quality, low dust, pelletized product which has been successfully marketed in this country. The primary disadvantage of direct dryers is the relatively large volume of odorous exhaust air from the dryer which requires thorough deodorization. Fortunately, in present day dryer systems, exhaust air recirculation is utilized which greatly reduces the volume of air requiring treatment. Also, regenerative thermal oxidizers have proven to be very effective in controlling the residual odorous air stream.

Indirect dryers are essentially simpler systems. However, they suffer from a few significant disadvantages. First, indirect dryers are more susceptible to wear and abrasion. In most indirect dryers, the solids fill the dryer vessel and are moved through the dryer by paddles, discs or augers with the result that there is significant wear and abrasion on the metal heat transfer surfaces. Metal wastage has been a frequently occurring problem at indirect dryer plants and has contributed to the shutdown of several plants. Second, indirect dryers do not make a hard, durable pellet for a product. The product from an indirect dryer is typically dusty, irregular in shape and size, and contains considerable chaff and debris. Lastly, primary solids have been known to cause fouling and coating of the heat transfer surfaces which can significantly reduce the evaporative capacity of the dryer and eventually shut down the system.

A direct heat, rotary drum drying system was selected as the basis of this evaluation, since it is the most reliable and most commonly used thermal drying system in the United States. In addition, the rotary drum system produces a hard, durable pellet which has minimal odor and has been readily marketed in this country. A process flow diagram of a rotary drum drying system is shown in Figure 3.10-1 located at the end of this section.

This process begins as dewatered solids are conveyed to and stored in a wet cake bin typically providing approximately 8 hours of storage capacity. The wet bin also acts as a surge bin to ensure a consistent feed of solids to the dryer. From the wet bin the solids are conveyed to a mixer where they are mixed with previously dried solids. The previously dried solids are actually fines or undersized solids which form the inner core or nuclei of the final pellet product. The function of the mixer is to coat the recycled fines with the incoming wet solids such that the wet material forms a thin outer coating around the dry inner particle. The mixer is either a pug mill or plow share type mixer which blends the wet and dry sludge feeds. At the outlet of the mixer the mixed feed, at 60- to 75-percent solids, is delivered to the front end of the dryer by a screw conveyor.

The dryer is a triple-pass rotary dryer, which contains two concentric steel cylinders that enable the dryer gases and solids to make three passes through the dryer before exiting. The heat source for the dryer is the hot gases produced from the dryer furnace which contains a gas-fired burner. The gas burner produces 2000°F hot gases which are mixed with recirculated air at 120°F from the condenser/scrubber tower. The resulting combined air stream at 750°F to 900°F is drawn through the inlet of the rotary dryer. At the inlet of the dryer the wet mixed feed is dropped into the combined air stream at the front end of the dryer. The fast moving air stream conveys the wet solids through the dryer as it evaporates moisture from the solids. As more moisture is evaporated, the temperature of the air stream drops until it reaches an approximate temperature of 185°F to 195°F at the outlet of the dryer. The dried solids exit the dryer at approximately 92-percent solids. The water contained in the solids is now water vapor in the dryer exhaust. The dryer exhaust also contains the dried solids which are now in the form of small granules. The dryer exhaust is conveyed to a pre- separator and then a polycyclone where most of the dried solids (approximately 96 percent) are separated from the air stream.

The air stream from the separator is then ducted to an ID fan which delivers the air to a condenser/ scrubber tower. In the condenser/ scrubber tower, water (usually plant effluent) is used to cool and condense out the water vapor in the air stream and also to remove particulate matter. The condensate is typically at 130°F to 140°F and it can be used for digester heating. Since the condensate contains particulate matter and dissolved organics, it eventually must be returned to the plant headworks for treatment. At the outlet of the condenser/scrubber tower, the air stream is split into two streams. Approximately 15 to 25 percent of the air stream is drawn through a small venturi-type scrubber and then a regenerative thermal oxidizer (RTO). The venturi scrubber provides additional control of fine particulate matter (PM) to ensure that the PM emission criteria are met and, also, to greatly reduce the carry-over of fine particulate into the ceramic heat transfer beds of the RTO. The RTO raises the exhaust air stream to 1500°F and thereby destroys any volatile organic carbon (VOCs) and odorous compounds in the exhaust.

The bulk of the air (75- 85 percent) from the condenser is recycled to the front end of the dryer where it is mixed with the hot gas from the dryer furnace. The recycle of the dryer exhaust is beneficial in three ways. First, it minimizes the amount of odorous air which must be treated by the RTO and thereby reduces the fuel usage in the RTO. Second, it recycles 120°F air to the dryer which improves the thermal efficiency of the drying process. Third, by recycling the furnace combustion gases the oxygen content in the dryer air can be lowered to 5 to 7 percent by volume. At this low percent oxygen, combustion cannot take place. This is an important safety feature, since a fire or explosion cannot be supported in such a low- oxygen atmosphere.

The dried biosolids from the separator chamber are dropped onto a triple-deck vibrating screen which separates the trash (>10 mm), the oversized dried material (4 -10 mm), the desired product (1- 4 mm), and the fines (<1 mm). The trash is delivered to a dumpster; the oversize sent to a roller crusher which crushes the material, producing fines; and the 1- 4 mm product is sent to a pellet cooler which cools the product to approximately 100°F. Cooling of the product is necessary to prevent auto-oxidation of the product and the potential for fires during storage of the product. The product is then conveyed typically by a dense-phase pneumatic transport system to a dry-product storage silo. The fines which fall through the screen and the fines produced from the crusher are sent to the recycle bin. The dry fines from the recycle bin are then mixed with the wet solids from the wet cake storage bin to form the feed to the dryer as previously explained.

The primary control variable in the dryer system is the dryer exhaust gas temperature. The set point of the dryer exhaust is approximately 185°F to 195°F. As the wet sludge feed rate and/ or the sludge moisture content vary, the dryer evaporative loading will vary causing the dryer outlet temperature to vary. When the dryer exhaust temperature drops, more fuel is burned in the dryer furnace to generate more hot gas for the drying process. When the dryer exhaust temperature rises, the fuel flow to the furnace is decreased. Once the combustion controls are set up and properly tuned, the control system is reliable and very stable.

Advantages and Disadvantages of Thermal Drying

The advantages of the rotary drum drying process include the following:

- The process produces a heat-dried biosolids product that can be used as a fertilizer or soil conditioner.
- Rotary drum drying of biosolids is a proven technology with hundreds of installations world-wide.
- The dried product is in the form of hard, durable pellets which can be easily handled, conveyed, and stored.
- The product can provide limited revenue, if marketed aggressively.

The disadvantages of the rotary drum drying process include the following:

- Thermal drying of solids has a high fuel usage. The total energy required to dry solids and treat the dryer exhaust in the RTO is approximately 1,600 Btu per pound of water evaporated.

- The rotary drum drying system has numerous conveyors and other pieces of vibrating or rotating equipment. Thus, the operation and maintenance requirements of the system are quite high. ·
- The abrasive nature of dried biosolids and the prolonged handling of the biosolids in the drying process results in extensive wear and erosion of the process equipment.
- Thermal drying works best with digested biosolids. Drying of undigested biosolids produces an odorous product that is not as acceptable to end users of the product and is more difficult to market. An undigested product will emit odors during truck loading and unloading activities and during application to fields, particularly if the product is wetted shortly after application. Another disadvantage is that undigested biosolids typically contain hair and clumps of fuzz which can clog the dryer system components and cause significant maintenance problems.
- A thermal drying system requires more operators and attention than a fluidized bed incinerator.
- Safety issues are a greater concern with thermal drying systems. Some of the safety issues include the explosive potential of the biosolids dust, the possibility of product overheating and auto-oxidizing, the potential for silo fires, and the generation of carbon monoxide from smoldering biosolids.

3.10.2 Estimated Construction and O&M Costs for Thermal Drying System

As previously stated, thermal drying of undigested solids results in a product that is significantly more odorous than the product from drying digested biosolids. The vast majority of thermal drying facilities in the United States process digested biosolids. While there are a few drying facilities which dry undigested solids, those plants have had a more difficult task marketing their product. The potential revenue from a heat-dried biosolids product is directly related to the quality of the product, and a product with a high odor level is at a distinct disadvantage in the biosolids market place.

Digestion has a beneficial effect on the drying process because it reduces the volatile content and fibrous material in the biosolids. High levels of volatile matter and fiber can reduce the hardness and integrity of the pelletized product. Also, high levels of volatile matter (scum) and fiber can coat and clog the drying system and cause significant maintenance problems. For the above reasons, it is recommended that the digestion process be utilized prior to thermal drying. Anaerobic digestion reduces the quantity of biosolids to be dried and has the added benefit of generating digester gas which can be used as the fuel for the drying system. Therefore, in this analysis thermal drying is evaluated with anaerobic digestion preceding thermal drying.

For the purpose of this evaluation, capital costs for Digestion with thermal drying were estimated. Table 3.10-1 below summarizes the estimated capital costs associated with this option.

Table 3.10-1 Capital Costs for Digestion with Thermal Drying

Digestion with Thermal Drying	Capital Cost
Sitework	$ 3,100,000
Buildings	$ 8,200,000
Digesters	$ 7,100,000
Dryer Building and Equipment	$ 23,100,000
Electrical	$ 3,100,000
I&C	$ 2,500,000
TOTAL	$ 47,100,000

Notes: Costs include escalation to 2019 midpoint of construction.
Costs include allowances for engineering and contingency.

3.11.1 Description and Design of Chemical Stabilization Systems

The following analysis presents the preliminary design and feasibility for Alkaline Stabilization installations for long-term biosolids management for Waterbury.

Alkaline Stabilization consists of the addition of alkaline materials to the dewatered sludge, (cement by-products, lime, (also known as quick-lime), or CaO), to treat and recycle the sludge into usable biosolids products. Two different patented processes that produce Class A (essentially pathogen-free) or Class B (significantly pathogen reduced), alkaline stabilized material are described and evaluated below for suitability at the Waterbury WPCF. End use for Class A alkaline stabilized material would be landfill cover material, agricultural use as a bio-organic and mineral fertilizer, and soil conditioner to farmers, nurseries or top soil dealers. End use for Class B products would be landfilling, agricultural use, and soil conditioner in land reclamation or further treatment. The chemical stabilization processes considered (EnVessel (RDP) and N-Viro Soil) are designed to produce a Class A final product.

The following Alkaline Stabilization technologies are discussed in more detail below:

EnVessel Pasteurization: Manufacturer provided design of a pasteurization technology through RDP Technologies and branded as EnVessel Pasteurization. This technology uses a conveyance and mixing system, which accepts high solids sludge (20% solids), lime addition, followed by heating to produce a Class A biosolid product.

N-Viro Soil: Manufacturer provided design of an advanced lime stabilization technology through N-Viro and branded as N-Viro Soil. This technology uses a conveyance and mixing system, which accepts high solids sludge (20% solids), lime addition, followed by heating to produce a Class A biosolid product. This system also requires an additional storage step to house the product for an additional 12 hours to achieve Class A.

The alkaline stabilization processes produce a Class A biosolid, as defined through the Environmental Protection Agency's (EPA) 503 regulations. This allows the sludge product to be land applied as a fertilizer as discussed in more detail later in this section.

3.11.1 EnVessel Pasteurization

The RDP Technologies, Inc. EnVessel Pasteurization is a two-step process where Class A pathogen reduction is achieved by maintaining the temperature at 158ºF for 30 minutes. It utilizes lime addition to increase the pH and then heat to destroy pathogens. This technology produces a pathogen free granular end product.

3.11.1.1 Design Criteria

The following RDP system processing rates are based on the sludge cake feed characteristics and rated capacity as specified by RDP Technologies, Inc. as presented in Table 3.11-1.

Table 3.11-1 EnVessel Pasteurization – Design Criteria

Parameter	Value
Sludge Source	Primary Sludge
Influent Sludge Percent Solids	20%
Sludge Cake Processing Rate	3,800 lbs/hr dry solids (19,000 lbs/hr dewatered cake)
Sludge Feed Rate through Process	600 ft^3/hr
Lime Dosage	30-60% (600 – 3,000 lbs/hr)

Figure 3.1-1 located at the end of this section, shows a simple schematic of the RDP system incorporated into the existing solids processing systems. The new system would be fed with the 20% solids material produced from the existing belt filter presses.

3.11.1.2 System Components

The RDP Technologies system is comprised of the following components.

- Sludge Transfer Screw Conveyors
- Lime Silo
- Volumetric Feeder
- Lime Feed/Transfer Screw Conveyor
- Lime Addition Screw Conveyor
- ThermoFeeder/ThermoBlender – where the sludge and lime are mixed together
- Pasteurization Vessel – provides temperature at specified amount of time (supplemental heat required for Class A)
- Biosolids Conveyor
- Odor Control System – Chemical Scrubber for Ammonia
- Instrumentation & Controls system with HMI

- Heat System Power Control Center
- Pasteurization System Control Console

The system components are described in more detail below.

Pasteurization System – The Pasteurization System is designed to produce a Class A product from dewatered sludge cake with the characteristics listed above. The alkaline stabilization process utilizes quicklime as a source of alkalinity in conjunction with supplemental electrical heat to qualify as a Class A Pasteurization Process under the EPA 503 Regulation.

Lime Storage Silo – The Lime Storage Silo is designed for storage of free-flowing quicklime at a compacted bulk density of 65 pounds per cubic foot in accordance with ANSI/ASCE 7088. Total approximate usable storage capacity would be 50 tons. The Silo would be 12 feet in diameter with an overall height of approximately 50 feet. A shaker type Dust Collector is provided for mounting on top of the Silo. The collector has a filter area of no less than 250 square feet of polyester fabric media. The Lime Silo also contains a Lime Truck Unloading Panel for chemical delivery.

Lime Feed Screw Conveyor & Lime Addition Screw Conveyor – The Lime Feed Screw is designed to feed quicklime at a rate of 600 – 3,000 pounds per hour and the motor is 3 HP. The Lime Addition Screw Conveyor is designed to feed quicklime at a rate of 600 – 3,000 pounds per hour and the motor is 2 HP.

Sludge Transfer Screw – The Sludge Screw Conveyors convey 600 cubic feet per hour and the motor is 7.5 HP.

Thermofeeders™ – The Thermofeeders™ preheat and convey the dewatered sludge to the ThermoBlender™ with a 15 HP motor at a rate of 600 cubic feet per hour.

ThermoBlenders™ – The ThermoBlenders™ blend the dewatered sludge and lime with a 15 HP motor at a rate of 600 cubic feet per hour.

Pasteurization Vessel – The Pasteurization Vessel will provide a minimum of a 30 minute retention time for the biosolids discharged from the ThermoBlender™ at a feed rate of 600 cubic feet per hour using a 1 HP motor.

Biosolids Discharge Conveyor – The Biosolids Discharge Conveyor conveys 600 cubic feet per hour of pasteurized sludge using a 3 HP motor.

Odor Control System – The Odor Control System will consist an ammonia chemical scrubber specifically designed to handle elevated temperatures with the presence of lime dust particles. The scrubber blowers will provide up to 3,500 cfm air flow through radial blade type blowers. The system will also require potable water.

Items outside of the manufacturer's scope of supply include the following.

- Sludge Storage area following pasteurization,

- Odor control system for storage area,
- Motor Control Center, motor starters and wiring conduit,
- Building, HVAC, Plumbing, Mechanical, & Electrical Systems.

3.11.1.3 Building Layout & Process Footprint

The estimated process footprint for the RDP En-Vessel Pasteurization process includes a process building to house the pasteurization equipment and conveyors, a lime silo adjacent to the process building and a sludge storage building designed for seven days of sludge storage and additional space for equipment to move the product. The preliminary dimensions for each building are presented in Table 3.11-2.

Table 3.11-2. RDP Process Dimensions

Building	Dimensions
Process Building	84 ft x 60 ft
Lime Silo	12 ft diameter
Sludge Storage Building	150 ft x 100 ft

3.11.2 N-Viro Soil: Advanced Lime Stabilization

The N-Viro Process is a patented technology process for the treatment and recycling of bio-organic wastes, utilizing certain alkaline by-products produced by the cement, lime, electric utilities and other industries. The N-Viro Process has been commercially utilized for the recycling of wastewater sludge from municipal wastewater treatment facilities. N-Viro Soil produced according to the N-Viro process specifications is an "exceptional quality" sludge product under the Part 503 Regulations qualifying as Class A.

The N-Viro process involves mixing of sludge with an alkaline admixture and holding the blended material for a controlled period of time with continuous mixing. The N-Viro process stabilizes and pasteurizes the sludge, reduces odors to acceptable levels, neutralizes or immobilizes various toxic components and generates N-Viro Soil™, a product which has a granular appearance similar to soil and has commercial uses. These uses include agricultural lime, soil enrichment, top soil blend, landfill cover and fill, and land reclamation.

The alkaline admixture used in the N-Viro process consists of by-product dusts from cement or lime kilns, certain fly ashes and other products of coal, coke or petroleum combustion and by-product dusts from sulfuric acid "scrubbers" used in acid rain remediation systems and from fluidized bed coal-fired systems used in electric power generation. The particular admixture that is used usually depends upon cost and availability in local markets. In certain cases, commercial lime may also be added to the admixture.

Raw dewatered solids are augured in a weight belt feeder and then delivered to a thermo-blender where it is blended with Lime (CaO). The Lime is delivered in steel tankers and would be pneumatically conveyed into a lime storage silo. The wastewater solids cake is pre-heated in a thermo-blender to pre-condition the cake before the addition of Lime. The pre-conditioning enhances the hydration reaction that occurs during the slaking of the Lime and significantly enhances the exothermic effect of the Lime.

The wastewater solids and Lime mixture is then augured into a pasteurization vessel. This is an insulated container with a slow moving belt conveyer floor. The electrical heating elements are in the walls of the vessel to maintain 70°C for 30 minutes of detention time. Table 3.11-2 below summarizes the design criteria of the system.

Table 3.11-2. N-Viro Design Criteria

Criteria	Value
Process Material Description	municipal sewage biosolids
Process Material Solids content	20 wt%
Processing Rate	40,000 lbs/day
Estimated alkaline Feed Rate	25 wt% (10,000 lbs/day)
Total Feed Rate	50,000 lbs/day

Figure 3.11-2 located at the end of this section, presents a simple schematic of the N-Viro Soil process incorporated into the existing solids processing train at the treatment plant. The system would be fed with the 20% solids from the existing belt filter presses.

3.11.2.1 System Components

- Lime Silos (1 @ 4,000 ft^3, 1@ 2,000 ft^3)
- Lime addition Auger
- Mixer for Lime and Sludge – contains mixing unit
- Air Compressor
- Augers & Conveyors for sludge and sludge/lime mixture (up to 75 feet)
- Instrumentation & Controls
- Odor Control System – Chemical Scrubber for Ammonia

Below is a narrative of the N-Viro Soil process.

Biosolids Dewatering and/or Receiving – The N-Viro process can receive biosolids as low as 12% solids, however, the higher the solids the better. Dependent upon facility design biosolids can be received directly from dewatering into the processor, tipped onto a receiving floor, or delivered into a receiving bin. A key aspect regarding receiving is the process allows for a wide spot in the line which allows operators to run the equipment automatically which enables more time to focus on the efficiencies of dewatering. For the Waterbury WPCF, the solids would be received following the Belt Filter Presses with a solids content of approximately 20%.

Mixing – The dewatered sludge is mixed with N-Viro's alkaline admixture. The mixing equipment is designed to accurately proportion and blend the biosolids with any combination of alkaline materials at output rates of 40,000 lbs per hour of total mixed materials. This blended material is then conveyed to heat pulse cells or a mechanical drying system. The admixture's are delivered via pneumatic truck and stored in silos. The alkaline material is then fed typically by auger to the mixing unit.

Heat Pulse Bunker – A chemical reaction, or "heat pulse", occurs between the biosolids and the alkaline admixture raising the temperature to between 52-62° C and the pH level > 12. This reaction, combined with other stresses, kills disease-causing bacteria, pathogens and eliminates noxious odors. Strict temperature control ensures the survival of valuable and useful normal soil microflora. (When utilizing the mechanical drying option, the heat pulse phase will follow the drying phase.).

Accelerated Drying Techniques – N-Viro BioDry: The BioDry process is a variation to the process where the product from N-Viro Soil is additionally dried to produce a more uniform product higher in organic content than the traditional N-Viro Soil. In addition, while the volume of the product from N-Viro Soil is a larger volume because of the admixture addition, the BioDry product is lower in volume than the original sludge because of the removal of water content. Is should be noted that this produce also requires the heat pulse step previously discussed.

Distribution – N-Viro Soil is normally shipped by the truckload to the end product user. Its physical characteristics are tailored to its utilization in standard materials handling equipment. Existing markets include agricultural limestone substitute/low analysis fertilizer, land reclamation, soil amendment/urban soils, soil blend ingredient, and landfill cover material.

Items outside of the manufacturer's scope of supply include the following:

- Sludge Storage area after pasteurization – requires storage bays for 12 hours of storage after processing,
- Odor control system for storage area,
- Motor Control Center, motor starters, wiring, and conduit,
- Building and associated HVAC, Plumbing, Mechanical, & Electrical Systems.

3.11.2.2 Building Layout and Process Footprint

The estimated process footprint for the N-Viro Soil process includes a process building to house the equipment and conveyors, two lime silos adjacent to the process building, a sludge curing structure, and sludge storage building for seven days with additional space for equipment to move product. Please note that the N-Viro Soil process requires an additional structure for the product to cure, as opposed to the RDP technology, which does not have this additional storage requirement. The preliminary dimensions for each building are presented in the Table 3.11-3.

Table 3.11-3. N-Viro Soil Process Dimensions

Building	Dimensions
Process Building	92.5 ft x 66 ft
Lime Silo	2 @ 10 ft diameter
Sludge Curing Structure	50 ft x 30 ft
Sludge Storage Building	150 ft x 100 ft

Figure 3.11-3 located at the end of this section, presents the preliminary layout proposed for the N-Viro Soil process.

3.11.3 N-Viro Lime Stabilization Capital Costs

For the purpose of this evaluation, N-Viro Lime stabilization capital and O&M costs were estimated. Table 3.11-4 summarizes the capital costs associated with this option.

Table 3.11-4 N-Viro Lime Stabilization Capital Costs

N-Viro Stabilization	Capital Cost
Sitework	$ 3,900,000
Buildings	$ 10,100,000
Equipment	$ 12,100,000
Electrical	$ 3,600,000
I&C	$ 1,700,000
TOTAL	$ 31,400,000

Notes: Costs include escalation to 2019 midpoint of construction.
Costs include allowances for engineering and contingency.

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Initial Screening - PRE-DIGESTION PROCESSING

Pre-Digestion Processing – Initial Screening

Technology	*Description*	*Common Manufacturer*	*Development Status*	*Typical Scale*	*Recommended for Further Consideration*	*Reasons for Not Considering Further*
High Voltage Lysis	Mechanical maceration combined with an electrokinetic process ruptures cells to enhance biogas production.	Vogelsang BioCrack	Embryonic	Small	No	Development status and scale
Electrical Lysis	Biological sludge is fed through a grinder pump, and then high-frequency electrical pulses are applied, causing cell walls to rupture. Can yield higher VS destruction and gas production.	OpenCEL	Innovative	Small to Medium	Yes	
Ozonation	sludge reduction using ozonation lysis	Praxair	Embryonic	Small	No	Development status and scale
Sludge Minimization Using Anaerobic sidestream reactor	A portion of return activated sludge undergoes anaerobic treatment in a side-stream tank reactor and returns back to the aeration basin. This is a sludge reduction process.	Umass Pilot	Embryonic	Small	No	Development status and scale
Enzyme Treatment	Enzymatic hydrolysis of the solids enhances digestion. Enzymes can be extracted from waste sludge through disintegration processes such as sonification or thermal treatment.	Biolysis	Embryonic	small	No	Development status and scale
Thermal Hydrolysis	Prior to digestion, dewatered sludge is fed through a hydrolysis reactor, in which the sludge is subjected to steam at elevated temperature (320°F approx) and pressure (100 psi). Following hydrolysis, sludge is fed to an anaerobic digester at approx 10% TS. Digestion yields high volatile solids destruction (55-65%) and increased biogas production.	Cambi; Veolia (BIOTHELYS)	Established	Small to Large	Yes	
Pasteurization	Sludge is heated to approx. 160°F for a minimum of 30 minutes; can be plug reactor or batch process. Sludge is cooled with heat exchangers before anaerobic digestion.	Kruger (BioPasteur), Ashbrook (ECO-THERM)	Innovative	Small to Large	Yes	
Ultrasonic Lysis	Biological sludge is subjected to ultrasonic waves before digestion, resulting in cavitation that ruptures the cells. Increases volatile solids destruction, and gas production.	Sonico (sonix), VTA Technologies Ovivo (Sonolyzer)	Embryonic	Small to Medium	No	Development status and scale
Mechanical Lysis	Biological sludge is homogenized by mechanical shearing, causing cells to break open. Increases volatile solids destruction, and gas production.	Huber (Sludge Squeezer), Siemens (CROWN) Kody	Embryonic	Small to Large	No	Development status
Chemical/Mechanical Lysis	Sodium hydroxide is added to weaken cells in biological sludge. Sludge is then fed through a grinder pump and subected to high pressures (12,000 psi) to lyse the cells. Higher VS destruction, and gas production.	Paradigm Environmental (MicroSludge)	Embryonic	Small	No	Development status and scale

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Initial Screening - DIGESTION

Digestion – Initial Screening

Technology	*Description*	*Common Manufacturer*	*Development Status*	*Typical Scale*	*Recommended for Further Consideration*	*Reasons for Not Considering Further*
Mesophilic Anaerobic Digestion	Sludge is sent to a digester which is maintained at 95°F with a minimum HRT of 15 days.	Not limited to specific vendors	Established	Small to Large	Yes	
Staged thermophilic Digestion	Sludge is sent to a digester which is maintained at 125oF with an HRT of 10-15 days. Staged system operated as batch or plug flow can achieve Class A standards	Not limited to specific vendors	Established	Small to Large	Yes	
Temperature-Phased Anaerobic Digestion (TPAD)	Combines the thermophilic and mesophilic digestion processes in a two stage process. The first stage is under thermophilic temperatures for 6 to 10 days HRT, followed by a second stage at mesophilic temperatures at 10 days minimum HRT. Class A is achieved by operation as batch or plug flow.	Not necessarily limited to specific vendors	Innovative	Small to Large	Yes	
Acid/Gas Anaerobic Digestion	Involves separation of the acidogenesis and methanogenesis stages of anaerobic digestion. The first stage is maintained at a pH of 5.5 to 6.0 to enhance acidogen growth, at a HRT of 1 to 2 days. The second stage us used for methane production at a HRT of 10-12 days. Stages can be mesophilic or thermophilic.	Non-proprietary, IDI (2PAD), GTI	Innovative	Small to Large	Yes	
Columbus Thermophilic Digestion	Combination of complete mix/continuous feed/ continuous withdrawal thermophilic digesters and either plug plow or batch reactors to achieve Class A	NA	Innovative	Small to Medium	Yes	
Aerobic Digestion	Sludge is sent to a digester and aerated with a minimum HRT of 15 - 20 days	Not limited to specific vendors	Established	Small to Medium	No	Odor
Dual Digestion	A two stage digestion process in which the first stage uses aerobic thermophilic digestion (pure oxygen) with 18 to 24 hr HRT and temperature between 130 to 150°F, and the second stage uses anaerobic digestion.	Not limited to specific vendors	Innovative	Small to Medium	Yes	
Autothermal Thermophilic Aerobic Digestion	An aerobic digestion process in which the sludge is heated autothermally, meaning that no supplemental heat is required beyond that supplied by mixing. Sludge is heated to thermophilic temperatures (130-140°F) for a min. HRT of 10 days.	Fuchs, Thermal Process Systems (ThermAer)	Established	Small to Medium	No	Odor
High Solids Anaerobic Digestion	Sludge is fed for anaerobic digestion at 20% TS. Digestion is achieved sequentially in a primary plug flow digester followed by a complete-mix secondary digester.	Schmack Bioenergy (Quasar), IDI (HiSAD)	Embryonic	Small to Medium	Yes	Although embryonic, recommended for further evaluation due to potential for higher volatile solids destruction.
Recuperative Thickening	Sludge is removed from an anaerobic digester, thickened, and returned to the anaerobic digestion process.	NA	Innovative	Small-Medium	No	Removed from screening as need digestion complex first to utilize recuperative thickening.

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES
Initial Screening - CHEMICAL STABILIZATION

Chemical Stabilization – Initial Screening

Technology	Description	Common Manufacturer	Development Status	Typical Scale	Recommended for Further Consideration	Reasons for Not Considering Further
Alkaline Stabilization	Lime is added to raise pH requirement for either Class A or Class B product	NA	Established	Small to Large	Yes	
Lime Pasteurization	Lime is mixed with dewatered sludge until a temperature of 70°C is achieved. The mixture is then passed through a pasteurization vessel, where the temperature is maintained at 70°C for 30 minutes producing a Class A product.	RDP Technologies	Established	Small to Large	Yes	
Advanced Alkaline Stabilization	Sludge is mixed with cement kiln dust, fly ash or other alkaline materials, stored for 72 hours at pH=12, with T=52 deg F for 12 hrs, then dried in rotary dryer or windrows.	N-Viro or non-proprietary	Established	Small to Large	Yes	
Alkaline and Acid Stabilization	Lime is added plus sulfamic acid to raise pH and temperature under slight pressure. Temps of 70°C attained and maintained for 30 minutes	Schwing (Bioset)	Established	Small to Medium	Yes	
Ferrate Treatment	Calcium hypochlorite, sodium hydroxide and ferric chloride are added to the solids which oxidizes solids odors and stabilizes the solids.	FTT_2 Inc.	Embroyonic	Small	No	Development status and scale
Neutralizer Chemical Stabilization	Combination of chlorine dioxide, sodium nitrite and sodium hydroxide in a multi-step process to produce a Class A product.	BCR Environmental	Innovative	Small	No	Scale
Clean B Chemical Stabilization	Similar to Neutralizer with less chemicals and production of Class B product.	BCR Environmental	Innovative	Small	No	Scale

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Initial Screening - COMPOSTING

Composting – Initial Screening

Technology	Description	Common Manufacturer	Development Status	Typical Scale	Recommended for Further Consideration	Reasons for Not Considering Further
Aerated Static Pile	Active composting in tall, contiguous piles for 21 to 30 days with no agitation and forced aeration; subsequent curing in piles for 60 days.	Non-proprietary, Gore (covered), ECS (covered)	Established	Small to Large	No	Odor and space requirements
Windrow	Active composting in long windrows for 15 to 30 days, with mechanical turning only for aeration, followed by 60+ days of curing in piles	Non-proprietary	Established	Small to Large	No	Odor and space requirements
Chemically-Enhanced Windrow Composting	Multi-stage chemical addition using Clean-B process, followed by conventional dewatering and window compostion	BCR Environmental	Embryonic	Small-Medium	No	Development status, odor and space requirements
In-vessel/agitated bed	Active composting in long bays with automated mechanical agitation and forced aeration for 21 to 30 days, followed by curing in piles for 60 days	Siemens (IPS), Longwood Manufacturing Corp	Established	Small to Large	No	Odor and space requirements
In-vessel/Tunnel	Composting occurs in tunnels with batch feed and withdrawl; aeration of the material supports active composting for 21 to 30 days, which is followed by a 60 day curing period	Gicom, Christiaens Group, ECS	Established	Small to Medium	No	Scale and development status
in-vessel Cage System	Active composting within stainless steel, perforated wall, cages with recirculated flow of material. Typically used for food-waste composting.	Ebara TEC Plc	Embryonic	Small-Medium	No	Scale and development status
Vermiculture	Use of worms to aerobically degrade solids in shallow beds, with castings sold as soil conditioner; composting period of 30-40 days	Vermitech	Embryonic	Small	No	Scale and development status

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Initial Screening - THERMAL DRYING

Thermal Drying – Initial Screening

Technology	Description	Common Manufacturer	Development Status	Typical Scale	Recommended for Further Consideration	Reasons for Not Considering Further
Rotary Drum Drying	Sludge is dried by contact with hot gases in a drum dryer to a solids content of 92-95%. Typical inlet temperature of drying gases is approximately 900 oF.	Andritz, Siemens, Baker-Rullman, etc	Established	Small to Large	Yes	
Belt Drying	Sludge is placed on moving belt in an enclosed vessel, exposed to hot air for drying, generally to a solids content of 92-95%. Typical drying temperatures are 250-350^{o}F.	Andritz, IDI (Evaporis LT), Kruger, Huber, Siemens	Innovative	Small to Medium	Yes	
Fluidized Bed Drying	Sludge is pumped into the fluidized bed dryer where spinning cutters create small granules that drop into fluidizing layer of granules. Heat is transferred to the granules by fluidizing gas that transfers heat from heat exchanger located in base of dryer. Heat medium is steam or hot oil.	Andritz, Schwing	Established	Small to Large	Yes	
Indirect Paddle Drying	Sludge is dried by contact with heated surface (walls, paddle and shaft) in a cylindrical dryer to a solids content of >92%; options for batch or continuous feed. The heat transfer medium (steam, or oil) circulates through a hollow auger and/or jacketed dryer shell. Typical drying temperatures are 350-450oF.	Komline Sanderson, Fenton, Haarslev	Established	Small to Medium	Yes	
Indirect Vertical Tray Drying	Sludge is dried through contact with a series of vertical trays heated internally with thermal oil. The cake forms granules as they travel through the dryer. Fine solids are recycled to the top of the unit, while the final product is discharged at the bottom of the dryer.	Seghers, Waterleau, WYSE	Innovative	Medium to Large	Yes	
Indirect Horizontal Thin Film Drying	Sludge is spread in a thin layer across the heated wall of a horizontal cylinder by rows of fixed blades. This indirect dryer can be heated by steam, hot water, or electricity.	Buss-SMS-Canzler, LCI Corp, IDI (Innodry 2E)	Innovative	Small to Large	Yes	
Indirect Hollow Flight Dryer	Sludge is dried using 2 counter rotating intermeshed hollow screens. The heat transfer medium is oil (500 F)	Therma Flite	Established	Small to Medium	Yes	
Solar Drying	Sludge is spread in layers on the floor of a greenhouse and agitated. Together, solar energy, large fans, and the agitation dry the sludge.	Parkson, Kruger (Soliamix), Huber , IDI (Heliantis)	Established	Small	No	Space requirements and scale
Microwave Drying	Sludge is continuously fed to a unit where microwave radiation is applied; microwaves heat the water within the sludge, causing water to evaporate.	Burch BioWave Inc. EnviroWave Corp	Innovative	Small	No	Scale

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Initial Screening - OTHER THERMAL PROCESSES

Other Thermal Processes – Initial Screening

Technology	*Description*	*Common Manufacturer*	*Development Status*	*Typical Scale*	*Recommended for Further Consideration*	*Reasons for Not Considering Further*
Incineration	Solids are combusted (at temperature of about 1500°F), typically in fluidized beds for modern facilties	IDI (Thermylis), Hankin, Technip/IFCO (all refractory arch)	Established	Medium to Large	Yes	
Vitrification	Use of a high temperature thermal process (2550°F) to melt the sludge and create a glass aggregate that can be used as a construction filler.	Minergy Corporation	Innovative	Medium to Large	Yes	
Gasification	Conversion of carbon-based feedstocks using incomplete thermal oxidation to create a synthetic gas (syngas) that can be combusted as an energy source. The sludge would be subjected to high heat (temperatures > 1400 °F) and controlled oxygen levels in a reactor. Byproducts of the process include a ash and liquid sidestreams, as well as exhausts.	MaxWest, Nexterra, M2 Renewables Alternative Energy Solutions, US Centrifuge, Kopf AG, Waste to Energy Limited	Innovative	Small to Large	Yes	
Wet Pyrolysis	Sludge is macerated into a uniform slurry, which is pressurized (600 psi) and heated (approx. 500°F), causing cells to rupture and release CO_2 gas. Sludge is dewatered to 50% TS, and can be dried and then used as fuel.	EnerTech Environmental (SlurryCarb)	Embryonic	Medium to Large	No	Development status with one manufacturer
Pyrolysis/Char	Dried solids @90% TS are sent to pyrolytic converter @1,200 to 1,800°F; Product is carbon char.	International Environmental Solutions	Embryonic	Medium to Large	No	Development status with one manufacturer
Pyrolysis/Oxidation	Dry pellets are dosed into a pyrolytic converter and the excess heat is recirculated for sludge drying.	Eisenmann	Innovative	Medium to Large	Yes	
Thermal/Chemical Processing	Using a combination of heat, alkali, and high shear mixing a high-solid, pathogen-free, liquid Class A fertilizer is produced.	Lystek	Embryonic	Small	No	Development status and scale with one manufacturer and scale
Pyrolysis to biodiesel	Chemical /thermal process to produce biodiesel fuel. Proprietary process piloted by Los Angelos County Sanitation District	KORE	Embryonic	Small to Large	No	Development status with one manufacturer
Plasma Assisted Sludge Oxidation	Solids are raised to a temperature of 900-1300° F in a rotation Kiln and are then subject to a plasma arc which oxidizes the solids	Fabrroups, Quebec	Embryonic	Small	No	Development status with one manufacturer and scale

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Initial Screening - OTHER PROCESSES

Other Processes – Initial Screening

Technology	*Description*	*Common Manufacturer*	*Development Status*	*Typical Scale*	*Recommended for Further Consideration*	*Reasons for Not Considering Further*
Struvite Reduction	Phosphorus and Magnesium are removed from the side streams to create a struvite fertilizer. Phosphorus can also be removed from WAS through fermentation.	Ostara	Innovative	Small to Medium	No	Removed from screening as solution not a comprehensive solution.
Supercritical Water Oxidation	Thickened sludge (not dewatered) is combined with air in a vessel under high heat (>705°F) and pressure (>3,204 psia). Under these supercritical conditions, organics are rapidly oxidized to inert material. The resulting material dewaters easily and is suiSub-Systemfor landfill disposal. Energy is recovered from the process to help sustain the reaction. Phosphorus recovery may be possible with the process.	SuperWater Solutions, General Atomics, Aqua Critox, Vermont Environmental Industries	Embryonic	Small to Large	No	Development status
Wet Air Oxidation	Thickened solids are oxidized by heating to 450°F under 300 psi in the presence of air or oxygen. The solids are then decanted and dewatered to produce a 40 percent solids material. Strong side-streams are created	Zimpro (formerly), Veolia	Established	Large	Yes	
High Nutrient Content Fertilizer Production	Chemical nutrients are added to sludge and retained under pressure (about 75 psi) and temperature (450oF) in a reactor for 15 minutes. Product goes to a granulator and then a dryer. Post processing is similar to rotary drum systems and includes screens, product coating systems.	VitAG, Unity Environmental	Embryonic	Medium to Large	No	Development status
Cannibal	Extended HRT sludge minimization with physical cell lysis and very fine drums screening that removes inert matter from the solids	Seimens	Innovative	small to Medium	Yes	
Pyrobiomethane	Anaerobic digestion of solids with subsequent dewatering and pyrolysis. Syngas is directed to digester to "strip" impurities.	NA	Embryonic	Small	No	Development status and scale
High Energy E-beam	In university studies thickened solids are subject to high intensity electron beams which inactivate pathogens.	NA	Embryonic	Small	No	Development status and scale
Deep Well Injection	Anaerobically digested solids are pumped under high pressure approximately 5,000 to 10,000 ft underground where the solids decompose over a long period of time. May allow extraction of biogas.	Terralog Technologies	Embryonic	Large	No	Development status, space, permitting
Fine Screening	Sludge flows into a container and through a fine screen/micro strainer where all solids over a certain size are removed.	IDI, Huber	Established	Small to Large	Yes	
Extended Recirculation	Extend Sludge circulation to achieve very long HRT combined with Aerobic or anaerobic digestion with chemical addition.	PMC Biotec	Embryonic	Small to Medium	No	Development status and one manufacturer
Sidestream Treatment	Ammonia in the dewatering sidestream is removed and converted to nitrogen gas without the use of an external carbon source.	DEMON, Anammox, and others	Established	small to medium	Yes	
Hydrogen Biofuel	Thermal drying followed by steam reformation to produce a hydrogen fuel. Piloted at California WWTF	Intellergy	Embryonic	small	Yes	Carried in screening process as a supplemental process to thermal drying.

TABLE 3.3-1 SLUDGE PROCESSING ALTERNATIVES

Advanced Biological Nutrient Removal (ABNR) using Algae	Algae takes up N and P and produces carbon source (marketable to bio-plastics market, soil enhancement or fuel source). Challenges include competition with filamentous algae and inadequate nitrogen during summer (6-8 parts N for 1 part of P uptake).	Clearas	Embryonic	small	No	Development status and scale. Also a nutrient removal process.
FOG to biodiesel	Digested sludge is used in algae production facility. The algae is then utilized as an oil feedstock for a refinery to produce diesel fuel. The glycerol waste from the refinery is processed to higher value chemicals or combined with the algae waste to produce a fertilized.	RPM Sustainable Technologies	Embryonic	small	No	Development status and scale. Would need multiple reactors and is a patented design.
Sludge Degritting	Primary Sludge is pumped through a cyclone degritter.		Established	small to large	No	Removed from screening as solution not a comprehensive solution.

TABLE 3.4-1 - SLUDGE PROCESSING ALTERNATIVES
SECOND SCREENING CRITERIA

CRITERIA	RATING	DEFINITION
Liquid Sidestream	No	No liquid sidestream to treat on-site
	Yes	High strength liquid sidestream to treat on-site
Sludge Dewaterability	Yes	Process impacts sludge dewaterability
	No	No impact on sludge dewaterability
Complexity of Operation	Complex	Significant mechanical/electrical systems.
	Moderate	Moderate mechanical/electrical systems.
	Simple	Minimal mechanical/electrical systems.
Emission Generation[1]	High	Direct Combustion
	Medium	Indirect Combustion
	Low	No Combustion
End Product Use	High	Beneficial Reuse
	Medium	Landfill with Beneficial Use (gas production)
	Low	Landfill, Stable with No Beneficial Use (i.e. ash)
Land Requirements	On-Site	Sludge Disposal Equipment is accommodated on plant property
	Off-Site	Sludge Disposal Equipment cannot be entirely accommodated on plant property
Odor Generation	Significant	Off-site impact
	Moderate	Lower potential for off-site impact
	Minor	Minimal to no off-site impact
Process Reliability	High	Simple process, minimal mechanical equipment
	Low	Complex process
Relative Capital Cost	High	Greater than $30 Million
	Medium	$15 to $30 Million
	Low	Less than $15 Million
Relative Operating Cost	High	Estimated $400/dry ton or more
	Medium	$300 to $400/dry ton
	Low	Less than $300/dry ton
Relative Energy Consumption	Significant	High thermal and electrical energy demand
	Moderate	Moderate thermal and electrical energy demand
	Minor	Low thermal and electrical energy demand with potential for power generation

1. Transportation requirements, trucks for pick up and disposal and trucks for delivery of chemicals, are not included under emmission generation. Emission generation includes combustion that occurs on-site. Indirect combustion being a secondary, supporting function. (i.e. tractors for moving compost)

TABLE 3.4-2 - SLUDGE PROCESSING ALTERNATIVES
2nd Screening

2nd Screening - DIGESTION

Digestion – 2nd Screening

Technology	*Description*	*Common Manufacturer*	*Liquid Sidestream*	*Sludge Dewaterability*	*Complexity of Operation*	*Emission Generation*	*End Product Use*	*Land Requirements*	*Odor Generation*	*Process Reliability*	*Relative Capital Cost*	*Relative Operating Cost*	*Relative Energy Consumption*
Mesophilic Anaerobic Digestion	Sludge is sent to a digester which is maintained at 95^{o}F with a minimum HRT of 15 days.	Not limited to specific vendors	Yes	Yes	Moderate	High	Medium	On-site	Minor	High	High	Medium	Minor
Staged thermophilic Digestion	Sludge is sent to a digester which is maintained at 125oF with an HRT of 10-15 days. Staged system operated as batch or plug flow can achieve Class A standards	Not limited to specific vendors	Yes	Yes	Complex	High	High	On-site	Minor	Low	High	Medium	Minor
Temperature-Phased Anaerobic Digestion (TPAD)	Combines the thermophilic and mesophilic digestion processes in a two stage process. The first stage is under thermophilic temperatures for 6 to 10 days HRT, followed by a second stage at mesophilic temperatures at 10 days minimum HRT. Class A is achieved by operation as batch or plug flow.	Not necessarily limited to specific vendors	Yes	Yes	Complex	High	High	On-site	Minor	Low	High	Medium	Minor
Acid/Gas Anaerobic Digestion	Involves separation of the acidogenesis and methanogenesis stages of anaerobic digestion. The first stage is maintained at a pH of 5.5 to 6.0 to enhance acidogen growth, at a HRT of 1 to 2 days. The second stage us used for methane production at a HRT of 10-12 days. Stages can be mesophilic or thermophilic.	Non-proprietary, IDI (2PAD), GTI	Yes	Yes	Complex	High	Medium	On-site	Minor	Low	High	High	Minor
Columbus Thermophilic Digestion	Combination of complete mix/continuous feed/ continuous withdrawal thermophilic digesters and either plug plow or batch reactors to achieve Class A	NA	Yes	Yes	Complex	High	High	On-site	Minor	Low	High	Medium	Minor
Dual Digestion	A two stage digestion process in which the first stage uses aerobic thermophilic digestion (pure oxygen) with 18 to 24 hr HRT and temperature between 130 to 150^{o}F, and the second stage uses anaerobic digestion.	Not limited to specific vendors	Yes	Yes	Complex	High	Medium	On-site	Minor	Low	High	High	Minor
High Solids Anaerobic Digestion	Sludge is fed for anaerobic digestion at 20% TS. Digestion is achieved sequentially in a biomass equalization tank, a digester tank, and a duel purpose tank (digestion and gas collection).	Schmack Bioenergy (Quasar)	Yes	Yes	Moderate	High	Medium	On-site	Minor	High	High	Medium	Minor
	Sludge is feed at 20% solids to a digester. A liquid steam out of the digester is fed through an anaerobic filter then recycled back to the digester. Biogas is recovered from the digester and the anaerobic filter.	IDI (HiSAD)	Yes	Yes	Moderate	High	Medium	On-site	Minor	High	High	Medium	Minor

TABLE 3.4-2 - SLUDGE PROCESSING ALTERNATIVES
2nd Screening

2nd Screening - CHEMICAL STABILIZATION

Chemical Stabilization – 2nd Screening

Technology	Description	Common Manufacturer	Liquid Sidestream	Sludge Dewaterability	Complexity of Operation	Emission Generation	End Product Use	Land Requirements	Odor Generation	Process Reliability	Relative Capital Cost	Relative Operating Cost	Relative Energy Consumption
Alkaline Stabilization	Lime is added to raise pH requirement for either Class A or Class B product	NA	No	No	Moderate	Low	High	Off-site	Significant	High	Medium	High	Moderate
Lime Pasteurization	Lime is mixed with dewatered sludge until a temperature of 70°C is achieved. The mixture is then passed through a pasteurization vessel, where the temperature is maintained at 70°C for 30 minutes producing a Class A product.	RDP Technologies	No	No	Moderate	Low	High	Off-site	Significant	High	Medium	High	Moderate
Advanced Alkaline Stabilization	Sludge is mixed with cement kiln dust, fly ash or other alkaline materials, stored for 72 hours at pH=12, with T=52 deg F for 12 hrs, then dried in rotary dryer or windrows.	N-Viro or non-proprietary	No	No	Moderate	Medium	High	Off-site	Significant	High	Medium	High	Moderate
Alkaline and Acid Stabilization	Lime is added plus sulfamic acid to raise pH and temperature under slight pressure. Temps of 70°C attained and maintained for 30 minutes	Schwing (Bioset)	No	No	Complex	Low	High	Off-site	Significant	Low	Medium	High	Moderate

TABLE 3.4-2 - SLUDGE PROCESSING ALTERNATIVES
2nd Screening

2nd Screening - THERMAL DRYING

Thermal Drying – 2nd Screening

Technology	*Description*	*Common Manufacturer*	*Liquid Sidestream*	*Sludge Dewaterability*	*Complexity of Operation*	*Emission Generation*	*End Product Use*	*Land Requirements*	*Odor Generation*	*Process Reliability*	*Relative Capital Cost*	*Relative Operating Cost*	*Relative Energy Consumption*
Rotary Drum Drying	Sludge is dried by contact with hot gases in a drum dryer to a solids content of 92-95%. Typical inlet temperature of drying gases is approximately 900 oF.	Andritz, Siemens, Baker-Rullman, etc	Yes	No	Moderate	High	High	On-site	Moderate	Low	High	High	Significant
Belt Drying	Sludge is placed on moving belt in an enclosed vessel, exposed to hot air for drying, generally to a solids content of 92-95%. Typical drying temperatures are 250-350^{o}F.	Andritz, IDI (Evaporis LT), Kruger, Huber, Siemens	Yes	No	Moderate	High	High	On-site	Moderate	Low	High	High	Significant
Fluidized Bed Drying	Sludge is pumped into the fluidized bed dryer where spinning cutters create small granules that drop into fluidizing layer of granules. Heat is transferred to the granules by fluidizing gas that transfers heat from heat exchanger located in base of dryer. Heat medium is steam or hot oil.	Andritz, Schwing	Yes	No	Moderate	High	High	On-site	Moderate	Low	High	High	Significant
Indirect Paddle Drying	Sludge is dried by contact with heated surface (walls, paddle and shaft) in a cylindrical dryer to a solids content of >92%; options for batch or continuous feed. The heat transfer medium (steam, or oil) circulates through a hollow auger and/or jacketed dryer shell. Typical drying temperatures are 350-450oF.	Komline Sanderson, Fenton, Haarslev	Yes	No	Moderate	High	Low	On-site	Moderate	Low	High	High	Significant
Indirect Vertical Tray Drying	Sludge is dried through contact with a series of vertical trays heated internally with thermal oil. The cake forms granules as they travel through the dryer. Fine solids are recycled to the top of the unit, while the final product is discharged at the bottom of the dryer.	Seghers, Waterleau, WYSE	Yes	No	Moderate	High	Low	On-site	Moderate	Low	High	High	Significant
Indirect Horizontal Thin Film Drying	Sludge is spread in a thin layer across the heated wall of a horizontal cylinder by rows of fixed blades. This indirect dryer can be heated by steam, hot water, or electricity.	Buss-SMS-Canzler, LCI Corp, IDI (Innodry 2E)	Yes	No	Moderate	High	Low	On-site	Moderate	Low	High	High	Significant
Indirect Hollow Flight Dryer	Sludge is dried using 2 counter rotating intermeshed hollow screens. The heat transfer medium is oil (500 F)	Therma Flite	Yes	No	Moderate	High	Low	On-site	Moderate	Low	High	High	Significant

TABLE 3.4-2 - SLUDGE PROCESSING ALTERNATIVES
2nd Screening

2nd Screening - OTHER THERMAL PROCESSES

Other Thermal Processes – 2nd Screening

Technology	*Description*	*Common Manufacturer*	*Liquid Sidestream*	*Sludge Dewaterability*	*Complexity of Operation*	*Emission Generation*	*End Product Use*	*Land Requirements*	*Odor Generation*	*Process Reliability*	*Relative Capital Cost*	*Relative Operating Cost*	*Relative Energy Consumption*
Incineration	Solids are combusted (at temperature of about 1500°F), typically in fluidized beds for modern facilties	IDI (Thermylis), Hankin, Technip/IFCO (all refractory arch)	Yes	No	Complex	High	Low	On-site	Minor	High	Low	Medium	Moderate
Vitrification	Use of a high temperature thermal process (2550°F) to melt the sludge and create a glass aggregate that can be used as a construction filler.	Minergy Corporation	No	No	Complex	High	High	On-site	Moderate	Low	High	Medium	Significant
Gasification	Conversion of carbon-based feedstocks using incomplete thermal oxidation to create a synthetic gas (syngas) that can be combusted as an energy source. The sludge would be subjected to high heat (temperatures > 1400 °F) and controlled oxygen levels in a reactor. Byproducts of the process include a ash and liquid sidestreams, as well as exhausts.	MaxWest, Nexterra, M2 Renewables Alternative Energy Solutions, US Centrifuge, Kopf AG, Waste to Energy Limited	Yes	No	Complex	High	High	On-site	Moderate	Low	High	High	Minor
Pyrolysis/Oxidation	Dry pellets are dosed into a pyrolytic converter and the excess heat is recirculated for sludge drying.	Eisenmann	No	No	Complex	High	High	On-site	Moderate	High	High	High	Significant
Pyrolysis to biodiesel	Chemical /thermal process to produce biodiesel fuel. Proprietary process piloted by Los Angelos County Sanitation District	KORE	No	No	Complex	High	High	On-site	Moderate	Low	High	High	Minor

TABLE 3.4-2 - SLUDGE PROCESSING ALTERNATIVES
2nd Screening

2nd Screening - OTHER PROCESSES

Other Processes – 2nd Screening

Technology	Description	Common Manufacturer	Liquid Sidestream	Sludge Dewaterability	Complexity of Operation	Emission Generation	End Product Use	Land Requirements	Odor Generation	Process Reliability	Relative Capital Cost	Relative Operating Cost	Relative Energy Consumption
Wet Air Oxidation	Thickened solids are oxidized by heating to 450°F under 300 psi in the presence of air or oxygen. The solids are then decanted and dewatered to produce a 40 percent solids material. Strong side-streams are created	Zimpro (formerly), Veolia	Yes	No	Complex	High	Low	On-site	Minor	Low	High	High	Significant
Cannibal	Extended HRT sludge minimization with physical cell lysis and very fine drums screening that removes inert matter from the solids	Seimens	No	Yes	Complex	Medium	Low	On-site	Minor	Low	High	High	Significant
Hydrogen Biofuel	Thermal drying followed by steam reformation to produce a hydrogen fuel. Piloted at California WWTF	Intellergy	Yes	Yes	Complex	High	High	On-site	Minor	Low	High	Medium	Minor
Haul Dewatered Biosolids	Hauling dewatered biosolids off-site for final disposal	NA	No	No	Simple	Low	Low	On-site	Moderate	High	Low	Low	Minor

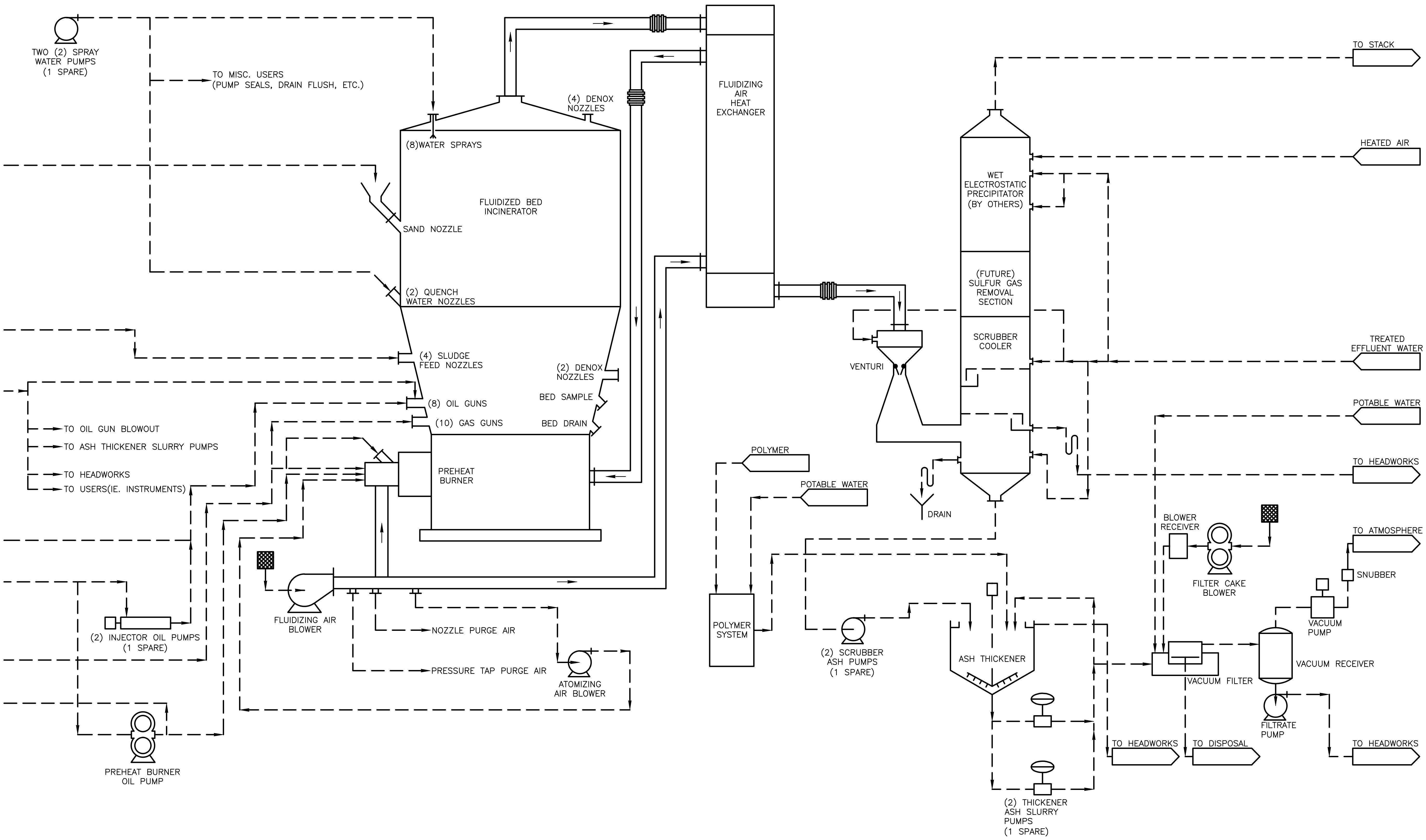


Figure No. 3.7-1
Fluidized Bed Incinerator Diagram
AUG 2015

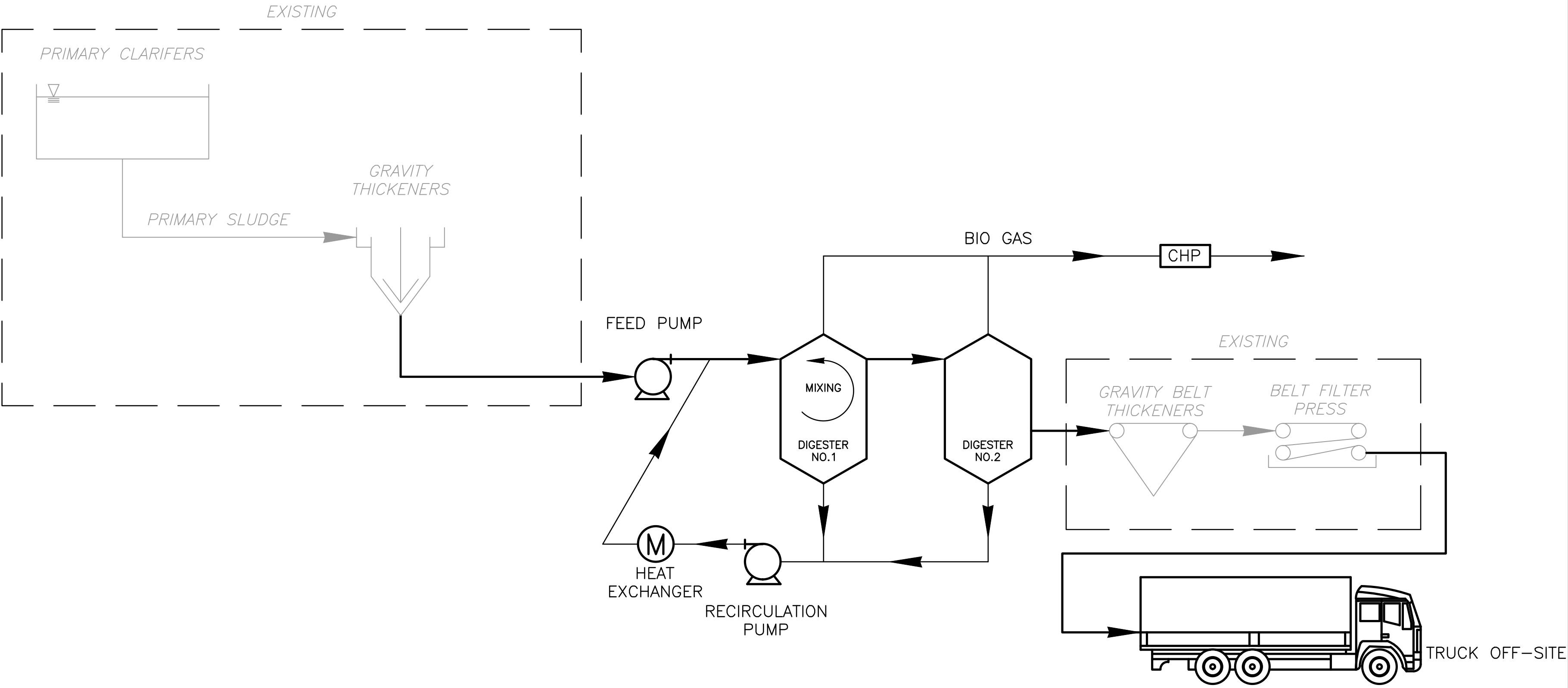


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Figure No. 3.8-1

Mesophilic Anaerobic Digestion Process Schematic

AUG 2015

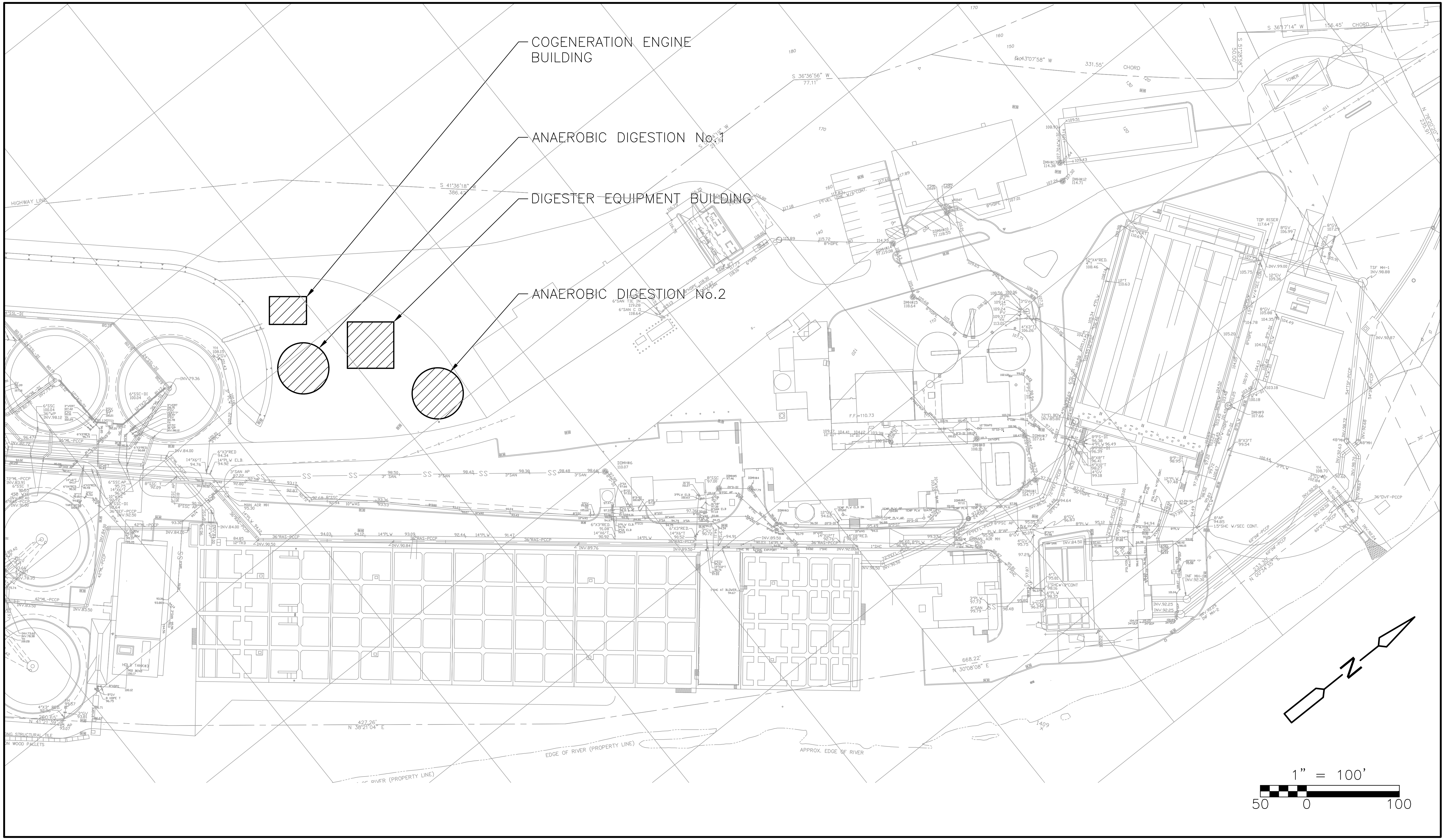

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Figure No. 3.8-2
Mesophilic Anaerobic Digestion Preliminary Site Plan
AUG 2015

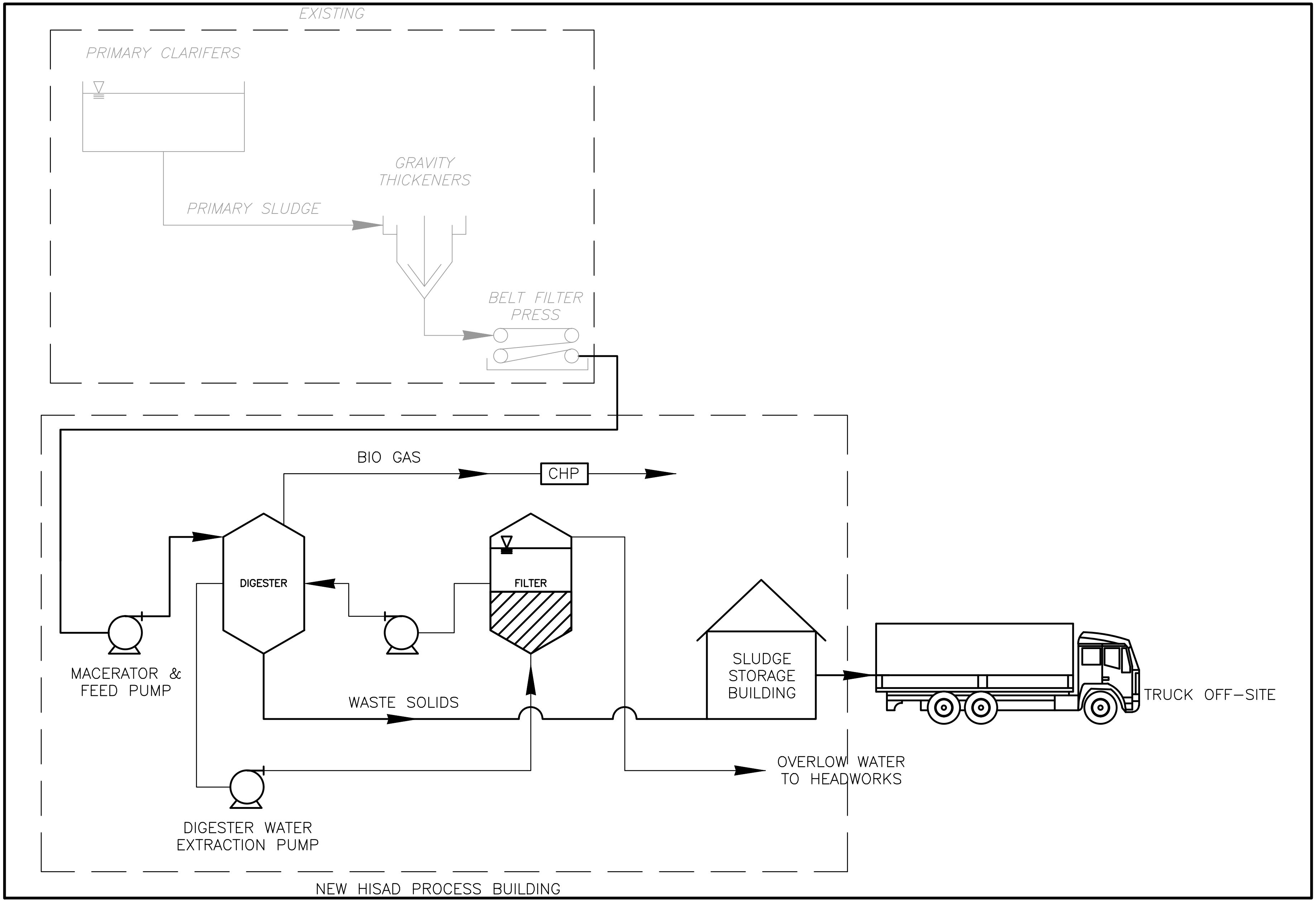

Figure No. 3.8-3
High Solids Anaerobic Digestion Process Schematic
AUG 2015

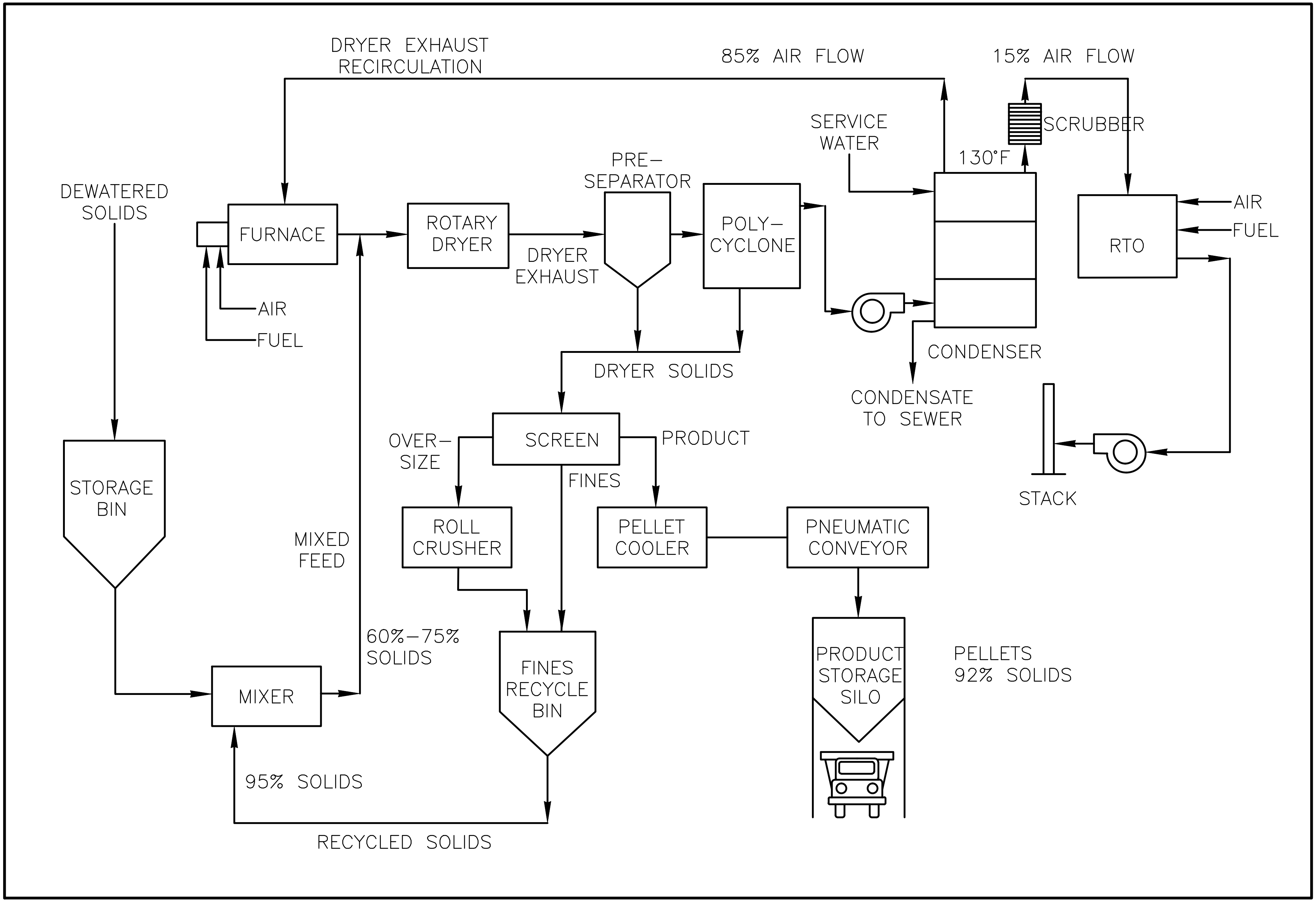

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Figure No. 3.10-1
Rotary Drum Drying Process Schematic
AUG 2015

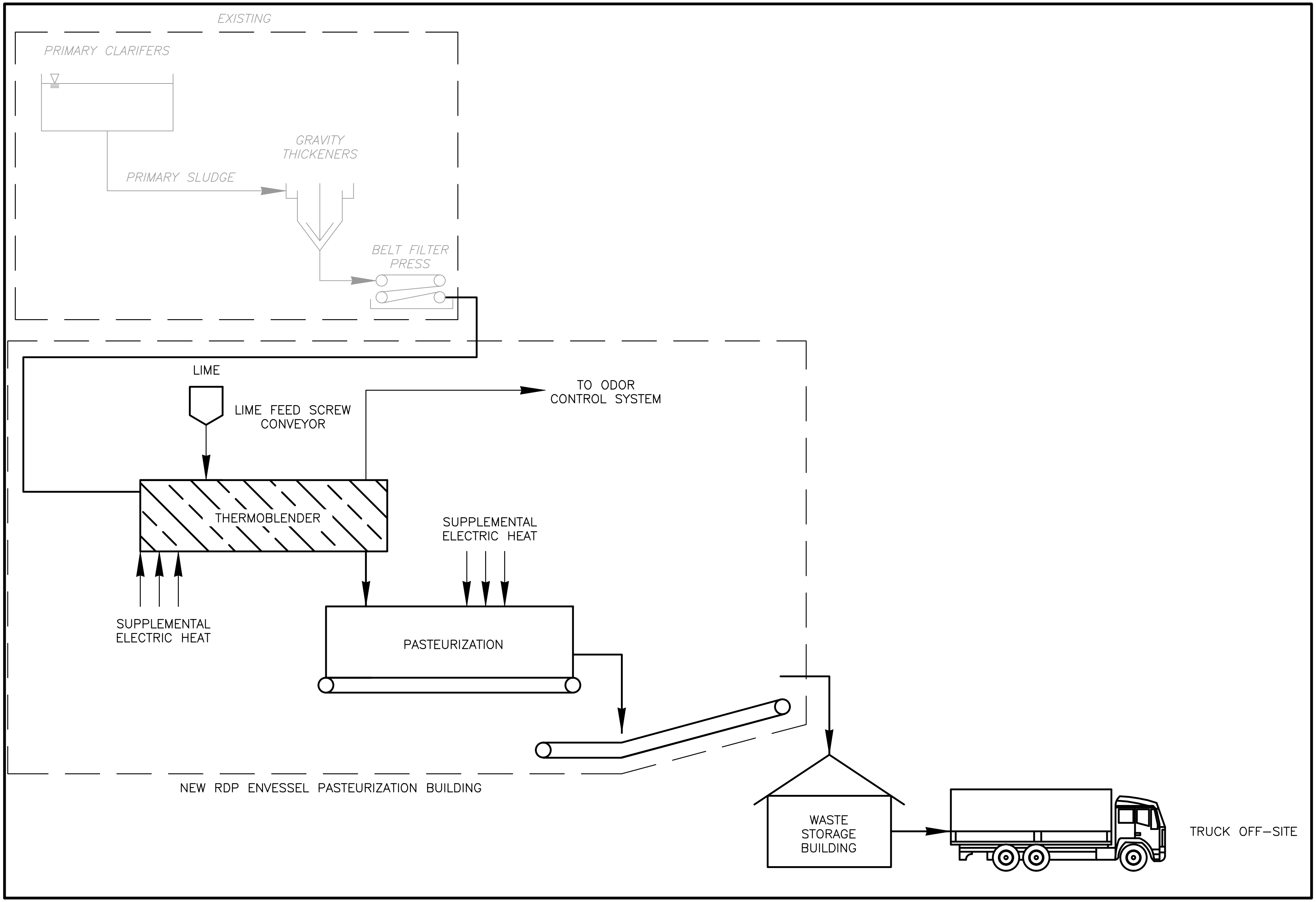

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Figure No. 3.11-1
RDP:EnVessel Pasteurization Process Schematic
AUG 2015

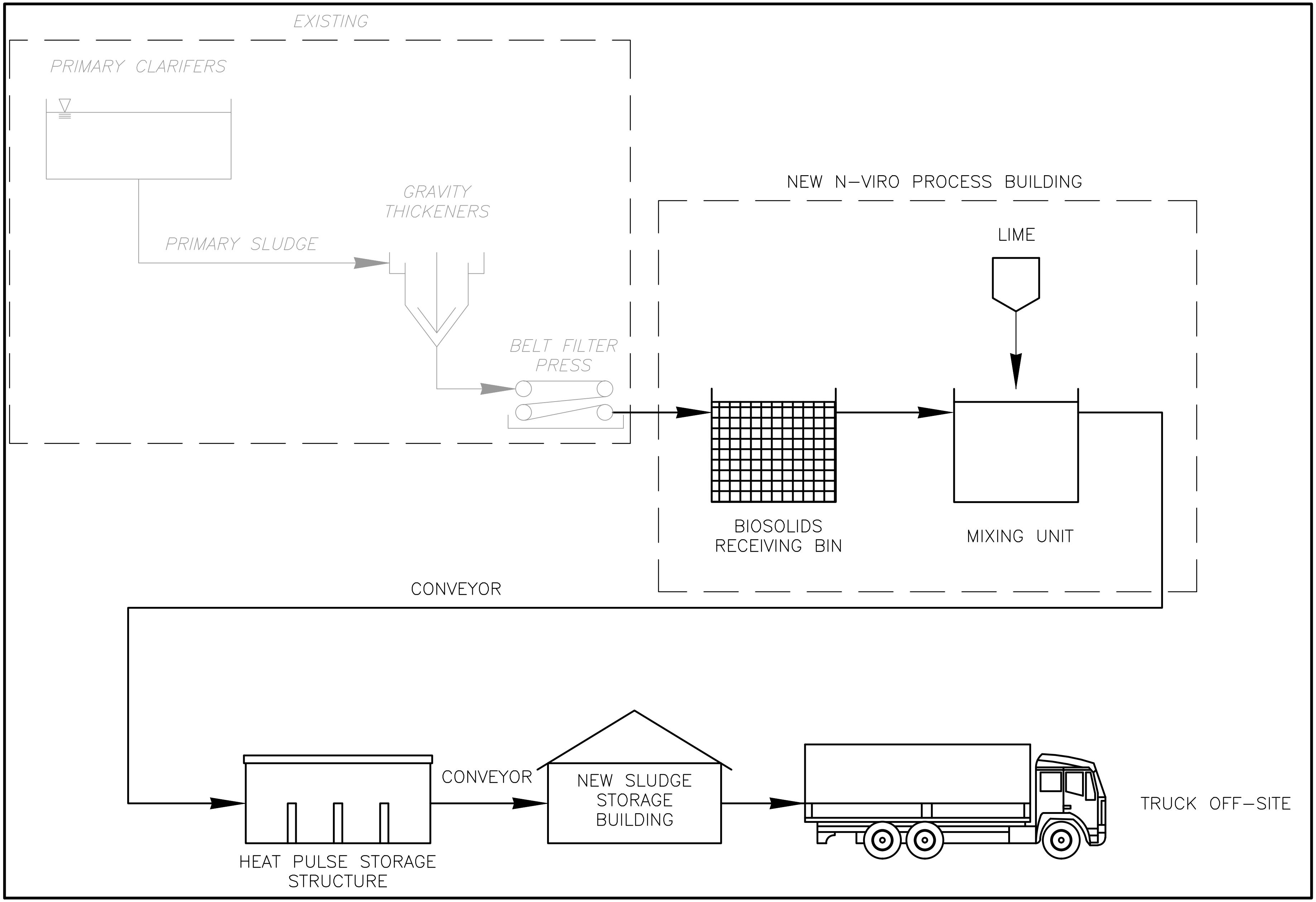

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Figure No. 3.11-2
N-Viro Soil Lime Stabilization Process Schematic
AUG 2015

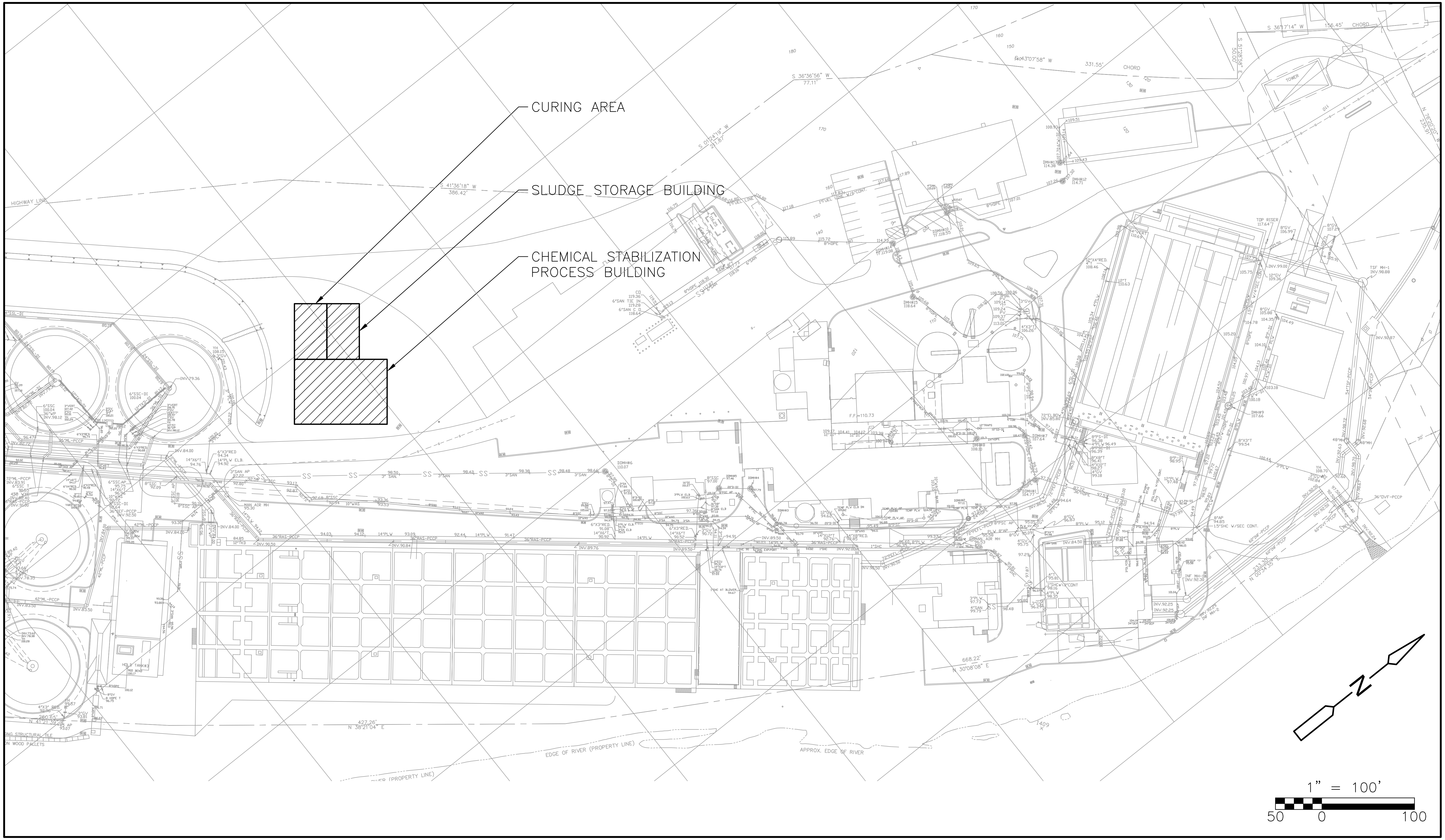

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Figure No. 3.11-3
N-Viro Soil-Preliminary Site Plan
AUG 2015

Section 4
Conclusions

4.1 Introduction

As outlined in this report, the Waterbury WPCF is facing a number of issues that will result in significant long term changes to the operations of the facility. These issues include:

- New NPDES limits being imposed on the WPCF for compounds such as phosphorus and metals;
- new Title V permit requirements that will require capital investments to the Sludge Incinerator facility;
- the impending contract expiration for third party operation of the sludge incinerator by Synagro;
- the limitations on landfilling ash at the South End Disposal Area;
- acceptance and processing of Fats Oils and Grease (FOG);
- WPC's and the City's desire to move toward more sustainable operations including improved energy efficiency and the use of renewable energy; and
- the ability to finance any proposed improvements.

In an effort to address these issues, CDM Smith developed this study to evaluate these issues, explore their interrelationships and to provide options for addressing these issues in a holistic manner.

4.2 Net Present Value of Phosphorus Removal Upgrade Alternatives

Table 4.2-1 summarizes the net present value of the two levels of phosphorus removal upgrades presented in Section 2.

Table 4.2-1 Net Present Value Summary of Phosphorus Removal Alternatives

Phosphorus Alternative	Capital Cost	Annual O&M Costs	20 Year Net Present Worth
Chemical Addition Alone	$ 4,300,000		**$ 11,300,000**
Annual Operating Cost		$ 470,000	
Chemical Addition with Filtration	$ 33,000,000		**$ 42,700,000**
Annual Operating Cost		$ 650,000	

4.3 Net Present Value Analysis of Sludge Disposal Alternatives

Table 4.3-1 on the following page provides the net present value of the various sludge disposal alternatives presented in Section 3.

Table 4.3-1 Net Present Value Summary of Sludge Disposal Alternatives

Sludge Disposal Alternatives	Capital Cost(1)	Annual O&M Costs	20 Year Net Present Worth (19)
Haul Dewatered Sludge Cake	$ 3,100,000		**$ 68,300,000**
Annual Hauling and Disposal (2), (3)		$ 4,380,000	
Incinerator Upgrade	$ 23,000,000		**$ 52,200,000**
Annual Cake Disposal (3), (4)		$ 1,610,000	
Annual Ash Hauling and Disposal (5), (6)		$ 350,000	
Digestion with Hauling	$ 26,600,000		**$ 55,600,000**
Annual Electricity(7)		$ (390,000)	
Annual Hauling and Disposal (2), (8)		$ 2,190,000	
Annual Labor (9)		$ 150,000	
N-Viro Lime Stabilization	$ 31,400,000		**$ 57,700,000**
Annual Electricity(10)		$ 100,000	
Annual Chemical Usage(11)		$ 500,000	
Annual Hauling and Disposal (12), (13)		$ 1,020,080	
Annual Labor (9)		$ 150,000	
Digestion with Sludge Dryer	$ 47,100,000		**$ 51,400,000**
Annual Electricity(14)		$ 150,000	
Annual Fuel Usage(15), (16)		$ 60,000	
Annual Pellet Revenue (17)		$ (220,000)	
Annual Labor (18)		$ 300,000	

Notes:
(1) Capital costs escalated to January 2019 mid-point of construction @ 3% per year.
(2) Projected hauling and disposal cost of $600/dry ton, based on market trends.
(3) Based 20 dry tons (design year) of cake produced.
(4) Net disposal cost of $220/dry ton, based on current market value. Covers operating costs including fuel, power and labor. Operating costs have potential to be reduced from this estimated value with a new third party operations agreement allowing for merchant operation and market trends moving toward limited disposal options for the region.
(5) Assume 20 tons cake with 75% Volatile Organics will produce 5 tons ash.
(6) Assume disposal cost of $190/dry ton.
(7) Assume 80% of power produced offsets current load; 4,389,000 kW-h/year produced; $0.11 per kW-h.
(8) Assume 50% reduction of cake via Digestion.
(9) Assume 2 full time employees @ $75,000 annually.
(10) Assume $100,000 increase in electrical usage for Lime Stabilization.
(11) Based on $230/dry ton of lime.
(12) Assume 40% increase in cake for Lime Stabilization.
(13) Assume disposal cost of $100/dry ton.
(14) 3,840 kw-hr/day; $0.11 per kw-hr.
(15) 4.9 M btu/hr; Natural gas $10 / M BTU; 15% of dryer fuel from natural gas.
(16) Digester gas used for balance of dryer fuel and digester heat.
(17) Sold at $60 / dry ton, 10 dry ton per day.
(18) Assume 4 full time employees @ $75,000 annually.

(19) Simple present worth, discount rate of 3% applied.

It should be noted that these net present values are all very dependent on the market rate that Waterbury can secure for hauling either digested or undigested biosolids, or ash; and on the market rate for a new potential third party operations agreement for maintaining the incinerator. Additionally, if a dryer were added to the digester option, this would increase the capital and operating costs, while lowering the hauling costs. Therefore, it is recommended that this report be considered draft until the Invitation to Bid results are received for the proposed hauling contracts, since these values can have a significant impact on the net present values presented herein.

4.4 Conclusion

As presented in this study, WPCF has a number of decision points that must be made in the near future. Since these are critical decisions that affect the long term operations of the facility as well as capital investment, a fully informed decision must be made. In the short term, CDM recommends the following:

1. Obtain the results of the Invitation to Bid for Hauling and update the biosolids alternatives analysis accordingly. This will allow the results of the biosolids analysis to more closely reflect the current market conditions that WPCF would be faced with.

2. Take advantage of the pending March 2016 regulation changes and use the time from March 17, 2016-October 31, 2016 (or at least the majority thereof) to obtain more data regarding phosphorous removal with just chemical addition and to gather more information regarding metals coming from on-site incineration side stream.

3. Since the incinerator cannot be operated in its current state after March 2016, an interim solution must be found. An option can be to haul biosolids off-site, but until bids are received, the cost to do so in unknown. The City is encouraged to investigate other interim solutions in the meantime and use of the present on-site drying system may be part of the solution.

4. Following completion of recommendations 1-3 above, it is recommended that this study be updated to include the results of the efforts, so that a definitive recommendation for phosphorus removal and biosolids removal can be made.

The efforts outlined above must be completed by September 30, 2016 so the City will be positioned to submit a final approved recommendation report to DEEP by the NPDES permit mandated deadline of April 1, 2017.

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