TECHNICAL STUDY
EVALUATION FOR INCREASING CAPABILITY OF WWTP COMBINED HEAT & POWER AND ANAEROBIC DIGESTER

CITY OF PITTSFIELD, MASSACHUSETTS
20181727.001

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A Report Prepared for:

Mr. David Turocy
Commissioner of Public Services/Utilities
City of Pittsfield
100 North Street
Pittsfield, MA 01201

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Prepared by:

____
Lucica Hiller, E.I.T.

____
Hannah Bloomquist, P.E.

Reviewed by:

____
David T. Peterson, P.E., LEED AP

KLEINFELDER
One Beacon Street, Suite 8100
Boston, MA 02108
Phone: 617.498.7800

Project Number:
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TECHNICAL STUDY
EVALUATION FOR INCREASING CAPABILITY OF
WWTP COMBINED HEAT & POWER AND
ANAEROBIC DIGESTER
CITY OF PITTSFIELD, MASSACHUSETTS

EXECUTIVE SUMMARY

Kleinfelder has completed an evaluation for increasing the capability of the combined heat and power (CHP) system and the anaerobic digester at the City of Pittsfield's (City) wastewater treatment plant (WWTP).

The CHP system began operating in 2012. The main goals for the CHP system included reusing the digester gas generated by the existing anaerobic sludge digesters to produce heat and electricity, supplying a portion of the WWTP's heating and electrical demands.

Over time, the CHP system has presented various operational and maintenance problems, resulting in lower heat and power output than estimated. The CHP system is not operating reliably because of issues with the incoming gas, the gas conditioning skid, and the microturbines themselves. The City would like this system to be improved to increase the reliability and operational run time of the equipment and better leverage their investment to produce renewable heat and power.

To address these issues, Kleinfelder has completed this technical study to identify ways to make the CHP system operational again and potentially increase the digester gas production by adding organic waste to the anaerobic digester. This study evaluated methods to increase the heat and power output of the CHP system, including operational and configuration improvements, and equipment upgrades. These methods were grouped by the following categories:

- Electrical system efficiency improvements
- Digester gas treatment
- CHP system equipment alternatives
- Use of natural gas as a blending fuel
- Digester mixing improvements
- Increased loading with additional organic matter
- Leverage additional heat gain from the CHP system

- Cell lysis

While improvements to the current CHP system can be made, they represent a major capital investment and warrant taking a holistic view of other viable CHP technologies. To evaluate alternatives, this study considered net present values (NPV), simple payback analysis, and non-cost factors, such as requirements for fuel gas quality and feed pressure, owner confidence in technology, and performance history of equipment as determined from interviews with other operators.

Findings and Recommendations

Based on the evaluations completed as part of this study, we developed both short-term and long-term recommendations. The primary goal of the short-term recommendations would be to make the CHP system fully operational again, utilizing the existing gas supply from the anaerobic digester. The short-term recommendations do not include the addition of organic waste to the WWTP or the resulting increase in gas generation but are scalable for such future improvements. The following are ***short-term recommendations***:

- ***Replace CHP system equipment*** **–** We recommend the City replace the current microturbines with reciprocating engines. Furthermore, we recommend that the existing gas conditioning skid be decommissioned, salvaged, and replaced with a new gas conditioning skid engineered specifically for operation with reciprocating engines.
- ***Automate the gas condensate control valves*** **–** Automating the gas condensate control valves is a relatively low capital investment and will greatly improve operations. This improvement will more effectively remove water content from the digester gas before entering the gas conditioning skid. It will also reduce the manual labor required to exercise the control valves.
- ***Leverage funding opportunities for design and construction*** **–** Considering the City's ongoing and planned projects for the WWTP and other City-owned assets (unrelated to the existing CHP system), we recommend the City evaluate availability and timing of future funding and budgets for the recommended CHP system improvements. The City should also confirm whether they are eligible for various grants and loans outlined in this study, and whether the sale of renewable energy credits to generate revenue is a process they would like to participate in and leverage.

After funding and implementation of the short-term CHP system improvements, and upon successful demonstrated CHP system performance, the City should contemplate additional long-term improvements to further increase the capability of the anaerobic digester and CHP system. These ***long-term recommendations*** include:

- ***Perform a detailed cost-benefit analysis for relocating the Reverse Power Relay –*** Using electricity output data from the operational CHP system, the City can determine the economic impact of relocating the Reverse Power relay. The cost-benefit analysis will consider the cost of relocating the reverse power relay vs. the cost of electricity purchased from the grid (when the CHP system output is limited by the current location of the Reverse Power relay).
- ***Increase loading with additional organic matter –*** The current available capacity for additional digester feedstock is approximately 57,000 gallons per day (GPD). Based on our research and knowledge about the WWTP, this study considered the addition of three organic matter sources: septage, source separated organics (SSO), and fats, oils and grease (FOG). Of these sources, septage is the preferred feedstock for the following reasons:
  - Septage is readily available near the WWTP. The City can readily increase septage receiving by lowering its septage tipping fee to be more cost-competitive with nearby facilities.
  - The WWTP is already designed to receive and accept septage at the headworks of the WWTP.
  - Septage is introduced to the liquid stream and, in the right quantities, is not anticipated to significantly affect the existing wastewater treatment process.
  - Conversely, both SSO and FOG would be fed directly to the digesters and not the liquid stream process. Because digesters do not respond well to variable feedstock quality and rate, both SSO and FOG would require some additional capital investment for processing, storage, mixing, and potentially heating of the material prior to introduction into the digester.
- ***Perform an evaluation to establish a septage tipping fee –*** Septage receiving could be a viable option to increase the CHP system output, but the rate would likely need to be decreased from its current value of $121/1,000 gallons to be more competitive with other WWTPs. The City could incrementally reduce its rate or perform a simple economic analysis to determine the most competitive rate. The economic benefit of septage receiving should consider revenue from tipping fees, costs of upgrades needed for the septage receiving area, additional O&M and labor considerations, and rates from other WWTPs.
- ***Monitor for other opportunities for digester feedstock –*** While septage is presently considered the best and simplest form of feedstock to increase digester gas production, the City should remain aware of other feedstock options that are available in the area. For instance, Divert Inc. was identified as a company that is looking to site an SSO pre-processing facility near

Pittsfield. If such a facility came online, then the City may have a good opportunity to consider an SSO amendment to the digester.

- ***Organic waste pilot studies* –** Small scale pilot studies should be performed to determine the impact of adding specific high-strength organic wastes to the anaerobic digesters and to identify operational needs. A pilot study that is tailored to the operational ranges in Pittsfield would help define the process better and identify limits and optimal operational parameters.
- ***Uses for additional heat* –** The addition of organic waste to the digesters will result in the generation of more gas and thereby more heat output from the CHP system. It is estimated that the potential heat generation could exceed the WWTP head demand for the digesters, especially in the summer months. If the City does increase heat output with the addition of organic waste, the recommendations presented in this study should be further advanced and potentially expanded.

In conclusion, this study developed, evaluated, and recommended several viable short-term and long-term alternatives for the City's consideration to increase the capability of the CHP system and the anaerobic digester at the City of Pittsfield's WWTP. The study also summarizes several financing alternatives for the City's consideration to help implement these recommendations.

Kleinfelder would like to extend thanks to the City of Pittsfield for the opportunity to complete this technical study and further advance understanding and use of the City's CHP system. Kleinfelder would also like to acknowledge and thank the Massachusetts Clean Energy Technology Center (MassCEC) for the opportunity to develop and assess methods for the City to increase its CHP capability and for offering financial assistance to fund this study under the Commonwealth Organics-to-Energy program.

1 EXISTING CONDITIONS

1.1 INTRODUCTION

Located at 901 Holmes Road, the Pittsfield Wastewater Treatment Plant is a conventional secondary treatment wastewater treatment plant (WWTP) that treats wastewater from the City of Pittsfield (City) and six (6) surrounding communities. The WWTP discharges its treated effluent into the Housatonic River. The permitted capacity of the WWTP is 17 million gallons per day (MGD), while it typically operates at 60-75% of its capacity with an average daily flow of 11.3 MGD. Based on population projections for Pittsfield and its surrounding communities, the WWTP's projected average daily flow is 12.7 MGD in 2035.

In 2008, Kleinfelder completed a Feasibility Study that evaluated the potential for reuse of the digester gas generated during the WWTP's anaerobic digestion process in a combined heat and power (CHP) system, with the goals of offsetting a portion of the peak energy demand of the WWTP and reducing the greenhouse gas emissions to the environment by eliminating flaring of the digester gas. After preliminary and final design in 2009, construction began in 2010 on this new CHP system. The CHP system was commissioned in 2012 and went online in 2014.

Since the beginning of its operation in 2012, the CHP system has presented various operational and maintenance problems, as well as lower heat and power output than expected. To address these issues, Kleinfelder has completed this Technical Study to evaluate methods to increase the capability of the existing CHP system. This Study develops and assesses methods to increase the heat and power output of the CHP system, including operational and configuration improvements, and equipment upgrades. Methods also consider increasing loading to the existing digesters with the acceptance of additional organic wastes like food waste, fats, oils and grease (FOG), sludge, and septage. Finally, this Study evaluates the technical feasibility, operation and maintenance considerations, costs, and payback analyses for such methods considered feasible. A final recommendation for implementation is provided for the method(s) determined to be most effective for increasing CHP capability.

1.2 FACILITIES AND EQUIPMENT

The City's WWTP was constructed in 1936, with major expansions in 1963, 1973, and 1986. Minor process upgrades were added to the site between 1986 and 2006. Since 2007, plant energy efficiencies were improved via various upgrades, including the installation of the CHP system, as shown in Appendix 2.

As part of the WWTP's sludge digestion system, there are primary and secondary digesters, mixing systems, a heat exchanger, recirculation pumping systems, and other ancillary equipment, instrumentation and controls, as shown in Appendix 1 and 2. The primary and waste activated sludge (WAS) are anaerobically digested in the primary and secondary digesters in a two-stage anaerobic digestion process. The first stage is contained to the primary digester, where active heating and mixing work to facilitate the destruction of volatile solids (VS) and produce digester gas. This gas, also referred to as biogas, is formed when the organics in the sludge decompose into methane, carbon dioxide, and hydrogen sulfide. In this primary digester, heating is accomplished by recirculating sludge through a heat exchanger, while mixing is accomplished by recirculating the gas from the headspace to the bottom of the digester vessel.

The second stage of the digestion process is contained to the secondary digester and does not utilize active heating or mixing of the sludge. Quiescent settling allows solids-liquid separation of the sludge to occur in this stage, and the methane gas is held inside the digester's cover prior to its use as a fuel for the WWTP boilers (for heat) and the CHP system (for electricity and heat generation). This steel gas holding cover of the secondary digester may be referred to as a 'floating' cover, since it will rise and fall in proportion to the volume of digester gas inside the digester's headspace.

The WWTP boilers (located in the Pump and Power Building and replaced in 2017) can operate using digester gas, oil, or natural gas. They are used to heat that building, the Digester building, and the primary digester sludge to maintain the sludge at the optimal temperature for anaerobic digestion. Heat generated from the CHP system itself is also used to heat the sludge in the primary digester. The existing heating load requirements and corresponding use of digester gas for fuel are seasonably variable. If not used as fuel, excess digester gas is flared through a waste gas burner located on the top of the Digester building.

The CHP system is comprised of three (3) 65 kW microturbines, three (3) 225,000 BTU/hr/unit microturbine heat recovery modules, and a skid-mounted gas conditioning system with one (1) 7.5 hp gas blower and two (2) 30 hp gas compressors. The microturbines are manufactured by Capstone Turbine Corporation. The system is housed in building #1A, which is a 1-story brick building with slab on grade built in 2012.

As mentioned above, the components that comprise the CHP facility include the following:

- **Microturbines** (3) – The microturbines receive conditioned digester gas for combustion and produce the heat and electricity.
- **Heat Recovery Modules (HRMs)** (3) **–** The integral HRMs recover heat from the exhaust of the microturbines into a hot water loop, which connects to an existing hot water loop to heat the digesters. The existing loop originates in the Pump and Power building but does not serve to heat anything other than the primary digester.
- **Gas Conditioning Skid** – The skid contains all the equipment necessary to ensure that the fuel supplied to the microturbines meets the gas specifications in terms of removal of targeted contaminants and supply pressure. Targeted contaminants include hydrogen sulfide, siloxanes and water vapor. The skid equipment includes:
    - **Gas Blower** – to boost the gas pressure to overcome the pressure drop across the conditioning system;
    - **Cross Flow Heat Exchanger** – to pre-cool incoming gas to the dryer heat exchanger, and reheat treatment gas before exiting to the siloxane vessels;
    - **Dryer Heat Exchanger –** to cool gas, and condense approximately 70 percent of the water in the gas;
    - **Chiller (Refrigeration Unit) –** to provide a close loop 35 percent glycol-water mix to cool the fuel processing components;
    - **Drain Traps** – to collect condensed water;
    - **Coalescing Filters** (2) – to remove water;
    - **Siloxane Filter** – to remove siloxanes from gas prior to combustion;
    - **Gas Compressors** (2) – to compress the gas to pressure required by microturbines.

Table 1-1 summarizes the equipment data for the CHP system.

Table 1-1: Equipment Table for CHP System

Name	Quantity	Manufacturer	Model	Motor Size (hp)	VAC
Microturbine	3	Capstone	C65	-	480
Gas Blower	1	Ametek	EN833	7.5	480
Heat Exchanger Tower	1	TTP	SSC-1218, SSC-1060	-	-
Chiller	1	Temptek, Inc.	TTOACS 5S-M1-1P	2.0	480
Filter Unit	1 2 1	Sparks Sparks Calpwr	R20-0201-MT-020, E22-0004-MT-040, -	-	-
Gas Compressor	2	CompAir	HV22GRS	30	480

1.3 PROCESS FLOW

1.3.1 Existing

A simplified process flow diagram (PFD) of the CHP system is shown below in Figure 1-1. A simplified PFD of the overall WWTP is illustrated in Figure 1-2. A detailed piping and instrumentation diagram (PID) of the Digester, CHP, and Pump and Power buildings is included as Appendix 1.

Figure 1-1: Existing Process Flow Diagram of CHP System

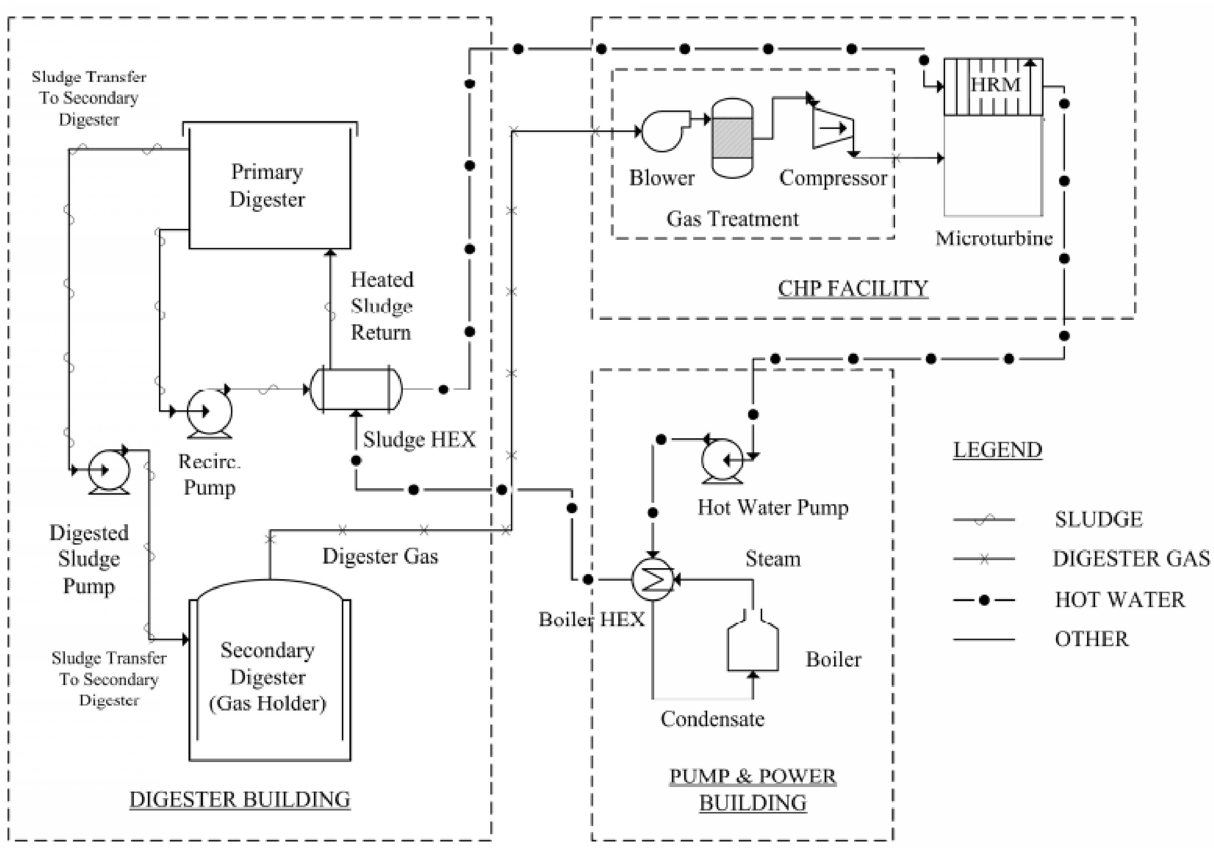
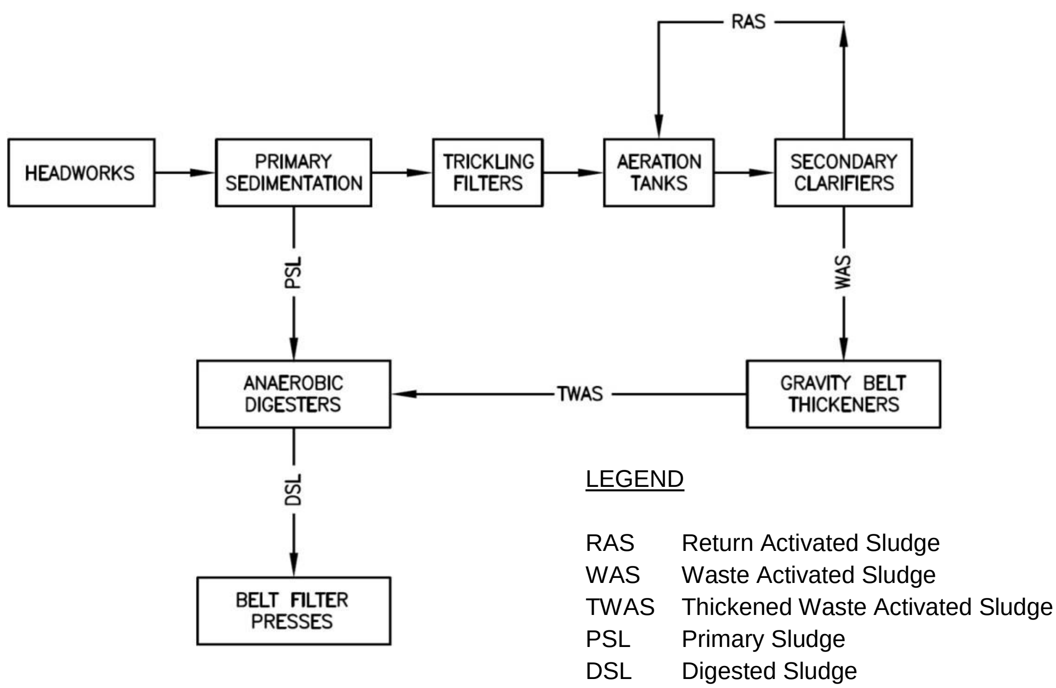


Figure 1-2: Existing Process Flow Diagram of Overall WWTP

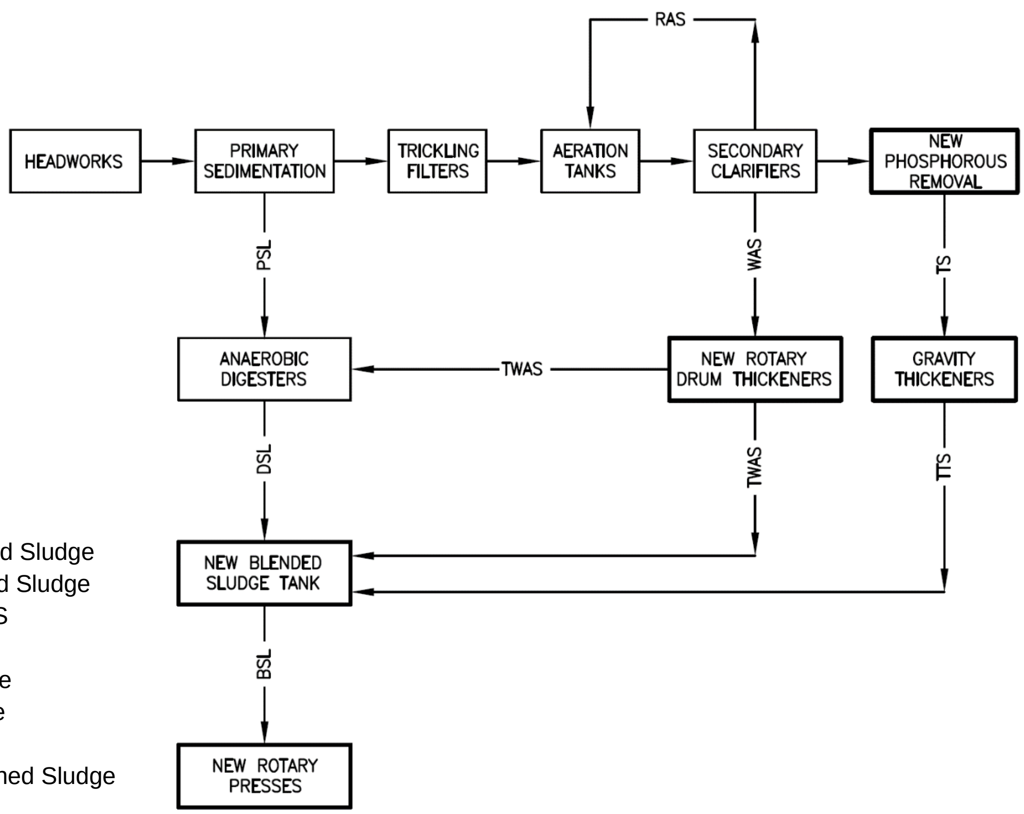


1.3.2 Proposed

The City is currently designing a Nutrient Removal Upgrade (Upgrade) to achieve compliance with their 2011 National Pollution Discharge Elimination System (NPDES) permit, issued by the United States Environmental Protection Agency (EPA). The Upgrade consists of the following major components:

- New ballast flocculation phosphorous and aluminum removal system (tertiary treatment),
- Sludge dewatering upgrade,
- Secondary clarifiers upgrade, and
- Nitrogen removal upgrade.

It is anticipated that public bidding for construction will occur in 2018. Once construction is complete, the WWTP PFD will be modified as illustrated in Figure 1-3. Primary sludge will still flow directly to the digesters. WAS will be thickened in rotary drum thickeners and the TWAS sent to the digesters with excess TWAS stored in a TWAS Storage Tank. Tertiary sludge will be thickened in gravity thickeners. Thickened tertiary sludge, digested sludge, and excess TWAS will be mixed in the Blended Sludge Tank then pumped to the rotary presses.



LEGEND

RAS	Return Activated Sludge
WAS	Waste Activated Sludge
TWAS	Thickened WAS
PSL	Primary Sludge
DSL	Digested Sludge
BSL	Blended Sludge
TS	Tertiary Sludge
TTS	Tertiary Thickened Sludge

Figure 1-3: Proposed Process Flow Diagram of Overall WWTP

1.4 SUMMARY OF KEY OPERATIONAL AND PERFORMANCE DATA

Table 1-2 shows key operational WWTP data from 2014 to 2017. On average, approximately 67,000 cubic feet of digester gas are produced daily, out of which a third is flared while the other two thirds are used by the CHP system or the steam boilers. Based on the latest gas sample analysis, the methane content of the digester gas is 62 percent, which translates to an approximate heating value of 620 BTU/CF. The average gas production has an energy value of 42 million BTU/d.

The average hydraulic retention time (HRT) of sludge in the digesters is approximately 63 days, which is significantly higher than the typical range of 15 to 20 days and three times as high as the design value of 20.3 days. Because of the high HRT, the average volatile solids destruction rate of 67 percent is higher than the typical range of 55 to 65 percent.

Table 1-2: WWTP Operating Data

Parameter	2014	2015	2016	2017	Average
Gas production (CF/day)	66,269	69,079	67,236	68,027	67,653
Gas used (CF/day)	32,250	55,819	45,882	52,020	46,493
Gas wasted (CF/day)	29,365	9,341	20,475	14,689	18,468
CF of gas per pound of VS	8.64	9.26	9.10	8.85	8.96
HRT (days)	63.4	64.3	61.74	63	63.1
% VS reduction	64.5	65.8	68.0	68.3	66.7
Digester sludge feed (GPD)	28,244	28,119	29,105	28,859	28,582
Digester sludge feed (VS lbs)	7,746	7,602	7,498	7,746	7,648
WWTP flow (MGD)	11.1	10.26	8.81	10.14	10.1

1.5 DIGESTER CAPACITY

Both the primary and secondary digesters are 80 feet in diameter and 25 feet deep, each with a volume of 142,000 cubic feet. The total sludge storage between both digesters is 2.1 million gallons. The primary digester’s mixing system relies on a 20 hp compressor with a capacity of

200 cfm. The secondary digester is also equipped with a steel gas holding cover that can hold 33,500 cubic feet of gas generated by the digesters.

The sludge digestion system includes a single heat exchanger, which was replaced in 2012. It has a hydraulic capacity of 300 GPM and a heat transfer capacity of 1,200,000 BTU/hour. The primary hot water source is the boiler in the Pump and Power building, and the integral heat exchangers of the CHP system are the secondary heat source.

1.6 ENERGY ANALYSIS

1.6.1 Digester and CHP System Energy Requirements

Various process equipment items are required to operate the digester system. Each equipment item has different horsepower requirements and is used for different durations throughout the day. This equipment and their nominal power requirements are summarized in Table 1-3.

Table 1-3: Digester Equipment Energy Requirements

Process Equipment (Quantity)	Nameplate Power Per Unit (HP)	(kW)	Typical Operation (hr/d)	Average Daily Requirement (kWh)	(BTU)	Instantaneous Requirement (BTU/hr)
Primary Digester Mixing System Gas Compressor (1)	20.0	14.9	16	238.4	813,421	50,839
Secondary Digester Mixing System Gas Compressor (1)	20.0	14.9	0[1]	0	0	0
Sludge Recirculation Pumps (2)	10.0	7.5	24	180	614,160	25,590
Muffin Monster	3.0	2.2	6	13.2	45,038	7,506
Digested Sludge Transfer Pumps (3)	7.5	5.6	6	33.6	114,643	19,107
Heat Loop Pumps (2)	7.5	5.6	24	134.4	458,573	19,107
Total	68.0	50.7	-	599.6	2,045,835	122,150

[1] Only used when primary digester is taken out of service for maintenance

Based on Table 1-3, the daily energy requirement for this equipment is approximately 2.0 million BTU. This value does not vary substantially by season, as the digester equipment runs with the same frequency and duration throughout the year.

The sludge temperature entering the primary digester is approximately the same temperature as wastewater flowing through the plant and averages 54°F annually. Heat is applied to the sludge in the primary digester to warm the sludge to approximately 97°F. Considering heat loss due to the size of the digester and the height of the sidewall exposed to ambient air, Table 1-4 summarizes the heat required to maintain the design temperature of the digester during both the summer and winter seasons at a design sludge flow rate of 300 gpm.

Table 1-4: Primary Digester Sludge Heating Requirement

Season	Peak Hourly Heat Requirement (BTU/hr)
Winter	1,200,000
Summer	800,000

The peak hourly energy requirements for operation of the digester system, including equipment (Table 1-3) and heat requirements (Table 1-4), are summarized below in Table 1-5.

Table 1-5: Peak Hourly Digester Energy Requirements

Season	Equipment Requirements (BTU/hr)	Peak Hourly Heat Requirement (BTU/hr)	Total (BTU/hr)
Winter	122,150	1,200,000	1,322,150
Summer	122,150	800,000	922,150

Various process equipment is required to operate the CHP system as described earlier in Table 1-1. Each equipment has different horsepower requirements and is used for different durations throughout the day. The equipment and their nominal power requirements required to operate the CHP system are summarized below in Table 1-6.

Table 1-6: CHP System Energy Requirements

Process Equipment (Quantity)	Nameplate Power Per Unit (HP)	(kW)	Typical Operation (hr/d)	Average Daily Requirement (kWh)	(BTU)	Instantaneous Requirement (BTU/hr)
Gas Blower	7.5	5.6	6	33.6	114,650	4,777
Gas Compressor (2)	30.0	22.0	6	132.0	450,400	18,767
Chiller Compressor	2.0	17.2	6	103.2	352,100	14,671
Total	39.5	44.8	-	268.8	912,150	38,215

1.6.2 Gross and Net Energy Production

Assuming two (2) microturbine HRMs are operating at any given time, gross energy production of the CHP system is 450,000 BTU/hr, since each HRM unit produces 225,000 BTU/hr. Additionally, gross electricity production of the CHP system for 2016 was 301,237 kWh/yr, as shown below in Table 1-7.

Table 1-7: CHP System Electricity Production

Electricity Production (kWh/yr)	Daily Output (kWh) (BTU)	Instantaneous Output (BTU/hr)
301,237	825 (2,815,016)	117,292

Gross and net energy production for two (2) microturbine HRMs are shown below in Table 1-8. Heat loss in piping (6%), energy requirements for the CHP system (Table 1-6), and energy requirements for the digester (Table 1-5) are considered.

Table 1-8: Gross vs. Net Energy Production

Gross Energy Production (BTU/hr)	Gross Electricity Production (BTU/hr)	Heat Loss in Piping (BTU/hr)	CHP System Requirements (BTU/hr)	Digester Requirements (BTU/hr)	Net Energy Production (BTU/hr)
450,000	117,292	(27,000)	(38,215)	(1,322,150)	(820,073)

With all energy requirements in consideration, net energy production is approximately (820,100) BTU/hr, when including sludge heating requirements.

1.6.3 System Efficiencies

Based on the gross energy production and energy requirements noted in Table 1-8, the CHP system is approximately 42% efficient. It was originally estimated that the CHP system would produce approximately 1,572,480 kW-hr/yr of energy, which equates to 608,729 BTU/hr. If the CHP system were producing this amount of electricity, gross energy production would be approximately 1,058,729 BTU/hr. Therefore, the CHP system would be 78% efficient per design. These values are shown below in Table 1-9.

Table 1-9: CHP System Efficiency

CHP System	Gross Production (BTU/hr)	Gross Requirements (BTU/hr)	Efficiency (%)
Current	567,292	1,360,365	41.7
Design	1,058,729	1,360,365	77.8

1.6.4 Surplus Energy Available

Under current operations of the CHP system, there is wasted or flared gas that could be used by the CHP system, in addition to the CHP inefficiencies stated above. This surplus energy is shown in Table 1-10. Improving the system’s efficiency and harnessing this surplus energy would increase the energy production the CHP system and reduce supplemental heating needs for the digester sludge.

Table 1-10: Surplus Energy for CHP System

Flared Gas (CF/day)	Flared Gas (BTU/hr)	CHP Inefficiency[1] (BTU/hr)	Total Surplus (BTU/hr)
21,510	555,675	491,437	1,047,112

[1]Difference between gross energy production of design vs. current system

1.7 OPERATING AND MAINTENANCE ISSUES

WWTP staff have experienced significant operations and maintenance issues with the CHP system. The reliability of the microturbines is poor, and there has been a consistent lack of factory support from the manufacturer. Major problems include failed microturbine igniters, exacerbated because the failed igniters fused themselves to the combustion chamber and are unable to be removed for replacement; catastrophic failure of the electrical generator unit associated with microturbine #2; failed electronical control modules associates with the microturbines; failed variable frequency drives (VFDs) associated with the gas compressors on the gas conditioning skid; failed seals on the gas compressors resulting in continuous oil leaks; and a failed gas blower on the gas conditioning skid. Additionally, the presence of moisture in the digester gas is a continuous problem, despite the gas conditioning system. The WWTP staff observe a significant accumulation of moisture in the underground gas line between the digesters and the gas conditioning skid. While a manual bleeder exists, it is problematic and not effective for removing the moisture from the digester gas supply pipe. The manual bleeder relies on WWTP Operations Staff to frequently open and close the valving associated with the bleeder, as seen in Figure 1-4 and monitor the bleeder for effective moisture removal. The required frequency and duration of this activity is variable, largely dependent on gas temperature, ground temperature, and season. Despite increased efforts by the WWTP Operations Staff, the manual bleeder has not proven effective and excessive gas condensate enters the gas conditioning system above levels which can be removed. As a result, excessive moisture can prevent the CHP engines from running and damage the gas conditioning system.

Figure 1-4: One of the Valves Used to Manually Bleed Moisture from the Digester Gas

The WWTP is currently using Vergent Power Solutions (Vergent) to service the microturbines. Vergent is the local authorized Capstone microturbine service representative. However, the company's New England office is located in eastern Massachusetts, and WWTP staff have generally experienced a response time of two (2) weeks to schedule a site visit and diagnose the problem. If replacements parts are needed, Vergent must order the part(s), which takes additional time for shipping and eventual installation. As a result, the CHP system is non-operational for months at a time when a problem occurs. Furthermore, Vergent will not commit to a service contract unless all three (3) microturbines are operational and running all the time, which is not feasible for the current digester gas production volumes at the WWTP.

At present, microturbine #2 has been decommissioned and its parts have been used to fix the other microturbines as needed, see Figure 1-5 below. Based on conversations with Sumner Bachman, Vice President of Technical Services at Vergent, at his last service visit at the Pittsfield WWTP approximately six (6) months ago, two (2) of the microturbines were running and operational.

Figure 1-5: Photo of Decommissioned Microturbine #2

Based on recent conversations with WWTP staff, the existing CHP system requires significant repairs in order to become fully operational and reliable. Major repair items include, but are not limited to:

- One (1) new microturbine and generator;
- Repairs for two (2) microturbines, with the expectation they will each need to be replaced entirely in the near future;
- Two (2) new gas compressors;
- Improvements to the digester gas supply system to remove excessive moisture prior to entering the gas conditioning skid; and
- Identification of a more responsive microturbine service representative and establishment of a new service contract.

2 POTENTIAL UPGRADE ALTERNATIVES

As indicated in Section 1, the existing CHP system is not operating reliably because of issues with the incoming gas, the gas conditioning skid, and the microturbines themselves. The City would like this system to be improved to increase the operational time of the equipment and better leverage their investment to produce renewable heat and power.

This section discusses potential upgrade alternatives that can improve the reliability of the CHP system, reduce parasitic loads and other inefficiencies in the process, and increase the output capacity of the CHP system and anaerobic digester facility at the WWTP. This section evaluates the following elements of the anaerobic digestion process and the CHP system:

- Electrical system efficiency improvements
- Digester gas treatment
- CHP system equipment alternatives
- Use of natural gas as a blending fuel
- Digester mixing improvements
- Increased loading with additional organic matter
- Leverage additional heat gain from the CHP system
- Cell lysis

A summary table of all the alternatives developed throughout this section can be found in Section 2.9.

2.1 ELECTRIC SYSTEM EFFICIENCY IMPROVEMENTS

Efficiency improvements to the electric system can be grouped into two categories:

- Decreasing parasitic electrical loads, and
- Optimizing CHP power fed back to WWTP.

2.1.1 Decrease Parasitic Electrical Loads

As discussed in Section 1.6, both the digester and CHP system have equipment that require significant energy input. Removing or replacing some of this equipment with more energy efficient equipment will reduce electricity costs for the WWTP and make more energy available for the sludge heating energy demands during peak periods. After reviewing existing electrical conditions at the WWTP and the energy demands of different CHP and digester system equipment, two possible alternatives have been identified:

- ***Remove the gas compressors on the digester gas conditioning skid*.** If the WWTP replaces the existing microturbines with reciprocating engines, the existing gas compressors can be decommissioned due to lower gas pressure requirements. This alternative will reduce the parasitic electrical load at the WWTP by 22 kW.

- ***Install digester mixer with greater efficiency***. The current digester mixing system runs with a 20 hp compressor. A linear motion mixer system (manufactured by Ovivo) sized for Pittsfield's anaerobic digesters will need 15 hp. Replacing the mixing system will reduce the parasitic electrical load at the WWTP by approximately 3.75 kW.

2.1.2 Optimize CHP Power Feed Back to WWTP

Presently, electrical power output from the existing microturbines is limited by a reverse power relay. The reverse power relay prevents power generated by the microturbines from flowing in reverse and back out to the electrical utility grid. The issue is, the microturbines are electrically connected to only a portion of the electrical service (branch service) to the WWTP. As such, it is possible (if all three microturbines are running and electrical demand at this branch service is limited) for the electrical generation from the microturbines to exceed the electrical demand associated with this branch service. When this occurs, the electrical supply from the microturbines is limited or suspended entirely.

The location of the existing power relay is shown Appendix 2. Electrical power to the Pump and Power Building, Digester Building, Trickling Filter Pump Station and the CHP Building is fed from Feeder A. When Feeder A enters the Pump and Power Building, it is stepped down from 23KV to 480/270V by an existing transformer, T2A. When power generated by the CHP system exceeds power output from the transformer (i.e. power is flowing reverse back out to utility grid), a Reverse Power Relay shuts down the CHP system automatically. This limits the CHP system output to the electrical demand associated with T2A. However, it is possible to abandon the existing Reverse Power Relay and construct a new Reverse Power Relay at the WWTP main electrical service feed, which would allow for acceptance of the full output of a CHP system up to the total electrical demand of the WWTP. This would be a significant electrical project but provides the benefit of allowing for increased output from any improved CHP system.

- ***Relocating the Reverse Power Relay.*** The electrical utility, Eversource, previously recommended this action. However, it was never implemented because of the high capital cost. This study assesses the potential economic benefit of relocating the Reverse Power Relay, as described above, to maximize the electrical production and utilization from the CHP system.

2.2 DIGESTER GAS TREATMENT

Based on knowledge about the WWTP and conversations with WWTP personnel, three digester gas treatment system upgrade alternatives were considered for further discussion. All three alternatives focus on improving moisture removal from the gas, and are as follows:

- ***Automate operation of the two valves used to bleed gas condensate.*** As discussed in Section 1, the existing gas treatment process at the WWTP does not adequately remove moisture. Microturbines operate efficiently when the gas is treated to limit siloxanes, hydrogen sulfide, and water vapor (moisture). The existing 6-inch digester gas supply pipe between the anaerobic digesters to the existing gas conditioning system has a manually-operated condensate bleeder. This manual bleeder is problematic and not effective for removing the condensate from the digester gas supply pipe. The manual bleeder relies on WWTP Operations Staff to frequently open and close the valving associated with the bleeder and monitor the bleeder for effective moisture removal. The required frequency and duration of this activity is variable, and largely dependent on gas temperature, ground temperature, and season. Despite increased efforts by the WWTP Operations Staff, the manual bleeder has not proven effective, and excessive gas condensate enters the gas conditioning system above levels which can be removed. As a result, excessive moisture can prevent the CHP engines from running and damage the gas conditioning system.

  Adding automation to the condensate bleeder and adding a condensate trap is anticipated to significantly improve moisture removal from the existing gas supply pipe, prior to its connection with a gas conditioning system. This improvement will reduce the amount of moisture introduced to the gas conditioning system, not only allowing the gas conditioning system to work more efficiently and trouble free but also resulting in a consistently drier treated gas for the CHP engines.

- ***Install a new moisture removal system.*** The microturbine performance issues are partially attributed to inadequate moisture removal. This potential upgrade will replace the components of the existing gas-pretreatment skid to provide improved moisture removal.

- ***Remove or repair gas compressors***. The existing gas compressors need repairs for the CHP system to be operational. However, if the City replaces the microturbines with reciprocating engines, then the gas compressors can likely be eliminated altogether because reciprocating engines operate with a much lower gas feed pressure in the range of 0.3 to 1.0 psi.

  After conversations with conditioning skid vendors, this study found that VOC and siloxanes have become more prevalent in wastewater in the last ten years because of increased use of personal care products. The current gas conditioning system includes an effective VOC and siloxane removal system but any changes to gas production or quality as a result of digester improvements will require review of the existing gas conditioning system and potential modifications or replacement.

2.3 CHP SYSTEM EQUIPMENT ALTERNATIVES

2.3.1 Microturbines

For this study, Kleinfelder contacted the facility managers at three other WWTPs that use microturbines for their CHP systems, as presented in Table 2-1.

Table 2-1: Waste Water Treatment Plants Contacted

Name of Waste Water Treatment Plant	Microturbines	Still Using Microturbines
Essex Junction Water Resource Recovery Facility (VT)	Capstone C-30 kW	No
Norwich Public Utilities WWTP (CT)	Capstone C-65 kW	N/A
South Burbank WWTP (VT)	Capstone C-65 kW	Yes

Essex Junction has replaced their microturbine with a reciprocating engine because of issues getting a new combustion core and the fact that Capstone (microturbine manufacturer) was no longer providing adequate support. They replaced the microturbine with one 150kW reciprocating engine in 2015. During a phone conversation with Jim Jutras, the facility manager, he acknowledged that initially the microturbine had been operational and efficient, before the combustion core failed and when the biogas was clean – pretreated for water vapor, siloxanes, and hydrogen sulfide.

Based on earlier conversations and a site visit, it is known that Norwich Public Utilities WWTP has had issues with their microturbines. At the time of writing this report, we have not been able to get in touch with them to confirm if they are still using microturbines.

South Burbank, VT is still using microturbine technology. Their C-65 kW microturbine was installed in 2011 and was used very little until 2015, when its core was replaced, and major repairs were completed. It has been working well ever since, with the caveat that the digester gas must be clean. They currently treat the digester gas for siloxanes, water vapor, and hydrogen sulfide. Because they have a service contract with both the microturbine and pre-conditioning skid, they have factory support when problems occur.

Presently in Pittsfield, none of the microturbines are being operated. All the digester gas produced when Kleinfelder visited in March was being used by the boilers and none by the CHP system. However, it was noted that in winter months the WWTP staff prefer to use the digester gas for the boilers in lieu of spending money on heating fuel.

This study evaluated replacing the microturbines with a different CHP technology that can improve overall system efficiency, increase reliability, decrease maintenance, and increase total run time. The two technologies included for evaluation here are reciprocating engines and fuel cells.

2.3.2 Reciprocating Engines

Reciprocating engines are the most prolific engines in use because they are a proven, reliable technology. Additionally, they are easy to operate and maintain. One advantage over microturbines is the fact that reciprocating engines can use gas at low pressures (~ 1 psi) versus microturbines (~100 psi).

Reciprocating engines with cogeneration were not recommended for the CHP system at the WWTP in previous studies because the smallest reciprocating engine had a minimum gas requirement that exceeded what can be produced at the plant. Currently, the market for reciprocating engines is such that units are now available to operate within the existing gas production at the WWTP. A list of the vendors contacted and the size of the engines they offer is presented in Table 2-2.

The WWTP produces an average of approximately 67,000 CF/day of digester gas. This gas volume can operate approximately a 180kW reciprocating engine. Because the digester gas production at the WWTP fluctuates between a minimum of 28,000 CF/day and a maximum of 76,000 CF/day, installing and running multiple smaller capacity units is more efficient and provides redundancy.

Three of the vendors Kleinfelder contacted (GE Jenbacher, Cummins, and Wartsilla) offer engines that are too large for the WWTP needs. Wuakesha manufactures engines small enough, but their engines do not run on digester gas. Only three vendors will be considered for further analysis in this study, as shown in Table 2-2: Tech3Solutions, which sells Liebherr engines, Northeast Energy Systems, which sells 2G engines, and Aegis Energy Services, which sells General Motors and Ford engines. Aegis Energy Services recommended only one engine size for this study after reviewing the operational data from the Pittsfield WWTP.

Table 2-2: Reciprocating Engines Vendors

Vendor	Engine Size (kW)	Can Run with Biogas	Considered for Further Evaluation
Tech3Solutions (Liebherr)	70, 90, 180	Yes	**Yes**
Northeast Energy Systems (2G)	50,100, 160	Yes	**Yes**
Aegis Energy Services (GM & Ford)	75	Yes	**Yes**
GE Jenbacher	330	Yes	No
Cummins	1,000	Yes	No
Wartsilla	4,200	Yes	No
Waukesha	165	No	No

2.3.3 Fuel Cells

Fuel cells were considered by the City in a previous study, however they were discounted at that time for a variety of reasons. Fuel cells were considered for this study to check if the technology was more established than a decade ago. As part of this study, Kleinfelder contacted the following manufacturers:

- General Electric (GE)
- Fuel Cell Energy (FCE)
- Doosan Fuel Cell America (Doosan)

The most prominent fuel cell manufacturer, GE, is no longer in the fuel cell business.

One of the companies considered in the feasibility study back in 2008 was Fuel Cell Energy. They are still producing fuel cells however their electrical output has increased significantly such that their unit is too large for the City's CHP system.

The other company considered in the previous study was Doosan Fuel Cell America (formerly UTC Power). Like Fuel Cell Energy, Doosan is still producing a very similar fuel cell product to what it was producing back in 2008, only at a larger scale.

The fuel gas flow and high heating value (HHV) requirements for these fuel cells are much greater than the digester gas being produced by the WWTP. The WWTP is currently producing an average of 47 SCFM of digester gas with a HHV of only 620 BTU/SCF. The outputs and fuel gas requirements of the fuel cells are found below in Table 2-3. These fuel cell products are designed to process large quantities of high quality gas which makes them less suitable for the WWTP.

Several WWTPs in Connecticut use Doosan's fuel cells, but these run on natural gas, not digester gas. Additionally, the SureSource 1500 manufactured by Fuel Cell Energy is marketed as being suitable for scenarios where combustion-based technologies are not feasible. In the case of this WWTP, combustion-based technologies such as reciprocating engines are a viable option.

Table 2-3: Fuel Cell Vendors

Vendor	Fuel Cell Energy	Doosan
Model#	SureSource 1500	PureCell 400
Output (kW)	1400	460
Heat Output (BTU/hr)	2,216,000	720,000
Fuel Gas Requirements (SCFM)	181	67
Fuel Gas HHV (BTU/SCF)	930	1025

Based on this research, fuel cells are not adequate technologies for the Pittsfield CHP system and are not considered further in this study.

2.4 USE OF NATURAL GAS AS BLENDING FUEL

As mentioned previously, the gas production at the WWTP fluctuates significantly. Although some of the CHP reciprocating engines can run at loads as low as 30 to 60 percent, reciprocating engines have the greatest efficiencies (electricity and heat generation) when they run at 100 percent load.

In this section, this study evaluates the addition of natural gas to supplement the digester gas supply to improve performance and efficiency of the CHP engines. The WWTP is in the process of bringing natural gas to the facility, with an expected completion date in the summer of 2018.

Both microturbines and reciprocating engines can be modified to allow blending of gases; however, it is not a common practice and each manufacturer and vendor has a preference on blending. Essex Junction blended natural gas for their microturbines after they had made significant modifications to the CHP system that voided the microturbines' warranty. The reciprocating engine they have now does not allow natural gas to be blended with the digester gas. Out of the three reciprocating engine vendors considered for this study, only Aegis has successfully blended natural gas with the digester gas. Both Tech3Solutions and Northeast Energy Services (NES) confirmed that blending is possible for their engines, but that will add complexity and cost to the project. NES recommends not blending natural gas into the digester gas at the WWTP because of the size of the operation.

2.5 DIGESTER MIXING IMPROVEMENTS

Sludge mixing is a critical component of the digestion process because it creates a homogeneous sludge within the digester, distributes heat evenly, increases the destruction rate of volatile solids and increases digester gas production. Because mixing is an energy-intensive operation, it presents an opportunity for lower operating costs by implementing more efficient mixing technologies.

The WWTP currently uses a Perth gas mixing system. Perth Gas recirculating pumps (200 cfm) recirculate compressed digester gas from the headspace of the primary digester to the bottom of the vessel though lances. A 20 hp gas compressor is located on top of each digester cover. Both the primary and secondary digesters are equipped with the gas mixing system, but the secondary digester is only mixed if the primary digester is offline. A system of lances operates in a sequential pattern and distributes the compressed gas to the bottom of the vessel.

Current operation of the digester mixing system is manual. Although the mixing system is designed to operate at all times, it currently runs for 16 hours a day. The sludge recirculation pumps operate 24 hours a day and they also provide some beneficial mixing.

One consequence of intermittent mixing is that the temperature of the primary digester is likely not homogenous. As a result, there may be zones of different sludge temperatures within the primary digester. Another consequence is that the organic solids in the sludge are not well distributed and the degree of solids destruction may be impacted.

The existing digestion system has a volatile solids reduction rate of 67 percent, which is within design value. However, we believe this is because the digester is underloaded and has an extended HRT. In a future scenario where the digester is loaded to design value and the HRT is lower, we would anticipate that the digestion process would require enhanced sludge mixing to maintain its current performance.

After reviewing existing mixing conditions and previous reports, we developed the following alternatives:

- ***Automation of the existing digester mixing system by introducing a programmable timer.*** As indicated above, the gas mixing system is run manually. A programmable timer with a process feedback loop would facilitate mixing operations. The parameters in the feedback loop would primarily be temperature and pressure sensors distributed throughout the digester.

- ***Evaluate the current lance operation sequence*.** The lances are currently operated in a sequence that is programed automatically. An evaluation of the optimal lance operating sequence can identify ways to improve mixing.

- ***Replace the gas mixing system with a linear motion mixer system*.** In the past few years, linear motion mixing has evolved as a successful mechanical mixing alternative. One technology this study considered in this study is the Ovivo LM™ Mixer. The LM mixer produces isotropic (uniform) mixing from the combined effect of oscillating velocity coupled with pulsating pressure waves. This motion is created by the controlled up and down movement of a ring-shaped hydro-disk (inside the tank) driven by an innovative cam-scotch-yoke operating system (above the tank). The equipment is suitable for both new and existing tanks. Computational fluid dynamic (CFD) modeling is used to custom design a system to meet mixing needs, by varying the frequency, stroke, and disk size.

2.6 INCREASED LOADING WITH ADDITIONAL ORGANIC MATTER

Additional organic loading to the WWTP anaerobic digesters would result in the production of additional digester gas and increased CHP output. The ability to accept new organics for treatment would also provide a potential new source of revenue to support operations at the treatment plant. These benefits are balanced by the potential for process impacts related to introduction of a new feedstock and reduction of the HRT.

Organic matter is available in many forms. The following sources of organic matter are being considered to amend anaerobic digester feedstock:

- Fats, Oils and Grease (FOG)
- Source Separated Organics (SSO) or food waste
- Septage
- Manure
- High-Strength Organic Waste
- Sewage Sludge from other WWTPs
- Deicing Fluid

The ideal scenario is to find a single, reliable source of organic waste that is easily digestible and does not need pre-treatment or arrives to the WWTP already pre-treated. Pre-treatment is important to ensure that the digestion process is not upset by the organic wastes being introduced. In some exceptions, organic wastes can be introduced without any pre-treatment. In general, the feedstock pre-treatment technologies are focused on achieving the following objectives:

- Removing toxic, inhibitory and unwanted substances for digestion process
- Reducing digester maintenance and clean up
- Homogenizing the feedstock mixture
- Adjusting moisture content, temperature etc. of the feed for digestion process

- Enhancing biogas production from the digester
- Promoting higher organic and volatile solid destruction inside the digester
- Reducing feedstocks volume and increasing in digester capacity
- Increasing hygienic safety and removing high pathogen from feedstocks
- Decreasing processing and disposal cost of the end products

2.6.1 Types and Sources of Compatible Organic Matter

Fats, Oil, and Grease (FOG) is typically material that has been pumped out of grease traps at food service establishments and could also include waste cooking oils. FOG has the highest energy content of all other organic wastes considered but requires additional heat and energy to be rendered, treated, mixed, and heated before being added into the digester. Based on literature, the maximum amount of FOG that can be added into a digester for optimal performance is 30 percent of volatile solids (VS).

Source Separated Organics (SSO) is typically food or beverage waste that has not been comingled with other wastes. SSOs are a viable feedstock amendment to anaerobic digesters because they are highly biodegradable and have a greater VS destruction rate (86-90 percent) than biosolids. Additionally, SSOs have three times the methane production potential as biosolids (13,491 CF/ton versus 4,306 CF/ton)[1].

In October 2014, MassDEP instituted a ban on the disposal of food waste in landfills by food service establishments generating one ton or more of food waste per week. MassDEP has been encouraging co-digestion with municipal sludges as an optional disposal mechanism. The amount of SSO that can be added into a digester for optimal performance can range from 25 percent to 100 percent of total sludge[2]. Without operational experience at Pittsfield in loading SSO to the digesters, we have assumed for this study that up to 50 percent the volume of the digester can be comprised of SSO.

Septage waste is waste from septic systems that local septic haulers and pumpers collect and dispose of regionally. The WWTP charges $121 per 1,000 gallons of septage and assume

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[1] *Tighe & Bond NEWEA Spring Meeting Presentation, June 2013*

[2] *Anaerobic Digestion and Energy Recovery from Food Waste, J. Amador, D. Nelsen, C. McPherson, P. Evans and D. Parry (CDM Smith), H. Stensel (University of Washington), and T. Hykes (U.S. Air Force Academy), WERF, 2012*

incoming trucks are full, as the WWTP does not have a weighting station. The rate is 20 percent higher than the rate neighboring WWTPs charge based on conversations with WWTP personnel. The reason for this high rate is to deter haulers from bringing septage to the WWTP.

The WWTP has a 25,000 GPD limit for receiving septage, but this limit was set when the flow to the WWTP was low and the WWTP has no headworks. Plant personnel estimate that they could accept approximately 100,000 GPD under current operating conditions. Septage comes to the WWTP when fuel prices are high, since this makes trucking to other WWTPs located further away costlier than disposing of septage at the Pittsfield WWTP.

Manure is animal feces from dairy and/or pig farms. Manure emits ammonia and hydrogen sulfide gases and is high in phosphorus and nitrogen. These two nutrients are undesirable at the Pittsfield WWTP because of their NPDES permit requirements, as mentioned in Section 1.3.2. Additionally, local farms started building their own anaerobic digesters to comply with regulations and have become more sustainable.

High strength organic waste

After digestion, these might produce unintended by-products (zinc, nutrients, etc.), which are considered pollutants and might be subject to additional discharge permit requirements. Examples of such high strength waste include:

- Brewery waste: spent hops, spent yeast, glycol
- Whiskey distilleries
- Hard cider
- Beauty products
- Chocolate manufacturers: used cocoa.

The WWTP receives calls on a regular basis from high biochemical oxygen demand (BOD) waste producers looking for a place to dispose of this waste. The WWTP does not currently accept high strength waste and are reluctant to accept it in the future because they are unsure how this high BOD waste will affect their current digestion process.

Airport deicing fluid contains ethylene glycol or propylene glycol, urea, potassium or sodium acetate, potassium or sodium formate. The pollutants associated with these fluids are: biochemical oxygen demand (BOD), nitrogen, and ammonia.

2.6.2 Survey of Organic Matter Sources

This study evaluated possible sources of organic waste situated within a 50-mile radius around Pittsfield. This radius includes areas in eastern New York, Connecticut, and Vermont. As part of this alternative, potential organic waste customers were contacted to assess the feasibility and quantitative estimates of outside organic waste sources. The results of this evaluation are summarized in Table 2-4.

Only one of the organizations contacted – Pittsfield Public School Department – was intrigued about the idea of sending their food waste from school cafeterias to the aerobic digester at the WWTP. Unfortunately, they do not have any information on food waste quantities and have concerns about how the food waste will be separated, stored, and collected.

Based on our research, the main competitors for food waste in the area are farmers, which use it both as food and compost, and other farms that have built their own anaerobic digesters and CHP systems.

Table 2-4: Possible Sources of Organic Waste for the WWTP

Type	Source	Company
FOG	Restaurants	
	Rendering/collecting co.	Western Mass Rendering
SSO	Supermarkets	Stop & Shop Big Y
	Restaurants	Pasta Prima
	Healthcare Facilities	Berkshire Medical Center Hillcrest Commons Nursing & Rehab Springside Rehab & Skilled Care
	Universities/Schools	Pittsfield Public Schools Department Berkshire Community College
	Food and beverage manufactures	Raven & Boar Pittsfield Rye Chicopee Provision (Kielbasa) Farmland Foods Slaughter House Frito-Lay
	Wholesale distributors	Whole Foods Inc.
Septage	Regional septic system haulers/pumpers	Berkshire Green Septic Sanitary Septic Cleaning Service Inc White Wolf Septic and Potables Sullivan Sanitation Services Roto-Plumbing and Drain Service Tri-town Septic Service Yankee Septic Tank Service Calan Phil and Nancy
Manure	Dairy farm	High Lawn Farm
High Strength	Breweries	Wandering Star Brewery Shire Bre-haus Big Elm Brewing
	Distilleries	Berkshire Mountain Distillers, Inc.
Airport Deicing Fluid (1)	Airports	Pittsfield Municipal Airport Albany International Airport Bradley International Airport Rutland Southern Vermont Regional Airport Great Barrington Airport

Note: (1) Deicing fluid was studied as a carbon source for the Field's Point WWTF project by CH2M Hill. Deicing fluid can be added to the biological process, but not necessarily to the digestion process.

2.6.3 Receiving and Pre-Processing Facilities

Many of the organic matter sources listed previously require storage and pre-processing before being added to the anaerobic digestion process. Some considerations for these facilities include:

- Adequate space at the WWTP to build a receiving / storage facility, including space for trucks to queue and turn around.
- Sufficient volume of storage to allow for organic matter to be introduced slowly to the anaerobic digesters.
- De-packaging and pre-processing facility.
- Heating and/or mixing equipment to keep organic matter homogenous before being added into the digester. This is especially important for FOG, which will need to be heated to be pumped though the pipes into the sludge system.

2.6.4 Business Approaches to Obtaining Additional Feedstock

- ***Reduce the septic waste receiving rate.*** Currently, the septic rate at the WWTP ($121 per 1,000 gallons) is approximately 20 percent higher than the rates at other WWTPs in the area. Local septic haulers contacted during this study would prefer disposing of their waste at the WWTP if the rate would be lower. The two main WWTPs that receive this local septic waste are in Lee and Great Barrington. Both currently charge $100 per 1,000 gallons, while the Great Barrington WWTP is planning a 10 percent increase in their rate starting in the next few months. If the WWTP can reduce the rate to at least match the rates of their two main competitors, they could increase the volume of sludge processed, which will increase gas production, thereby increasing the heat and electricity generation potential. Another potential benefit would be the reduction of regional greenhouse gas emissions associated with reduced travel distances for the septage hauler trucks.

  The Pittsfield City Council will have to approve any rate changes and they have been reluctant in the past to reduce the rates, as they see it as a loss in revenue. An economic analysis that will look at current and future septage receiving volumes and revenue generated by both scenarios is beyond the scope of this study but can be developed to show the cost benefits of reducing the septage rate at the WWTP.

- ***Partner with a de-packaging and pre-processing food waste company.*** The main food generators in Pittsfield, based on the Massachusetts Department of Environmental Protection (MassDEP) 2012 database, are supermarkets as shown in Table 2-5. Stop &

Shop has partnered with Divert, Inc. (a de-packaging and pre-processing food waste company) and currently uses an anaerobic digester in Freetown, MA to process food waste from their stores.

Table 2-5: Large Organic Food Generators in Pittsfield, MA

Name	Address	Generation (tons/year)	Generation (tons/week)
Stop & Shop	660 Merrill Road	432	8.31
Big Y	200 West Street	375	7.21
Stop & Shop	7 Dan Fox Road	300	5.77

Divert, Inc. has three food waste pre-processing facilities in Massachusetts and is looking to open another one in Western Mass or Eastern NY. They can process inedible food waste into a slurry with 30 to 70 g/L TSS concertation and 95 percent VS content. Divert, Inc. could be a viable choice for a partnership should the WWTP decide to introduce supermarket food waste to their digester system.

- ***Sign up as a processor on the RecyclingWorks web site*.** RecyclingWorks in Massachusetts is a recycling assistance program funded by MassDEP and is designed to help businesses and institutions maximize recycling, reuse, and composting. One feature of this service is a searchable database to find local recycling haulers and processors of organic waste. The WWTP could sign up as a processor on their web site, as this is a simple and cost-free endeavor. To benefit the most from this service, the WWTP will have to provide as much information as possible about:
  - types and volumes of organic waste it will accept,
  - total solids content, TSS percent, VS percent,
  - other organic waste parameters that are important for the Pittsfield WWTP.

- ***Partner with haulers to bring in food waste.*** Waste Management and Save that Stuff, Inc. are two of the largest waste haulers in Massachusetts. Jointly, they opened a pre-processing facility for food waste in Charlestown, MA. Although they generate a food slurry suitable for WWTP anaerobic digesters, the facility is too far from Pittsfield to be economically beneficial to truck the slurry from Charleston to Pittsfield.

- ***Partner with other processors in the area.*** Other processors in the area might have too much supply, and they could send the oversupply to the WWTP. Dan Hill at Mass DEP has permitted five additional anaerobic digesters at farms in Western Massachusetts. These farms digest manure and additional organic matter that they receive from other nearby facilities.

  In addition to these farms, numerous facilities within 50 miles from Pittsfield take and process FOG. These facilities are listed on the RecyclingWorks in Massachusetts web site (https://recyclingworksma.com).

2.7 LEVERAGE ADDITIONAL HEAT GAIN FROM THE CHP SYSTEM

This study assumes that heat supplied from a more efficient and robust CHP system, coupled with increased gas production from the possible addition of organic waste, will exceed summer and possibly winter heat demands required to keep the anaerobic digester at 97 °F. This section considers alternative ways to utilize this excess heat generation. We present a detailed technical feasibility and accounting of the heat supply and demand in Section 3.1.5.

- ***Construct a heat exchanger for future FOG receiving and mixing tank*.** FOG is considered as a future amendment to the digester for increased gas production in Section 2.6. Under this scenario, the WWTP would require a vessel to store, heat, and mix the FOG. Heat from the CHP could potentially be utilized to heat FOG prior to introducing it into the digesters.
- ***Hot water station in the Pump and Power Building for washing vehicles.*** The potable hot water demands at the WWTP are small, but equipment at the WWTP needs to be washed on a regular basis. WWTP personnel came up with the idea of using the additional heat from the CHP system to heat water and use a hot pressure washing station for utility vehicles and other equipment at the Plant.
- ***Air conditioning for process buildings in the summer.*** Excess heat can potentially be converted into air conditioning. One technology that has evolved in the past few years and that can convert waste heat into cold air in the summer months, is adsorption chillers. Adsorption chillers use solid sorption materials instead of liquid solutions to condense the refrigerant.

Systems that are available to the market now use water as refrigerant and silica gel as sorbent. The evaporated refrigerant is adsorbed by the silica gel. When the gel is heated, it releases water vapor into a chamber. As the concentration of water vapor in the chamber increases, the pressure rises until the water condenses. Recently, Zeolith (a new engineered nano material) has been used as an alternative to silica gel. Zeolith has more surface area, which allows more water molecules to sorb, and binds less strongly to the water molecules, which requires less heat.

Adsorption chillers have the disadvantage of being less efficient than conventional refrigerant chillers that use electrical compressors, and they are generally larger and currently more expensive. However, they have the advantage of being simplistic and inexpensive to operate, since they require very little electricity[1] and will be able to run on surplus heat from an expanded CHP system at the WWTP.

2.8 CELL LYSIS

The rate-limiting step for anaerobic digestion of WAS is the destruction of the cell membrane of each microbe. Anaerobic digestion of WAS is both slow and incomplete because the individual cell membranes are not significantly degraded in conventional mesophilic (35 to 37 degrees Celsius) anaerobic digesters that rely on enzymes to promote cell lysis. Consequently, anaerobic digesters deliver only a fraction of the potential cell destruction during practical residence times. This leads to high capital and operating costs, and contributes to the public's growing concern regarding odors, negative environmental impacts, and public health of the undigested residuals.

A few technologies have emerged in the past few decades that try to address this rate-limiting step and are reviewed by EPA in *Biosolids Management*[2]:

- Chemical cell destruction (MicroSludge™)
- Ultrasonic cell bursting
- Thermal hydrolysis - (Cambi® and LysteMize™) have the potential to break up cellular matter to make it easier to digest, while increasing volatile solids destruction and digester gas production.

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[1] https://www.technologyreview.com/s/423466/using-heat-to-cool-buildings/

[2] EPA, "Emerging Technologies for Biosolids Management," EPA #832-R-06-005, September 2006.

The addition of organic waste to anaerobic digesters can warrant the addition of any of these cell lysis technologies to aid with the overall VS destruction rates.

2.9 SUMMARY OF POTENTIAL UPGRADE ALTERNATIVES

The potential upgrade alternatives developed in this section are shown in Table 2-6. In Section 3, each of these alternatives will be evaluated.

Table 2-6: Potential Improvements to the CHP and AD systems at the WWTP

Category	Potential Improvements
Digester Gas Treatment	• Automate the operation of the two valves used to control gas condensate • Install a new moisture removal system • Replace the gas compressors
Efficiency Improvements (decreasing parasitic loads)	• Remove the gas compressors • Relocate the existing Reverse Power Relay • Replace the current gas mixing system with a different mixing system that will require less energy
CHP System Technology	• Replace the broken microturbine • Replace the gas conditioning skid • Repair the existing microturbines • Replace existing microturbines with reciprocating engines • Replace existing microturbines with fuel cells
Leverage Additional Heat Gain from CHP	• Construct heat exchanger for future FOG receiving/mixing tank • Hot water station in the Pump and Power Building for washing equipment • Air conditioning or process buildings in the summer
Digester Mixing Improvements	• Automate of the existing digester mixing system by introducing a programmable timer • Evaluate the current lance operation sequence • Replace the gas system with the Ovivo LM Mixer
Increased loading with additional organic matter	• FOG • Food waste • Septage waste • Manure • High strength organic waste • Sludge from other WWTPs • Airport deicing fluid
Business approaches to obtaining additional feedstock	• Reduce septic waste receiving rate • Sign up as a processor on the Recycling Work web site • Partner with other processors in the area • Partner with haulers to bring in food waste
Cell Lysis	• Chemical cell destruction • Ultrasonic cell bursting • Thermal hydrolysis

3 EVALUATION OF UPGRADE ALTERNATIVES

3.1 TECHNICAL FEASIBILITY

3.1.1 Preliminary Screening of Potential Alternatives

Kleinfelder performed a preliminary screening of all the potential improvements presented in Table 2-6 to identify alternatives that do not support the primary objectives of the project and are not worth analyzing through a detailed evaluation at this time. Based on our screening assessment and conversations with the WWTP, the following reasons warrant exclusion of potential alternatives:

1. Significant changes to the existing infrastructure
2. Large capital investment
3. Limited opportunities – as research did not yield enough information at this time
4. Potential future upgrade – to be considered in the future dependent on outcome of other potential alternatives

This study grouped all the potential improvements developed in Section 2 into five alternatives. During the preliminary screening, Kleinfelder found that fuel cells (Alternative 3) and cell lysis (Alternative 5) are not mature technologies and not appropriate for consideration at this time.

- **Alternative 1.** Replace and repair existing CHP system components – microturbines and gas conditioning skid.
- **Alternative 2**. Replace existing microturbines and gas conditioning skid. The microturbine technology will be replaced with reciprocating engines.
- **Alternative 3**. Replace existing microturbines and gas conditioning skid. The microturbine technology will be replaced with fuel cells.
- **Alternative 4**. Upgrade the process to add organic material to the digester. This alternative is independent of Alternatives 1 through 3. However, Alternative 4 is considered in conjunction with Alternatives 1 through 3.
- **Alternative 5**. Upgrade the process for cell lysis. Currently, the VS destruction rate is high and does not necessitate a cell lysis upgrade. Therefore, this study only considers this alternative in conjunction with other alternatives that provide additional organic matter that will stress the current anaerobic digestion process.

Table 3-1 lists the potential improvements and assigns each to one or more alternative projects defined below. Table 3-1 also summarizes the results of our preliminary screening.

Table 3-1: Preliminary Assessment of Potential Alternatives Matrix

Potential Improvements	Alternative(s)	Considered for Detailed Evaluation	Reason(s) Eliminated from Detailed Evaluation			
			Significant Changes to Infrastructure	Large Capital Investment	Limited Opportunities	Potential Future Upgrade
Digester Gas Treatment						
Automate gas condensate control valves	1,2,3	✓				
Install a new moisture removal system	1					✓
Replace existing gas compressors	1	✓				
Electrical System Efficiency Improvements						
Remove gas compressors	2	✓				
Relocate the existing Reverse Power Relay	1, 2	✓				
CHP Technology						
Replace existing microturbines with reciprocating engines	2	✓				
Replace existing microturbines with fuel cells	3				✓	
Replace/Repair the existing microturbines	1	✓				
Replace the gas conditioning skid	1	✓				
Leverage Additional Heat Gain from CHP						
Construct heat exchanger for future FOG receiving/mixing tank	1, 2, 4					✓
Hot water station in the Pump and Power Building	1, 2, 4					✓
Air conditioning for process building in the summer	1, 2, 4					✓
Digester Mixing Improvements						
Add programmable timer to automate existing digester mixing	1, 2	✓				
Evaluate the current lance operation sequence	1, 2				✓	
Replace the gas system with the Ovivio LM Mixer	1, 2	✓				

Potential Improvements	Alternative(s)	Considered for Detailed Evaluation	Reason(s) Eliminated from Detailed Evaluation			
			Significant Changes to Infrastructure	Large Capital Investment	Limited Opportunities	Potential Future Upgrade
Supplemental Organic Loading						
Add FOG to the digester and construct a FOG receiving/mixing/heating tank	4		✓	✓		✓
Add food waste to the digester	4		✓	✓	✓*	
Add septage waste to the digester	4	✓				
Add manure to the digester	4				✓*	
Add high strength organic waste to the digester	4				✓*	
Add sludge from other WWTPs to the digester	4				✓*	
Add airport deicing fluid to the digester	4				✓*	
Business Approach to Obtaining Additional Feedstock						
Reduce septic waste receiving rate	4	✓				
Sign up as a processor on the Recycling Work web site	4	✓				
Partner with other processors in the area	4				✓	
Partner with haulers to bring in food waste	4				✓	✓
Cell Lysis						
Chemical cell destruction	5					✓
Ultrasonic cell bursting	5					✓
Thermal hydrolysis	5					✓

Note:
* Limited interest from organic waste generators to dispose of their waste at the WWTP

3.1.2 Alternative 1 – Repair Microturbines

This alternative assumes that the current microturbine technology will be repaired and upgraded to improve its overall performance. In this alternative, the study included the following potential improvements:

- Replace the gas conditioning skid.
- Replace the microturbine that is now broken (MT #2).
- Repair the two microturbines that need work (MT #1 and 3).

To evaluate the options and cost of replacing and repairing the microturbines, Kleinfelder contacted Vergent, the current service provider for the microturbines at the WWTP. Their recommendation, based on their last visit to the WWTP and known status of the CHP system, is to replace the C65 power head, power head gasket, and the ECM IGBT for MT #1. The other microturbines need new ignitors and injectors.

Understanding the consistent problems that the WWTP staff have experienced with moisture and the existing gas conditioning skid, this study also evaluated replacing the entire skid with a new unit. Unison Solutions provided us with a quote for a digester gas conditioning skid, which includes a:

- Hydrogen sulfide removal system,
- Gas compression/moisture removal system, and
- Siloxane removal system.

This digester gas conditioning skid was sized to meet the microturbine gas treatment requirements and based on the latest digester gas sample the City has on file.

3.1.3 Alternative 2 – Reciprocating Engines

This alternative assumes that the existing microturbines and gas conditioning skid, including the gas compressors, will be replaced with reciprocating engines and a new gas conditioning skid. In this alternative, the following potential improvements/alternatives are included:

- Relocate the existing Reverse Power Relay.
- Replace existing microturbines with reciprocating engines.

As mentioned in Section 2.3.2, three reciprocating engine manufacturers provided equipment specifications and budgetary estimates. This data is summarized below in Table 3-2. The rest of this study will focus on the cost benefit analysis of installing reciprocating engines under current sludge loading conditions and accounting for the possibility of receiving additional organic waste.

Table 3-2: Reciprocating Engine Vendors – Specifications

Company	Aegis Energy Services	Tech3Solutions			Northeast Energy Systems (NES)		
Engine	Aegen Thermopower TP75	Leibherr			2G agenitor 104	2G agenitor 404b BG	2G agenitor 404 c
Electrical Power Output (kW)	75	150	90	70	50	100	160
Power (bhp)					72	141	141
Thermal Output (BTU/hr)	324,260	777,968	470,875	375,335	249,000	405,000	578,000
Thermal Output (kW)		228	138	110			
Gas Input (SCFH)	930	2160	1320	1020	882	1914	2856
Gas Input (SCFM)	15.5	36	22	17	14.7	31.9	47.6
Required Gas Pressure (psi)	0.22 to 0.43	0.5 to 1	0.29 to 0.72	0.29 to 0.72	0.435 to 1.015	0.435 to 1.015	0.435 to 1.015
Heating loop temperature (F)		185	185	185			
Return temperature (F)		155	155	155			
Hot water flow at 100% load (GPM)		52	32	25	18.4	30	
Electrical efficiency (%)		34.1	33.9		33.4	37	
Thermal efficiency (%)					48.7	44	
Efficiency (%)	82	87.6	87.2		82	81	81.7
Size of unit							
Length	96	149	134	134	113	120	150
Width	46	48	48	48	36	39	44
Height	49	99	99	99	62	67	77
Min load (percent)	30	60	60	60	75	60	60
Noise (dB)	70	70	70	70	100	104	104

3.1.4 Alternative 4 – Septage, SSO, and FOG

This alternative assumes that the WWTP will operate a CHP system able to produce heat and electricity reliably. The goal of this alternative is to estimate the increased gas production after organic matter is added to the digester. The objective is to maximize the design capacity of the digester without sacrificing the current operational performance. This additional gas production will be then used to determine CHP sizing needs and potential energy savings.

Based on research and knowledge about the WWTP, this study considered the addition of three organic matter sources: septage, SSO, and FOG. Three scenarios are detailed below. Each scenario corresponds to one of the three organic waste sources considered and will include, where possible:

- calculations of maximum volume of organic waste that can be added, and
- additional and total gas production.

Because there is limited information or interest from generators available about organic waste source quantities and disposal costs in Berkshire County, we are unable to prepare a cost-benefit analysis for taking in additional organic sources.

3.1.4.1 Organic Waste Scenarios

Scenario I – Septage Only

This scenario will maximize the available capacity of the primary digester. Under this scenario, only septage waste will be added to the digester, but the determination of the exact volume and supply of septage to be added is outside the scope of this study. Currently, the WWTP receives limited septage waste. This study assumed that there is enough septage waste in the area to meet capacity based on phone conversations with local septage haulers. These haulers are eager to dispose of septage at the WWTP if rates would be lower.

Scenario II – SSO only (50 percent of sludge)

This scenario will maximize addition of SSO to 50 percent of the current sludge capacity. This percentage is a conservative amount of SSO that can be added to an anaerobic digestion process without potential loss of performance, as discussed in Section 2.6.1.

Scenario III – FOG only (30 percent of VS)

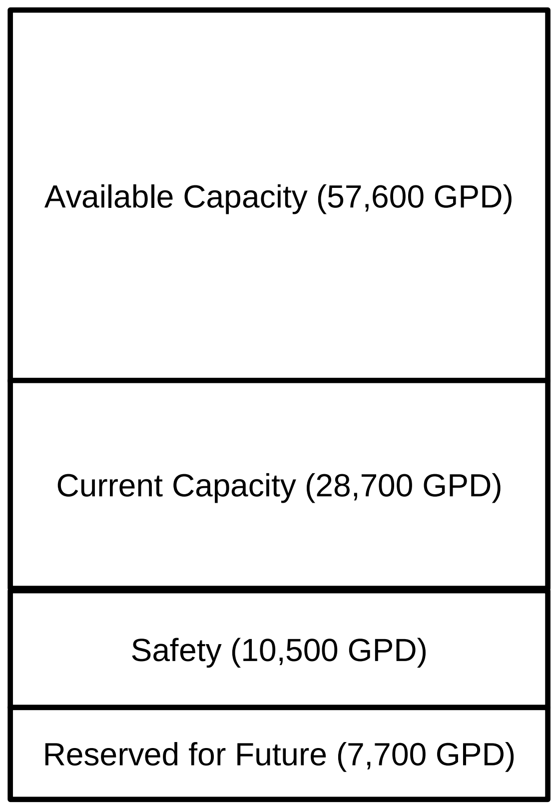
This scenario will maximize the addition of FOG to 30 percent of volatile solids. This percent was taken from pilot studies done at the Riverside WWTP in California. Similar to the addition of SSO, careful consideration needs to be taken when adding FOG to a digester. Wastewater engineers recommend performing a demonstration study to determine operating parameters before deciding how much FOG to add to digesters.

3.1.4.2 Calculations and Results

To determine the available existing sludge capacity in the primary digester, this study considered design capacity parameters, future projected flow, and a safety factor of 10 percent. The total design capacity for the primary digester is 104,500 GPD. Given the anticipated flow due to future growth through 2035, 27 percent of the current capacity (or 7,700 GPD) of digester capacity was reserved for future. We included a safety factor of 10 percent to accommodate uncertainty and fluctuations in sludge loading to the digester.

Based on these assumptions, there is approximately 57,600 GPD of available capacity to load to the primary digester and remain within original design. Figure 3-1 shows the breakdown of the primary digester volume based on the above stated assumptions.

Figure 3-1: Sludge Capacity of Primary Digester (Total Capacity 104,500 GPD)



The estimated additional gas production of the three organic loading scenarios are presented below in Table 3-3. The maximum additional capacity for each of the scenarios was calculated based on the assumptions from Section 3.1.4.1. For example, because SSO can only be 50 percent of the total sludge by volume, and the existing sludge volume is 28,700 GPD, the maximum volume of SSO that can be added to the digesters is 14,350 GPD.

Table 3-3: Gas Production Potential

Scenario	Max Additional Capacity (GPD)	Additional Gas Production (CF/day)	Total Gas Production (CF/day)
I – Septage	57,600	123,500	185,100
II – SSO	14,350	110,400	171,900
III – FOG	3,100	13,800	75,300

Using the maximum additional capacity for each scenario and the parameters in Table 3-4, we calculated the additional gas production based on the formula below:

$$\boldsymbol{Additional\ Gas\ Production} = \boldsymbol{Max\ Additional\ Capacity} * \boldsymbol{Density} * \%\ \boldsymbol{TSS} * \%\ \boldsymbol{VS} * \%\ \boldsymbol{VSR} * \boldsymbol{Gas\ Production}$$

Table 3-4: Gas Production Parameters by Source

Parameter	Sewage[1]	Septage[2]	SSO[3]	FOG[3]
Density (lbs/ gal)	7.23	7.23	8	8.74
% TSS	4.14%	4.14%	10%	5%
% VS	81%	81%	80%	80%
% VSR	67%	67%	80%	80%
Gas production (CF gas/ lbs VSR)	13.24	13.24	15	15

1 Parameter data from the WWTP (last three years)

2 Assumed septage has the same characteristics as sewage

3 Based on Kleinfelder project experience

Based on our calculations, septage and SSO have the greatest potential for maximizing gas production. Septage requires the least amount of additional infrastructure to construct at the WWTP and it is readily available today, whereas SSO and FOG are not.

3.1.5 Heat Balance

We presented the design heating needs for the sludge and the digester in Section 1.6.1. In this section, we calculate heating needs based on average and peak sludge loads during winter conditions for both current and future conditions. Adding organic waste to the digester increases the sludge volume and the heating needs. The heat balance is used to determine if the current heat exchanger, which is designed for 1.2 MMBTU/hr, is appropriately sized to heat the sludge in future conditions.

Table 3-5 shows the summary of digester heating needs for the winter months, when demand is the highest. Appendix 3 shows detailed calculations of the heating needs under current and future conditions. The future sludge loading values are based on Figure 3-1 and include the current sludge loading volumes plus the following volumes:

- Available capacity – 57,600 GPD
- Reserved for future – 7,700 GPD

Table 3-5: Winter Heat Requirements

Loading Condition	Sludge Pumped to Digester (GPD)		Heating Need (MMBTU/hr)	
	Average	Peak	Average	Peak
Current Sludge Loading	28,000	35,600	0.85	0.98
Future Maximum Loading	94,000	101,000	2.0	2.2

Adding additional organic waste to the digester requires more heat than is available through the existing sludge heat exchanger. Therefore, additional heat exchanger capacity will be required if sludge loading to the digester is increased.

The heating needs of the digester process are about 35 percent reduced in the summer months. During this period, there will be more heat available than there is demand. Possible ways to utilize this excess heat are identified in Section 2.7.

3.1.6 Upgrades Independent of the CHP Technology

The following upgrades are independent of the CHP technology at the WWTP and represent improvements to the digester system. They will not be included in the cost benefit analysis of any of the CHP system technology alternatives but will be evaluated separately.

- Replace the gas mixing system with the Ovivo LM Mixer.
- Relocate the existing Reverse Power Relay.
- Automate of the existing digester mixing system with a programmable timer.
- Automate the operation of the two valves used to control gas condensate.

Replace the gas mixing system with the Ovivo LM Mixer

The existing gas mixing system does an adequate job at mixing. However, this study considers a change to the linear mixer technology as a possible means to save operating costs. The horsepower of the linear mixer is less than the horsepower for the existing gas compressors.

After discussions with the vendor, the following considerations are important in deciding to install the Ovivo LM Mixer:

- The digester cover needs to withstand the additional dead and dynamic loads of the mixer. The vendor can conduct an inspection and determine if the existing cover needs to be replaced or not.
- The optimum location of the LM mixer is at the center of the digester. Again, the vendor can verify the location of the gas collection piping, gas handling equipment, and other interior piping, for possible interference. The LM mixer can be offset from the center, but that adds complexity and cost for the design and installation.
- For mixing to be effective, an 8-foot radius around the mixer needs to be available and free of interference.
- The digester will have to be offline for the installation of the LM mixer.
- The power needed to operate based on sludge loading is 10 to 15 HP (approximately 0.2 to 0.3 HP per 1,000 gallons of sludge).

The horsepower of the existing mixing system (20 HP) is greater than the proposed LM mixer (15 HP). This study estimated the potential energy savings of the LM mixer a presumed life cycle of 20-years. This is summarized below in Table 3-6.

Table 3-6: Present Worth Electrical Cost Comparison of Digester Mixing

Parameter	Gas Mixing (Current)	LM Mixer (Proposed)
Horsepower	20	15
Daily Operating Hours	16	24
Annual kWh	87,097	97,985
Cost of Electricity [1]	$0.1057 / kWh (2018)	$0.1057 / kWh (2018)
Life Span	20 years	20 years
Net Present Value of Electricity	-$179,000	-$201,000

[1]The electricity costs are inflated annually at 3 percent for the purposes of this calculation.

Based on the comparison above, replacing the gas mixing system with a 15 HP LM mixer will save approximately $22,000 more in electricity over the 20-year lifespan of the equipment. We do not recommend replacing the existing mixing system at this time. Rather, we recommend that the City review this technology in the future when the gas mixing system reaches the end of its useful life.

Relocate the existing Reverse Power Relay

This improvement will allow the City to maximize the potential benefit of electricity generated by the CHP system, as described in Section 2.1. Relocating or more accurately, reconstructing the reverse power relay will require high voltage work and possibly replacement of the main WWTP service switch gear, which is original equipment dating back to the 1963 WWTP expansion. Additionally, signal conduit and conductors will be required between the reverse power relay and the CHP system. It is our understanding, based on conversations with Eversource (electrical utility provider) that this work will be a requirement as part of any CHP system modification, which will require a new electrical interconnection agreement between the City and Eversource. Understanding that relocating the reverse power relay will be a requirement of Eversource, a payback analysis was not conducted as part of this study. Rather, the cost for relocating the reverse power relay can be considered a fixed cost as part of any CHP system upgrade, to be developed as part of any future planning or design phase.

Automating the existing digester mixing system with a programmable timer can potentially improve mixing efficiency and reduce both the electrical needs and labor hours. After discussions with WWTP personnel, the mixing system works well for them and automating it is not a priority. The mixing system runs for 16 hours every day and does not add significant labor hours to the operators. Understanding this, it was decided not to estimate costs for this improvement at this time but instead recommend revisiting it in the future.

Automate the operation of the two valves used to control gas condensate

This improvement aims to mitigate the current issue with too much gas moisture going into the microturbines by removing condensed water from the gas piping under the driveway between the Digester Building and the CHP Building automatically.

The automated condensate bleeder system will generally include the following components:

1. Addition of a low point or trap leg on the existing 6-inch digester gas supply pipe, providing a location for moisture in the digester gas to coalesce.
2. Addition of a bleeder pipe off the trap leg, providing a means of removing moisture from the trap leg.
3. Addition of two normally closed automatic gas bleeder valves (Class 1, Division 1 Explosion Proof), providing a means of opening/closing the bleeder pipe automatically based on a programable timer and/or an in-line moisture sensor. Second valve is redundant.
4. Connection of the bleeder line to the existing gas drain manhole.
5. Improve drainage from the existing gas drain manhole, to prevent standing water from collecting in the manhole.
6. Addition of a gas detector to the existing gas drain manhole, providing an alarm to the WWTP's existing gas detection system in the event of a gas release to the manhole.
7. Addition of a gas bleeder valve control panel with audible and visible alarm, providing for local control of the gas bleeder valves and alarm indication. Connect the valve control panel into the WWTP SCADA system.

3.2 POTENTIAL OFFSITE IMPACTS

Because the WWTP is located in a remote location, the potential for offsite impacts is limited for the alternatives considered as part of this study.

The most significant potential offsite impact would be increased truck traffic if additional organic waste (SSO, FOG, or septage) was accepted. Receiving additional organic waste would add trucks on the roads, which will generate additional traffic and noise on the local and state roads leading to the WWTP.

Receiving additional septage at the WWTP will also have impacts to the traffic on the local and state roads leading to the WWTP. However, understanding that this septage is already being shipped to other locations, and in some instances longer distances as compared to Pittsfield, a decrease in regional truck traffic would be expected. Table 3-7 provides an estimate of trucks based on the different scenarios for accepting additional organic waste at the WWTP.

Table 3-7: Truck Estimates for Organic Waste Scenarios

Scenario	Max Additional Digester Capacity (GPD)	Number of Trucks per Day*	Number of Trucks per Year
I – Septage	57,600	20 [a]	7,300
II – SSO	14,400	3 [b]	1,000
III – FOG	3,100	1 [c]	365

[a] Calculated based on 100,000 GPD, which is the septage volume the WWTP can accommodate now (per WWTP Superintendent) and average truck capacity of 5,000 gallons
[b] Typical size for truck carrying SSO slurry is 6,000 gallons
[c] Typical size for trucks carrying FOG is 3,000 gallons
* This study did not further investigate the capacity of local roads to accommodate the increase in trucks on local or state roads.

3.3 PERMITTING

3.3.1 Air Permits

According to the MassDEP air pollution control requirements, any construction or modification of a facility that emits air contaminates must have a written Plan Approval. Within the agency's air pollution control regulations, combustion turbines and reciprocating engines are exempt from the Plan Approval. Instead, any engine with a rated power output over 50 kW needs to apply for approval to emit through the Environmental Results Program (ERP). To be approved through the ERP, the owner or operator of the WWTP must obtain a completed Supplier Certification of Emission Performance form from the supplier. This form certifies that the engine or combustion turbine will comply with the applicable emissions limits. The form must certify compliance for the first three years or 15,000 hours of operation. The applicable emissions, set by the MassDEP, are listed below in Table 3-8.

Table 3-8: MassDEP Emission Limitations for Engines[1]

	Emission Limitations (lb/MW-hr)	
Pollutant	Biomass Digester Gas*	Any Fuel
NO_X	0.50	0.15
CO	0.60	1
PM 2.5/ PM10	0.030	-
PM (Liquid Fuel Only)	-	0.03
CO_2	1000 (See Note 1)	1650
VOC	0.30	-
SO_2	0.50	-
H_2S	See Note 2	-

*Anaerobic digestion of source-separated organic (SSO) (and other digestible) material
Note 1. Facility-wide CO_2 caps are undefined for this source category. The CO_2 emission limit for the engine is based upon CO_2 emissions resulting from combustion of methane only.
Note 2. H_2S emissions are regulated by restricting the inlet H_2S emissions to the IC engine and flare to less than or equal to 200 ppm. SO_2 emissions are based upon 99.5 percent oxidation of 200 ppm H_2S inlet emissions to the IC engine and flare.

All the reciprocating engines evaluated for this study are EPA certified engines, and all the ones sold in Massachusetts meet the emissions requirements set by MassDEP.

3.3.2 Effluent Discharge Permits

The section of the Housatonic River (MA21-04) where the WWTP discharges is categorized as a Category 5 water body, according to the 2016 Massachusetts Integrated List of Waters, pursuant to section 303(d) of the Clean Water Act. A Category 5 water body is considered impaired and requiring a Total Maximum Daily Load (TMDL). From a regulatory perspective, when a water body is impaired to the point that it can no longer support its designated uses, a mechanism known as the TMDL is put into place. This legally enforceable mechanism sets specific mass load allocations (typically based on a total annual load) for the pollutant causing the impairment to all permitted point sources discharging to the tributary waterways.

Section MA21-04 of the Housatonic River is impaired and requires a TMDL for E. coli, fecal coliform, and polychlorinated biphenyls. None of these three pollutants have a TMDL at the time

[1] MassDEP, "BACT Requirements for Anaerobic Digester Biogas-to-Energy Facilities," November 2017 and "Engine and Turbine Environmental Certification Workbook," May 2012.

of writing this report, which means that no additional mass load restrictions for these pollutants apply for the Pittsfield WWTP.

The WWTP discharges into the Housatonic River under NPDES permit number MA0101681. The permit sets discharge limits for the WWTP for the pollutants shown below in Table 3-9.

Table 3-9: NPDES Permit Discharge Pollutants

Conventional Pollutants	Non-Conventional Pollutants	Toxics
• Carbonaceous Biochemical Oxygen Demand (CBOD5) • Total Suspended Solids (TSS) • pH • E. coli	• Nitrogen • Ammonia-nitrogen • Phosphorus • Dissolved Oxygen	• Total Residual Chlorine (TRC) • Aluminum • Copper • Zinc • Lead

As required by the NPDES permit, several system upgrades are being implemented to reduce the nutrient loading of the WWTP effluent. Discharge limits for phosphorus and aluminum of 0.1 mg/l and 171 µg/l, respectively, are required by the current NPDES permit. A nitrogen discharge limit is also expected to be implemented though the exact limit is not known at this time. These nutrient concentration limits are driving secondary and tertiary process upgrades which will impact sludge production.[2]

These system upgrades do not consider the addition of organic wastes - SSO, FOG, or septic. As discussed in Section 2.6, some organic wastes are contaminated with pollutants that are subject to permit limits. Because of these two reasons, pre-treatment of any addition of any organic waste to the WWTP will need to be evaluated, as well as any future impact on the NPDES permit, fees, treatment technologies, and fines. Pre-treatment options have been discussed in Section 2.6.3 and 2.6.4. and can be achieved either at the WWTP (requires capital investment and a significant O&M commitment from staff at the WWTP) or at a pre-treatment facility outside of the WWTP (i.e. Divert, Inc.).

[2] *WWTP Nutrient Upgrade Design Report – Draft, Project Nr. 20164502.002*

3.4 OPERATION AND MAINTENANCE

Operation and Maintenance (O&M) on the specific schedule required by each system component and by staff that is properly trained, is essential with any process.

According to manufacturers and vendors, microturbines require limited O&M: oil change for the compressors once a year and media replacement for the digester gas conditioning skid. To reduce costs, media replacement can be done by WWTP staff or by hiring a local company that specializes in activated carbon replacement. However, Pittsfield's O&M experience with microturbines has been problematic and much more intensive and costly than anticipated, as described in previous sections of this study.

Reciprocating engine technology is much more familiar to WWTP personnel than microturbines. Certain O&M tasks (i.e. oil changes, filter replacements) could easily be performed by WWTP staff, which could reduce the overall cost.

To ensure the proper operation of the CHP system, vendors recommend service contracts. These service contracts can range for 20,000 to 50,000 operating hours and will need to be renewed though the 20-year estimated life-time of the system. Service contracts work well assuming the vendors are near the WWTP and can address issues in a timely manner, so the system is not down for extended periods of time.

Special considerations will need to be made to manage feed stock coming into the WWTP if the WWTP decides to add organic waste to their digester process. WWTP personnel will need to be trained in proper management of receiving, storing, handling, and disposing of organic waste.

3.5 COST-BENEFIT ANALYSIS

This section includes a detailed evaluation of the:

- Estimated costs for design, construction, and operation and maintenance.
- Estimated savings.
- Lifecycle cost and payback analysis.

Alternative 1: Repair Microturbines - Existing Gas Production: Evaluates repairing the two existing microturbines, replacing the gas conditioning skid, which includes new gas compressors, and replacing the third permanently disabled microturbine entirely. This alternative does not consider adding additional organic waste and is based on utilizing the existing digester gas production of 67,000 CF/day.

Alternative 2A: Reciprocating Engines - Existing Gas Production: Evaluates replacing the existing microturbines with reciprocating engine unit configurations for all three vendors considered (Aegis, Tech3Solutions, North East Energy Systems (NES). This alternative does not consider adding additional organic waste and is based on utilizing the existing digester gas production of 67,000 CF/day.

Alternative 2B: Reciprocating Engines - Increased Gas Production: Evaluates replacing the existing microturbines with larger capacity reciprocating engine configurations, within the constraints of the current size of the CHP building, for all three vendors considered (Aegis, Tech3Solutions, North East Energy Systems (NES). This alternative assumes increased gas production based on adding additional septage. We calculated potential gas production increases for each vendor based on engine gas input values and sizing limitations, as detailed in Section 3.5.3.

To evaluate all these alternatives and configurations, this study uses a Net Present Value (NPV) over 20 years approach. The NPV represents the sum of all the money coming in (i.e. savings from electricity and reduced fuel use) and money going out (i.e. capital cost, O&M, and loan repayment). Money coming in will be positive values, while money going out will have negative values. A positive NPV signifies that the economic benefits are higher than the costs for a specific scenario, and hence a positive NPV is desired. If multiple configurations have positive NPVs, the configuration with the highest NPV amount is considered the best. A negative NPV signifies that costs are higher than the economic benefits.

The cost-benefit analysis (CBA) for this study was predicated on a set of common assumptions, which are outlined below. Additionally, the detailed cost-benefit analysis for each of the alternatives is presented in appendices. The assumptions common to all alternatives are:

- Equipment costs include the cost of the reciprocating engines, gas conditioning system (where available from vendor), and any associated WWTP upgrades.
- Recapitalization costs were not included and assumed to be similar for all alternatives.
- System installation costs are estimated to be 35 percent of the equipment costs and do not reflect costs associated with demolition, building construction, heat, or any specialized site/civil or geotechnical design report.

- Electrical and instrumentation costs are estimated to be 15 percent of the equipment costs.
- A construction contingency of 30 percent of the sum of the equipment costs, system installation costs, and electrical and instrumentation costs is included.
- An undefined work items contingency of 25 percent of the sum of the equipment costs, system installation costs, and electrical and instrumentation costs is included.
- A general contractor overhead and profit (OH&P) contingency of 20 percent of the construction subtotal is included.
- Engineering design, construction administration, and resident engineer costs are estimated to be 25 percent of the total construction cost. Note that the engineering design considered here is associated with the final engineering design phase and does not include preliminary engineering design.
- Annual maintenance is based on information from each vendor.
- The value of annual electricity savings is calculated based on continuous operation of the units at their rated kW outputs.
- The value of annual fuel savings is calculated assuming a 141,000 BTU/gallon energy content of #2 fuel oil at a price of $1.842/gallon. This study did not account for an escalator because inflation is included in all the cost - benefit analyses.
- The reduction in kWh from the Grid for removing existing gas compressors is calculated based on continuous operation of the compressors at their rated kW output.
- We assume a conservative inflation rate of 3 percent.
- March 2018 20-City CCI ENR Index = 10,958.78
- Cost estimate accuracy +/- 30 percent
- In providing opinion of probable construction cost, the client understands that the consultant has no control over the cost or availability of labor, equipment or over market conditions or the Contractor’s method of pricing. The consultant makes no warranty, express or implied that the bids will not vary from this estimate.

3.5.1 Alternative 1: Repair Microturbines – Existing Gas Production

To evaluate this alternative, we contacted the current service provider for the microturbines at the WWTP and relied on their knowledge about the system to recommend repairs and upgrades to the microturbines.

Table 3-10 details the equipment needed for this alternative and includes a new gas conditioning skid.

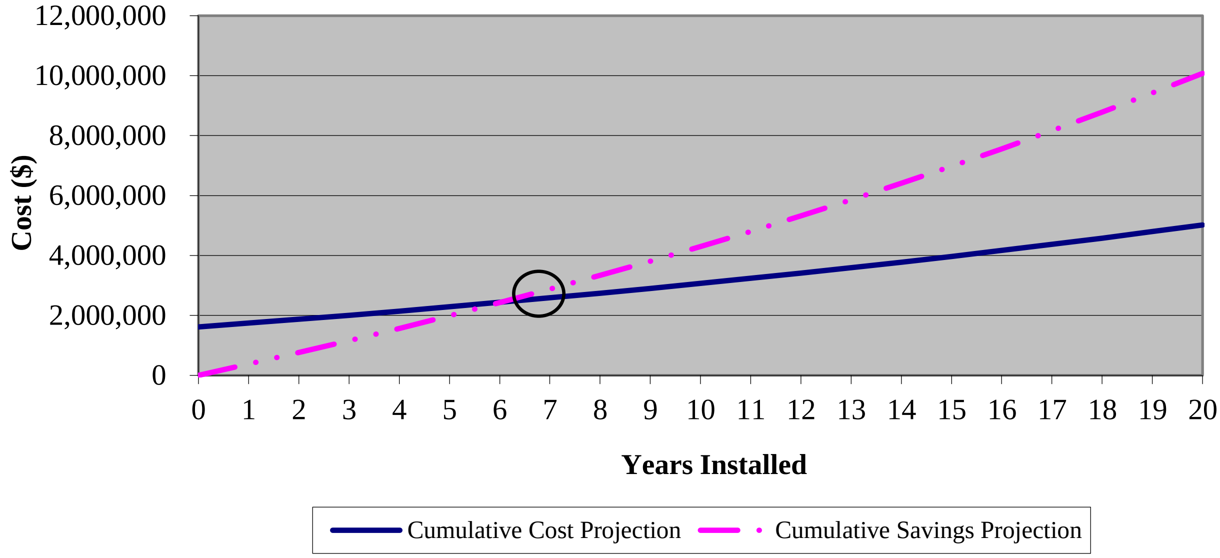
Table 3-10: Equipment Configuration and Cost Table – Alternative 1: Repair Microturbines – Existing Gas Production

Component	Equipment	Cost
Microturbine	One new C-65 powerhead, gasket, ECM IGBT (1)	$46,000
	Repairing two MT (replace igniters, injectors)(1)	$22,000
Gas Skid (3)	Hydrogen Sulfide Removal System	$65,000
	Siloxane removal System	$40,000
	Gas Compression/Moisture Removal System	$250,000
Bleeding valves (2)		$50,000
	Total Equipment Cost	*$473,000*
	Estimated Installation, Ancillary, and Contractor OHP Costs	*$701,000*
	Construction Contingency	*$213,000*
	Engineering Design and Construction Support	*$231,000*
	Total Capital Investment	***$1,600,000***
	Total Annual O&M	***$120,000***
Annual Benefits	Electricity	*$214,000*
	Fuel Savings	*$150,000*

Note: (1) Estimated based on input from City and Vergent.
(2) Engineering estimate
(3) Quote from Unison Solutions

The total capital investment for this alternative is $1.6 million with an estimated annual O&M cost of approximately $120,000. This configuration has a positive NPV value estimated at $3.2 million and an estimated payback period of seven (7) years, as shown below in Figure 3-2. Appendix 4 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this engine configuration.

Figure 3-2: Payback Analysis for Alternative1: Repair Microturbines



3.5.2 Alternative 2A: Reciprocating Engines – Existing Gas Production

To evaluate the reciprocating engine vendors for this alternative, this study developed engine configurations that will meet the current average gas production at the Plant. These configurations consider minimum engine loads, minimum gas production data, and the physical size of the room in the CHP Building 1A where the engines would be installed. For these reasons, Kleinfelder decided to take a modular approach in planning these configurations and allow for both limitations in gas production and expansion of the WWTP. Equipment configurations and the cost associated with all three vendors are shown in Table 3-11.

Table 3-11: Equipment Configuration and Cost Table – Alternative 2A: Reciprocation Engines – Existing Gas Production

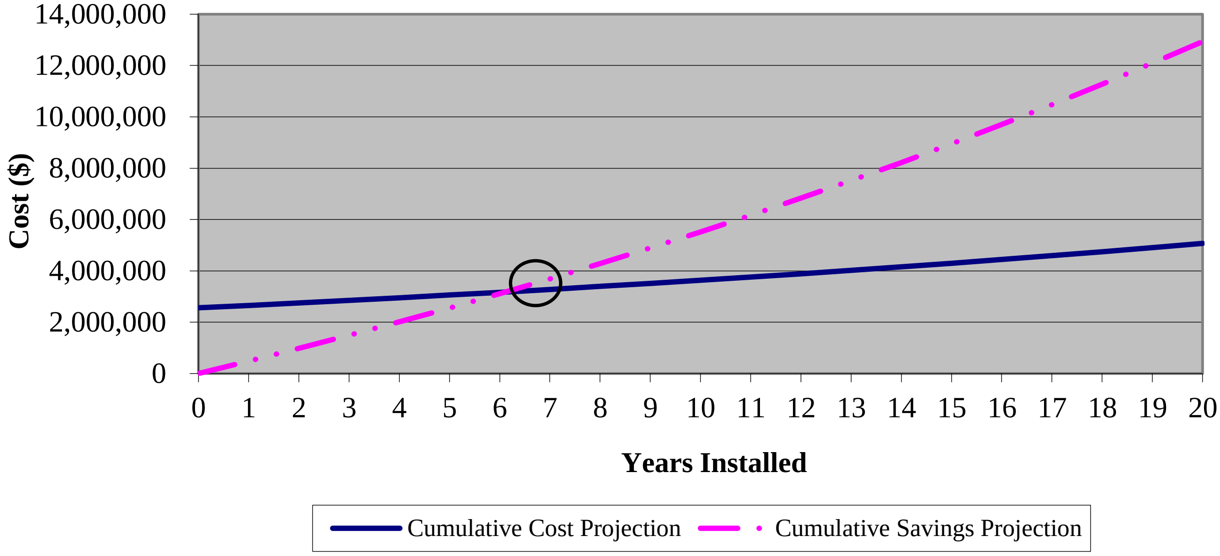
Alternative		**2A.1 - Aegis**	**2A.2 - NES**		**2A.3 – T3S**	
Reciprocating Engine	Size (kW)	75	160	50	150	90
	Units (#)	3	1	1	1	,1
	Cost ($/unit)	-	$401,510	$272,810	$375,000	$285,000
	Run Gas Load	100%	65%	100%	65%	100%
Gas Conditioning Skid	Units (#)	1	1		1	
	Cost ($/unit)	-	$83,040		$100,000	
Total Equipment Cost		*$750,000*	*$810,000*		*$810,000*	
Total Capital Investment		***$2,600,000***	***$2,800,000***		***$2,800,000***	
O&M	Cost ($/hr/unit)	$2.5	$3.7		$3.0	
Total Annual O&M		***$91,000***	***$90,000***		***$77,000***	
Annual benefits	Electricity	$271,000	$193,000		$230,000	
	Fuel	$196,000	$139,000		$197,000	
Net Present Value		***$5,000,000***	***$2,100,000***		***$4,200,00***	

3.5.2.1 Alternative 2A.1 - Aegis Energy Services Reciprocating Engines

The average digester gas production data indicates that enough digester gas is produced to fuel three Aegis 75 kW engines at full load. Under minimum digester gas conditions, one 75kW engine can run at full load, while under maximum digester gas production conditions, the WWTP will have additional digester gas available to potentially store and use during low gas production days. The vendor provided us with a quote of $700,000 for a turn-key solution, which included three engines and a gas conditioning skid. This configuration will generate approximately 1.9 MMWh and 0.9 MMBTU/hr.

The total capital investment for this configuration is $2.6 million, with an estimated annual O&M cost of approximately $91,000. This configuration has a positive NPV value estimated at $5.0 million and an estimated payback period of seven (7) years, as shown in Figure 3-3. Appendix 5 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this engine configuration.

Figure 3-3: Payback Analysis for Alternative 2A.1 - Aegis Reciprocating Engines

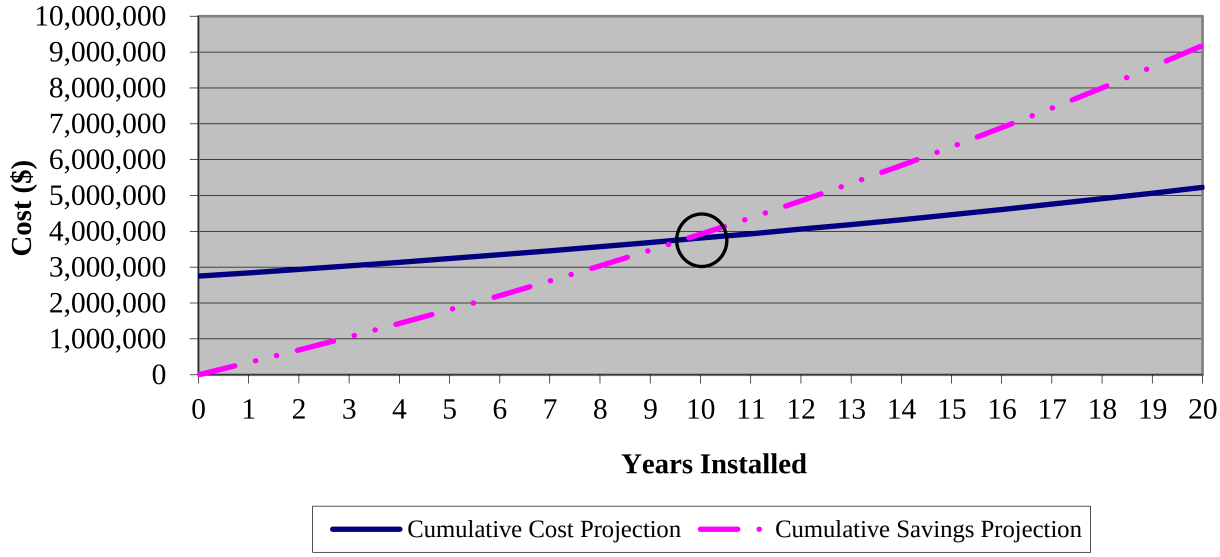


3.5.2.2 Alternative 2A.2 - Northeast Energy Systems (NES) Reciprocating Engines

The average digester gas production data indicates that enough digester gas is produced to fuel one 50kW engine running at full load all the time and one 160kW engine running at 65 percent load all the time. Under minimum digester gas conditions, only the 50kW engine can run at full load, while under maximum digester gas production conditions, both engines will be able to run at full load. This configuration will generate approximately 1.3 MWh and 0.6 MMBTU/hr.

The total capital investment for this configuration is $2.8 million with an estimated annual O&M of $90,000. This configuration has a positive NPV value estimated at $2.1 million and an estimated payback period of 10 years, as shown in Figure 3-4. Appendix 6 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this configuration.

Figure 3-4: Payback Analysis for Alternative 2A.2 - NES Reciprocating Engines



3.5.2.3 Alternative 2A.3 - Tech3Solutions Reciprocating Engines

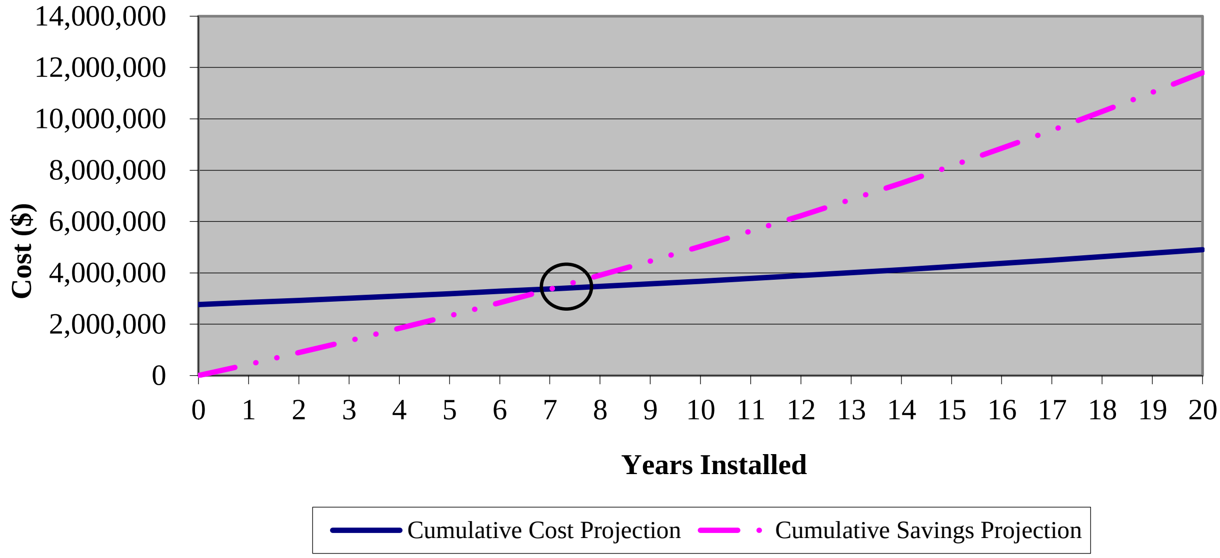
The average digester gas production data indicates that enough digester gas is produced to fuel one 90kW engine at full load and one 150kW engine running at 65 percent load all the time. Under minimum digester gas conditions, only the 90kW engine can run at full load, while under maximum digester gas production conditions, both engines will be able to run at full load. This configuration will generate approximately 1.6 MWh and 0.9 MMBTU/hr.

Tech3Solutions does not provide gas conditioning skids and our efforts to get a quote from a skid vendor yielded no results. Using information from other reciprocating vendors and our engineering judgement, Kleinfelder estimated the cost for a gas conditioning skid to be $100,000. We used this estimate in the CBA for Tech3Solutions.

The total capital investment for this configuration is $2.8 million, with an estimated annual O&M of $77,000. This configuration has a positive NPV value estimated at $4.2 million and an estimated payback period of eight (8) years, as shown in

Figure 3-5. Appendix 7 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this configuration.

Figure 3-5: Payback Analysis for Alternative 2A.3 - Tech3Solutions Reciprocating Engines



3.5.2.4 Summary of Cost-Benefit Analysis for Alternatives 1 and 2A

Table 3-12 shows a side-by-side comparison of the costs and savings for Alternative 1 and each of the three configurations evaluated for Alternative 2A. Keeping the microturbine technology and making the necessary repairs and upgrades – Alternative 1– has a lower initial capital investment cost than replacing the microturbines with reciprocating engines – Alternative 2A. The annual O&M costs are higher for Alternative 1 ($120,000) than the annual O&M costs for Alternative 2 ($77,000 to $91,000).

Because the two alternatives are comparable when looking at the net present values, estimated payback periods, operation and maintenance costs, electricity and fuel savings, and reduction in sludge heating requirements, we recommend replacing the microturbine technology and the existing gas conditioning skid with reciprocating engines and a new gas conditioning skid. This recommendation is based on the premise that new reciprocating engines and a gas preconditioning skid will ensure an operational CHP system, and on the knowledge that the WWTP is more comfortable operating reciprocating engines.

Table 3-12: Opinion of Probable Cost and Overall Benefits Summary for Alternative 1 and Alternative 2A

Alternative	1- Microturbines	2A.1 - Aegis	2A.2 - NES	2A.3 – T3S
Units	**Three C-65 kW MT**	**Three 75kW**	**One 160kW One 50kW**	**One 150 kW One 90kW**
Total Capital Investment Cost	$1,600,000	$2,600,000	$2,800,000	$2,800,000
Total Annual O&M Cost	$120,000	$91,000	$90,000	$77,000
Annual Electricity Savings	$214,000	$271,000	$193,000	$230,000
Annual Fuel Savings	$150,000	$196,000	$139,000	$197,000
Reduction in Electric Utility Bill	28%	35%	25%	30%
Reduction in Sludge Heating Requirements	53%	76%	49%	76%
Net Efficiency (1)	45%	70%	58%	85%
Net Present Value (2)	**$3,200,000**	**$5,000,000**	**$2,100,000**	**$4,200,000**
Estimated Payback Period	**7 years**	**7 years**	**10 years**	**8 years**

Notes:

(1) Heat and electricity output versus digester gas input. Estimated value for the units only, not the overall CHP system. Excludes heat lost through pipes (6 percent) and heating needs for the digester (122,155 BTU/hr). For microturbines, it includes the parasitic load associated with the gas compressor.

(2) Over the 20-year life time of the equipment

3.5.3 Alternative 2B: Reciprocating Engines – Increased Gas Production

To evaluate the reciprocating engine vendors for this alternative, this study evaluated engine configurations that will maximize the number of units that can fit into the existing space at the WWTP and determined the maximum amount of digester sludge and digester gas production that can be utilized by the CHP systems. We assumed the increased gas production to be a result of adding organic waste. The engine configurations for this alternative build on the configurations for Alternative 2A and include the cost associated with the disposal of additional sludge. We decided to take a modular approach in designing these configurations and allow for limitations in digester capacity and expansion of the WWTP. Equipment configurations and the cost associated with all three vendors are shown in Table 3-13.

Table 3-13: Equipment Configuration and Cost Table – Alternative 2B: Reciprocating Engines – Increased Gas Production

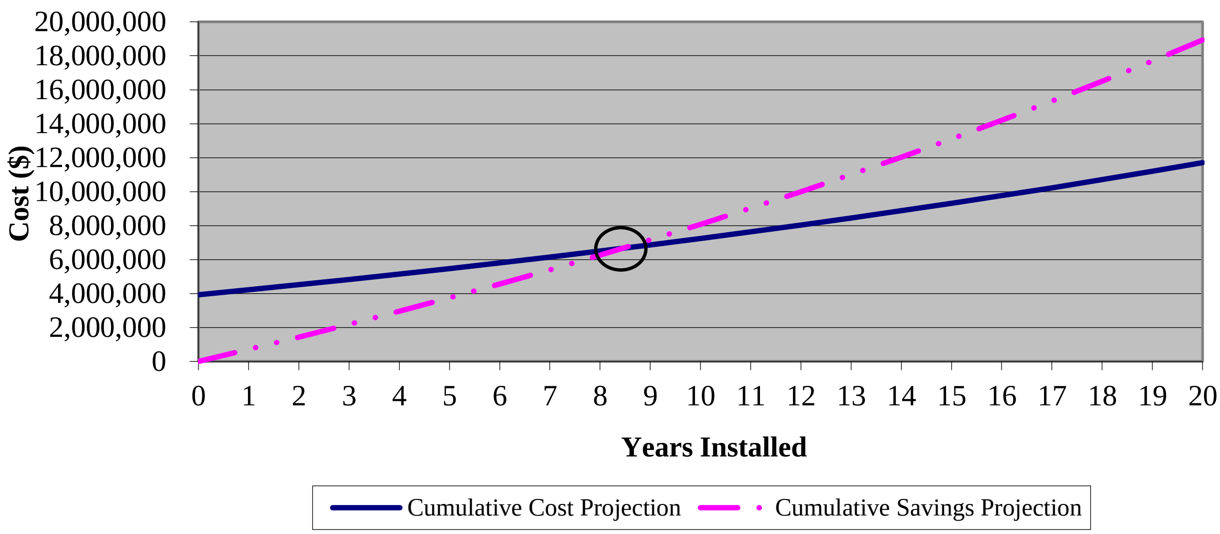
Alternative		**2B.1 - Aegis**	**2B.2 - NES**		**2B.3 – T3S**	
Reciprocating Engine	Size (kW)	75	160	50	150	90
	Units (#)	5	2	1	2	1
	Cost ($/unit)	$200,000	$401,510	$272,810	$375,000	$285,000
	Run Gas Load	100%	65%	100%	65%	100%
Gas Conditioning Skid	Units (#)	1	1		1	
	Cost ($/unit)	$100,000	$83,040		$100,000	
Total Equipment Cost		*$1,150,000*	*$1,200,000*		*$1,200,000*	
Total Capital Investment		***$3,900,000***	***$4,100,000***		***$4,000,000***	
O&M	Cost ($/hr/unit)	$2.5	$3.7		$3.0	
Total Annual O&M		***$281,000***	***$424,000***		***$331,000***	
Annual benefits	Electricity	$435,000	$430,000		$450,000	
	Fuel	$250,000	$230,000		$290,000	
Net Present Value		***$4,100,000***	***$600,000***		***$4,200,000***	

3.5.3.1 Alternative 2B.1 - Aegis Energy Services Reciprocating Engines

The maximum number of Aegis 75 kW units that can fit in the space available is five. This configuration will generate approximately 3.2 MWh and 1.5 MMBTU/hr and can provide an additional of 0.2 to 0.8 MMBTU of heat to be used for other demands at the Plant.

The total capital investment is $3.9 million, with an estimated annual O&M cost of approximately $281,000. This configuration has a positive NPV value estimated at $4.1 million and an estimated payback period of nine (9) years, as shown in Figure 3-6. Appendix 8 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this engine configuration.

Figure 3-6: Payback Analysis for Alternative 2B.1 - Aegis Reciprocating Engines

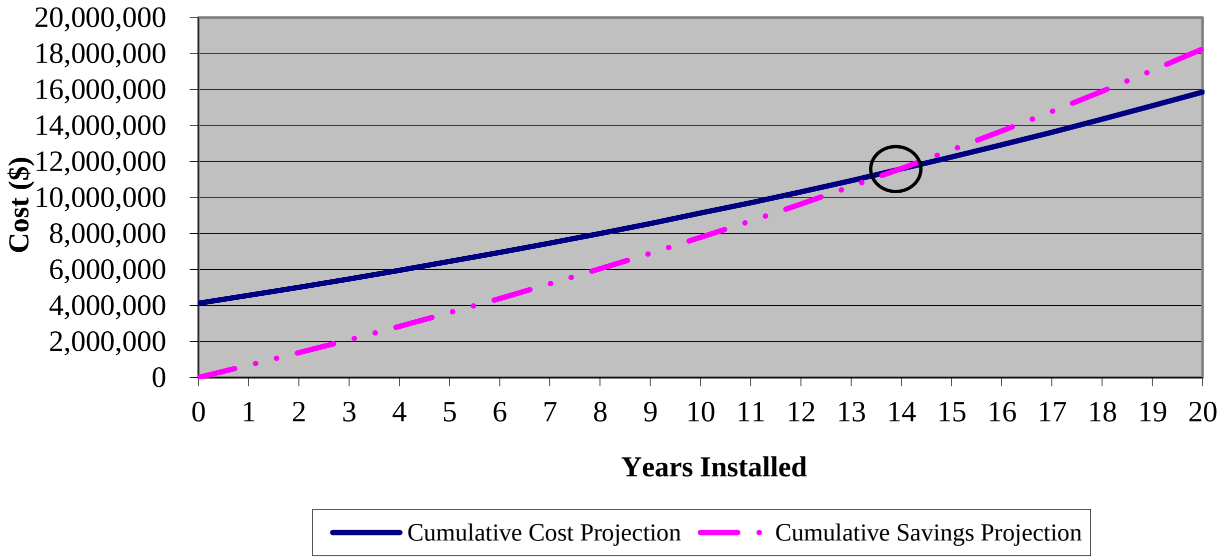


3.5.3.2 Alternative 2B.2 - Northeast Energy Systems (NES) Reciprocating Engines

The maximum number of NES units that can fit in the space available is three. Kleinfelder evaluated a configuration consisting of one 50kW and two 160kW units. This configuration will generate approximately 3.2 MWh and 1.3 MMBTU/hr, which is not enough heat to meet the winter sludge heating demands of 1.7 MMBTU/hr.

The total capital investment is $4.1 million with an estimated annual O&M cost of approximately $424,000. This configuration has a positive NPV value estimated at $600,000 and an estimated payback period of 14 years, as shown in Figure 3-7. Appendix 9 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this engine configuration.

Figure 3-7: Payback Analysis for Alternative 2B.2 - NES Reciprocating Engines

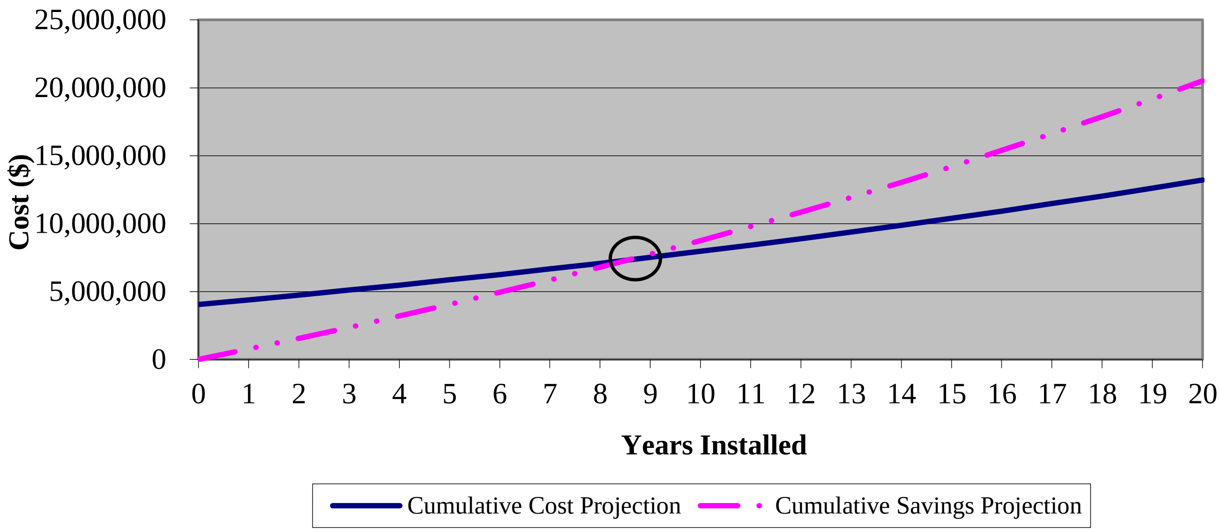


3.5.3.3 Alternative 2B.3 - Tech3Solutions Reciprocating Engines

The maximum number of Tech3Solutions units that can fit in the space available is three. Kleinfelder evaluated a configuration consisting of one 90kW and two 160kW units. This configuration will generate approximately 3.4 MWh and 1.9 MMBTU/hr and can provide an additional of 0.4 to 1.1 MMBTU of heat to be used for other demands at the Plant.

The total capital investment is $4.0 million with an estimated annual O&M cost of approximately $331,000. This configuration has a positive NPV value estimated at $4.2 million and an estimated payback period of nine (9) years, as shown in Figure 3-8. Appendix 10 details the cost estimates based on our assumptions and calculations of electricity and heating benefits for this engine configuration.

Figure 3-8: Payback Analysis for Alternative 2B.3 - Tech3Solutions Reciprocating Engines



3.5.3.4 Summary of Cost-Benefit Analysis for Alternative 2B – Reciprocating Engines – Increase Gas Production

The addition of organic waste to the anaerobic digest at the WWTP will increase the digester gas production, which in turn can be used by the CHP system to generate more heat and electricity. To maximize the increased gas production input to the CHP system, the WWTP will need to increase the number of reciprocating engine units for each of the three configurations evaluated in Alternative 2A.

Table 3-14 shows a side-by-side comparison of the costs and savings for each of the three configurations we evaluated for Alternative 2B.

Increasing the size of the CHP system using reciprocating engines has a positive net present value range of $0.6 to $4.2 million and a relatively short estimated payback period of nine (9) to fourteen (14) years. For these two reasons, the WWTP should consider adding organic waste to their operations in the future.

Table 3-14: Opinion of Probable Cost and Overall Benefits Summary for Alternative 2B – Reciprocating Engines – Increased Gas Production

Alternative	2B.1 - Aegis	2B.2 - NES	2B.3 – T3S
Total Capital Investment	$3,900,000	$4,100,000	$4,000,000
Total Annual O&M	$281,000	$424,000	$331,000
Sludge Disposal Volume Increase (tons/year)	1,500	3,100	2,300
Annual Electricity Savings	$435,000	$430,000	$450,000
Annual Fuel Savings	$250,000	$230,000	$290,000
Increased Biogas Production (million CF/year)	16.3	33.2	24.8
Reduction of Electric Utility Bill	56%	56%	59%
Reduction in Sludge Heating Requirements	120%	80%	120%
Reduction in Digester Heating Requirements	110%	75%	110%
Net Present Value	**$4,100,000**	**$600,000**	**$4,200,000**
Estimated Payback Period	**9 years**	**14 years**	**9 years**

4 RECOMMENDED ALTERNATIVES

4.1 ALTERNATIVE 2 – REPLACE MICROTURBINES WITH RECIPROCATING ENGINES

The intent of this study is to identify ways to make the CHP system operational again and potentially increase the digester gas production by adding organic waste to the anaerobic digester at the WWTP. Although improvements to the current CHP system can be made, they represent a major capital investment and, therefore, taking a holistic view of other CHP technologies is warranted.

Our recommendation is predicated on a cost-benefit analysis of the alternatives as well as other non-cost factors. The cost-benefit analysis utilizes NPV and simple payback to represent the preferred alternative from an investment perspective. Non-cost factors considered include the following:

- Requirements for fuel gas quality and feed pressure
- Owner confidence in technology
- Performance history of equipment as learned through interviews of other operators

Based on our review of cost and non-cost factors, we recommend the City replace the current microturbines with reciprocating engines (Alternative 2). Further, we recommend that the existing fuel pre-treatment skid be decommissioned, salvaged, and replaced with a new gas conditioning skid engineered specifically for operation with reciprocating engines.

With an operational CHP system, the WWTP can consider adding organic waste to their digester, as they have available capacity. Additional 75kW reciprocating engines can be installed in the future when the sludge capacity at the WWTP demands it. Currently, a total of five Aegis 75 kW units can fit in the CHP Building.

4.2 ALTERNATIVE 4 – SEPTAGE, SSO, AND FOG

The current available capacity for additional digester feedstock is approximately 57,000 GPD. Alternative 4 compared the addition of septage, SSO and FOG, presented in three Scenarios described in Section 3.1.4. Based on our assessment, septage is the preferred feedstock for the following reasons:

- Septage is readily available near the WWTP. The City would need to decrease its tipping fee for septage to be more cost-competitive with nearby facilities and increase its septage volume.
- The WWTP is already designed to receive and accept septage at the headworks of the WWTP.
- Septage is introduced to the liquid stream and, in the right quantities, is not anticipated to significantly affect the existing wastewater treatment process.
- Both SSO and FOG are fed directly to the digesters and not the liquid stream process. Because digesters do not respond well to variable feedstock quality and rate, both SSO and FOG will require some additional capital investment for processing, storage, mixing, and potentially heating of the material prior to introduction into the digester.

The maximum daily septage acceptable to the WWTP without negatively affecting the treatment process or its operations was not determined and is outside the scope of this study. We recommend that the WWTP methodically increase its septage intake over time and monitor treatment performance.

4.3 RELOCATE THE EXISTING POWER RELAY

We recommend relocating the existing power relay from its current location to accommodate an efficiently running CHP system and the possible future addition of organic waste. The relocation can be done with other major electrical work during the proposed major upgrades at the WWTP.

5 ASSESSMENT OF FINANCING METHODS

5.1 IDENTIFY ALTERNATIVES

Several alternative methods for supplementing the financing of the design and construction phases of the given recommendations, as described in Section 4, have been identified. These alternative financing methods include federal and state grants, loans, and environmental offset credits. It is assumed that these alternative financing methods could be used in conjunction with more typical funding approaches such as municipal bonds, sewer banks, or leasing options. These typical funding options are not discussed in further detail in this technical study.

Alternative financing methods, organized by the funding agency, that will be evaluated herein include the following:

- Massachusetts Department of Environmental Protection (MassDEP)
    - Sustainable Materials Recovery Program Municipal Grants
    - Gap Funding Grant Program
    - State Revolving Fund Loan Program
- Massachusetts Department of Energy Resources (MassDOER)
    - Renewable Energy Portfolio Standard
    - Alternative Energy Portfolio Standard
- U.S. Department of Energy (DOE)
    - Energy Independence and Security Act, Section 471, Subtitle F
    - Energy Policy Act of 2005, Title XVII, Innovative Clean Energy Projects Loan
    - Flexible Combined Heat and Power for Grid Reliability and Resiliency
- Massachusetts Clean Energy Center (MassCEC)
    - Commonwealth Organics-to-Energy Program

5.2 EVALUATE ALTERNATIVES

Further detail and evaluation of the financing alternatives is provided below.

<u>MassDEP</u>

- *Sustainable Materials Recovery Program (SMRP) Municipal Grants, Section Eight: Waste Reduction and Organics Capacity Projects*

  Funding is available to municipalities for organics capacity development, with grant amounts ranging from $10,000 to $250,000. MassDEP accepts applications annually between April and June, with current deadline of June 13, 2018. Applicants are required to have a Buy Recycled Policy in place, complete Municipal Recycling and Solid Waste Surveys for the past two calendar years and have recycling available in all municipal buildings. This project may not qualify, as the organics entering the anaerobic digester are not source-separated. A more detailed assessment would be needed to determine if this project would be a candidate for this grant funding.

- *Gap Funding Grant Program, Clean Energy Results Program (CERP)*
  MassDEP, in partnership with the Massachusetts Department of Energy Resources and the Massachusetts Clean Energy Center, is offering grants for projects that save energy and generate clean energy. Though this project has been discussed with MassDEP with the potential to remove the units and replace them with reciprocating engines, a more detailed assessment would be needed to complete a successful application and secure funding.

- *State Revolving Fund (SRF) Loan Program*
  The Clean Water SRF (CWSRF) Program, which competitively provides low-interest loans to helps municipalities meet water quality requirements, may offer funding in order to integrate renewable energy and energy conservation, including digester gas use, for power and/or heat. A more detailed assessment would be needed to determine if this project meets the CWSRF program's renewable energy component. MassDEP accepts applications on an annual basis, and awards are a maximum of $50 million per applicant.

MassDOER

- *Renewable Energy Portfolio Standard (RPS) (225 CMR 14.00)*
  MassDOER adopted regulations known as the Renewable Energy Portfolio Standard (RPS) that creates an incentive for retail electricity suppliers to purchase Renewable Energy Certificates (RECs) as part of their overall energy portfolio. Each REC corresponds to one (1) megawatt hour (MWh) of electricity produced from a renewable energy source. By 2020, suppliers must purchase an amount of RECs equivalent to 15 percent of the total electricity they serve in the state. Since anaerobic digester gas is specifically listed as a qualifying renewable energy source under RPS Class I, this project may allow the WWTP to be a REC-generating facility if it meets other eligibility criteria. This would generate revenue, though a more detailed assessment would be needed to confirm this project is eligible and an application to MassDOER would be approved. The WWTP's photovoltaic field is currently a Qualified Generation Unit under this program.

- *Alternative Energy Portfolio Standard (APS)*
  Separate from but designed to complement the RPS program, MassDOER's Alternative Energy Portfolio Standard (APS) was established to incentivize alternative energy systems that increase energy efficiency and reduce the need for fossil fuel-based power generation. The APS requires that 5 percent of an electricity supplier's retail sales must come from alternative energy sources by 2020, with the annual percentage requirements increasing by 0.25 percent per year indefinitely. Similar to the RPS program, suppliers must purchase Alternative Energy Certificates (AECs) from qualified generation units. CHP systems that use biomass or biogas may qualify as a Renewable Thermal Generation Unit (RTGU) and may qualify as both an RPS and an APS generator, allowing them to earn revenue in one of two ways. A more detailed assessment would be needed to determine the optimal method for this project to earn revenue through the APS and/or RPS, and to confirm the CHP system will meter data as required by MassDOER.

U.S. Department of Energy (DOE)

- *Energy Independence and Security Act (EISA) of 2007, Section 471, Subtitle F*
  This section of EISA details funding mechanisms for energy sustainability and energy efficiency projects. Grants are available for efficiency improvement and energy sustainability (up to $1 million) and innovation in energy sustainability (up to $50,000). A more detailed assessment would be needed to determine if this project qualifies under this program by meeting criteria relating to: improvement in energy efficiency, reduction in greenhouse gas emissions, increase use of renewable or thermal energy sources, reduction in fossil fuel use, and need for funding assistance.

- *Energy Policy Act of 2005 (EPAct), Title XVII, Innovative Clean Energy Projects Loan*
  Loan guarantees are provided in response to open technology-specific solicitations, one of which is currently a Renewable Energy & Efficiency Energy (REEE) Projects Solicitation. Up to $4.5 billion is available to finance projects that employ innovative and renewable or efficient energy technologies. A more detailed assessment would be needed to determine if this project would comply with this loan program's renewable energy and efficiency requirements.

- *Flexible Combined Heat and Power for Grid Reliability and Resiliency, Office of Energy Efficiency and Renewable Energy (EERE)*

This grant opportunity provides funding in amounts between $1-1.5 million for projects that further the utilization of cost-effective, highly efficient CHP systems, specifically those designed to provide cost-effective support to the electric grid. A more detailed assessment would be needed to determine whether this project would enable the City to sell electricity and serve as stabilizing factor, which are requirements of the grant, which has a cost sharing requirement. Additionally, this project would not meet this grant's current deadline of May 10, 2018.

MassCEC

- *Commonwealth Organics-to-Energy Program, Implementation*
  This grant program offers funding for projects that transform certain wastes into renewable electricity or heat, including the development of facilities that convert sewage sludge into heat or electricity. Projects must be located within the service territory of electric distribution companies that pay into the MA Renewable Energy Trust Fund, and applications are reviewed on a rolling basis with no current deadline. Grant amounts for project implementation are up to $500,000 per applicant, with cost-share requirements.

5.3 REVIEW EFFECT OF DIFFERENT APPROACHES

Multiple federally- or state-funded grant and loan opportunities exist for the City to further investigate. These financing methods could potentially leverage the costs of the engineering and construction phases. The sale of RECs or AECs, which could occur once the CHP system were to operate successfully, could potentially generate annual revenue to offset the construction and/or operation and maintenance costs of the system as well. All options require further analysis to determine if the City and this CHP system would fit the eligibility criteria, and whether a loan, grant, and/or sale of energy would be preferable with the City's current financial status. Further economic analyses are also recommended for any preferred financing methods, using conservative assumptions regarding potential grant and revenue amounts.

6 RECOMMENDED NEXT STEPS

6.1 SUMMARY OF RECOMMENDATIONS

This study concluded that replacing the microturbines and gas conditioning skid with reciprocating engines and a new gas conditioning skid is preferred.

Additional improvements considered by this study include the following:

- Automate the gas condensate control valves – Automating the gas condensate control valves is a relatively low capital investment and will greatly improve operations. This improvement will more effectively remove water content from the digester gas before the fuel treatment skid. It will also reduce the manual labor required to exercise the control valves.
- Remove gas compressors – Reciprocating engines do not require additional compression of the fuel gas. Therefore, the new gas conditioning skid will not require compressors.

This study also evaluated the cost-benefit of adding supplemental feedstock to the anaerobic digester to produce additional digester gas and increase the CHP output. This study recommended septage as the preferred feedstock source. Septage is readily available, the WWTP is already set up to receive septage, and the City would increase revenue from septage tipping fees.

6.2 IMPLEMENTATION PHASING

We recommend that the City phase the implementation of these recommendations.

<u>Phase 1: Technology Replacement</u>

First, the City should concentrate on replacing the gas conditioning skid and CHP equipment. In addition, the City should proceed with automating the gas condensate control valves. To complete this initial improvement, the City should complete the following:

- ***Perform a Digester gas sample analysis* –** The last gas sample analysis dates to 2007, and the composition of wastewater has significantly changed since then with the increase of personal care products use. All the vendors we contacted recommended a new digester gas sample analysis before actual equipment design and construction. To move forward and start a preliminary design study to make the CHP system operational again, the WWTP needs a new digester gas sample analysis.

- ***Leverage funding opportunities for Design and Construction*** – In light of the City's unrelated ongoing and planned projects for the WWTP and other City-owned assets, we recommend the City evaluate future funding and budgets to determine when funding is available. The City should also confirm whether they are eligible for the various grants and loans outlined in Section 5. We recommend the City also consider whether the sale of RECs or AECs to generate revenue is a process they would like to get involved in; if so, they should begin the application and approval process once funding for the CHP work is appropriated or otherwise becomes available.

- ***Complete Design and Construction*** – for replacing the gas conditioning skid and the CHP equipment, which will make the CHP system operational again.

<u>Phase 2: Optimization</u>

Once the City has proven through operational experience that the CHP system operates reliably, and the operations staff are comfortable with the operation and maintenance of the system, then the City could contemplate additional improvements. These include:

- ***Perform a detailed cost-benefit analysis for relocating the Reverse Power Relay -*** Using electricity output data from the operational CHP system, the City can determine the economic impact of not relocating the Reverse Power relay. The cost-benefit analysis will consider the cost of electricity bought from the grid when the CHP system will be shut down by the current location of the Reverse Power relay.

- ***Perform an evaluation to establish a septage tipping fee –*** Septage receiving could be a viable option to increase the CHP system output, but the rate should be decreased from its current value of $121/1,000 gallons to something that is more competitive with other WWTPs. The WWTP can reduce its rate to $100 or perform a simple economic analysis to determine what the most competitive rate would be. The economic benefit of septage receiving should consider revenue from tipping fees, costs of upgrades needed for the septage receiving area, additional O&M and labor considerations, and rates from other WWTPs.

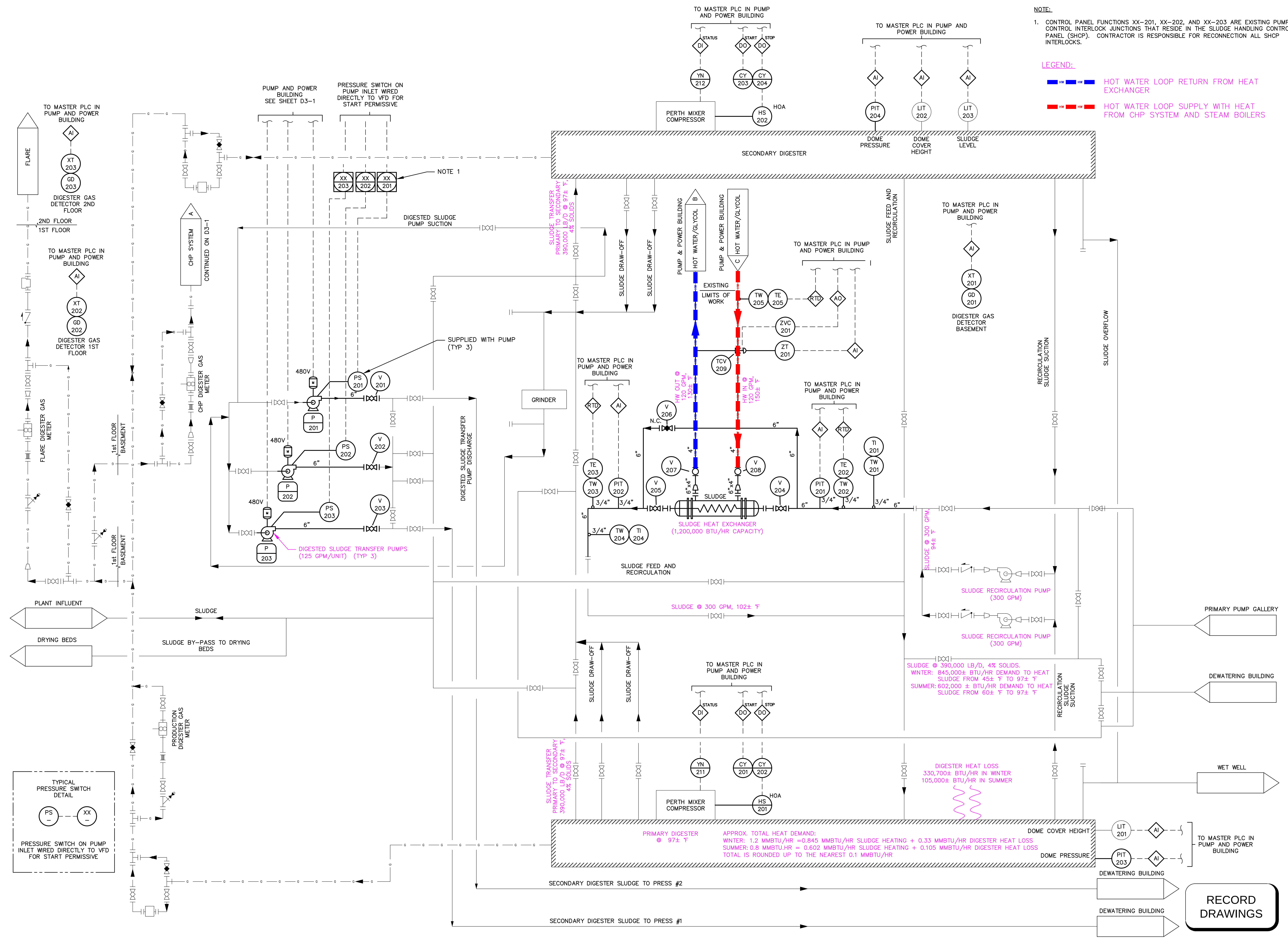
- ***Add additional septage to the WWTP –*** As indicated in this study, septage has the potential to generate additional revenue for the City and increase digester gas. The City should slowly increase the septage added to the WWTP and monitor treatment performance, financial metrics and logistics associated with additional truck traffic at the WWTP.

- ***Monitor for other opportunities for digester feedstock –*** While septage is presently considered the best feedstock to increase digester gas production, the City should remain aware of other feedstock options that are available in the area. For instance, Divert Inc., was identified as a company that is looking to site a SSO pre-processing facility near Pittsfield. If such as facility came online, then the City may have a good opportunity to consider a SSO amendment to the digester.

- ***Organic waste pilot studies –*** Small scale pilot studies should be performed to determine the impact of adding specific high-strength organic wastes to anaerobic digesters and to identify operational needs. As WWTP operators are reluctant to add anything in that might upset the current digestion process, a pilot study that is tailored to the operational ranges in Pittsfield might help understand the process better and identify limits and optimal operational parameters.

- ***Uses for additional heat –*** The addition of organic waste will result in more heat output from the CHP system than the WWTP needs to heat the sludge, especially in the summer months. The City should evaluate using the additional heat for other needs at the WWTP, for example air conditioning or hot water station for vehicle washing.

Appendix 1: Piping and Instrumentation Diagram



NOTE:

1. CONTROL PANEL FUNCTIONS XX-201, XX-202, AND XX-203 ARE EXISTING PUMP CONTROL INTERLOCK JUNCTIONS THAT RESIDE IN THE SLUDGE HANDLING CONTROL PANEL (SHCP). CONTRACTOR IS RESPONSIBLE FOR RECONNECTION ALL SHCP INTERLOCKS.

LEGEND:

HOT WATER LOOP RETURN FROM HEAT EXCHANGER

HOT WATER LOOP SUPPLY WITH HEAT FROM CHP SYSTEM AND STEAM BOILERS

RECORD DRAWINGS

SEA
SEA CONSULTANTS INC.
Scientists/Engineers/Architects

Scale	AS NOTED		
Date	10/28/09		
Job No.	2009121		
Designed by	LJT		
Drawn by	LJT	1	RECORD DRAWINGS 08/16/11
Checked by	JMF	No.	Description / Date
Approved by	MAN		REVISIONS

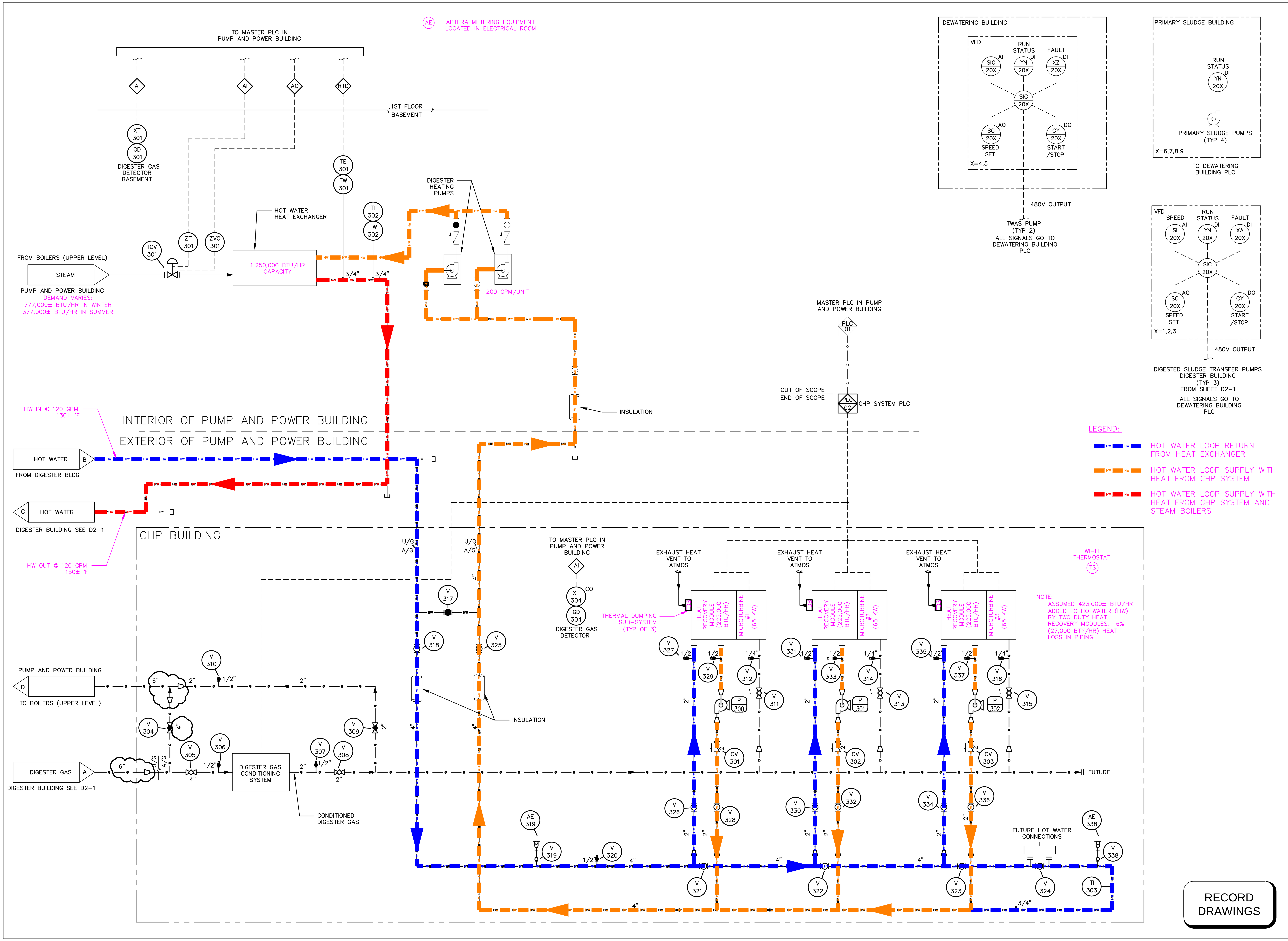
Client: CITY OF PITTSFIELD

Project: WWTP CHP FINAL DESIGN

Drawing: PIPING AND INSTRUMENTATION DIAGRAM DIGESTER BUILDING

Sheet: D2-1

PLOT DATE=12/14/2015 4:23:46 PM USER=JASON TANG FILENAME=I:_clients\Pittsfield MA\2009121.01 - WWTP CHP Final Design\Drawings\P&ID\D2-20151210.dwg



RECORD DRAWINGS

SEA CONSULTANTS INC.
Scientists/Engineers/Architects

No.	Description	Date
2	RECORD DRAWINGS	08/16/11
1	REVISED PIPE SIZES	12/02/09

REVISIONS

Scale	AS NOTED
Date	10/28/09
Job No.	2009121
Designed by	LJT
Drawn by	LJT
Checked by	JMF
Approved by	MAN

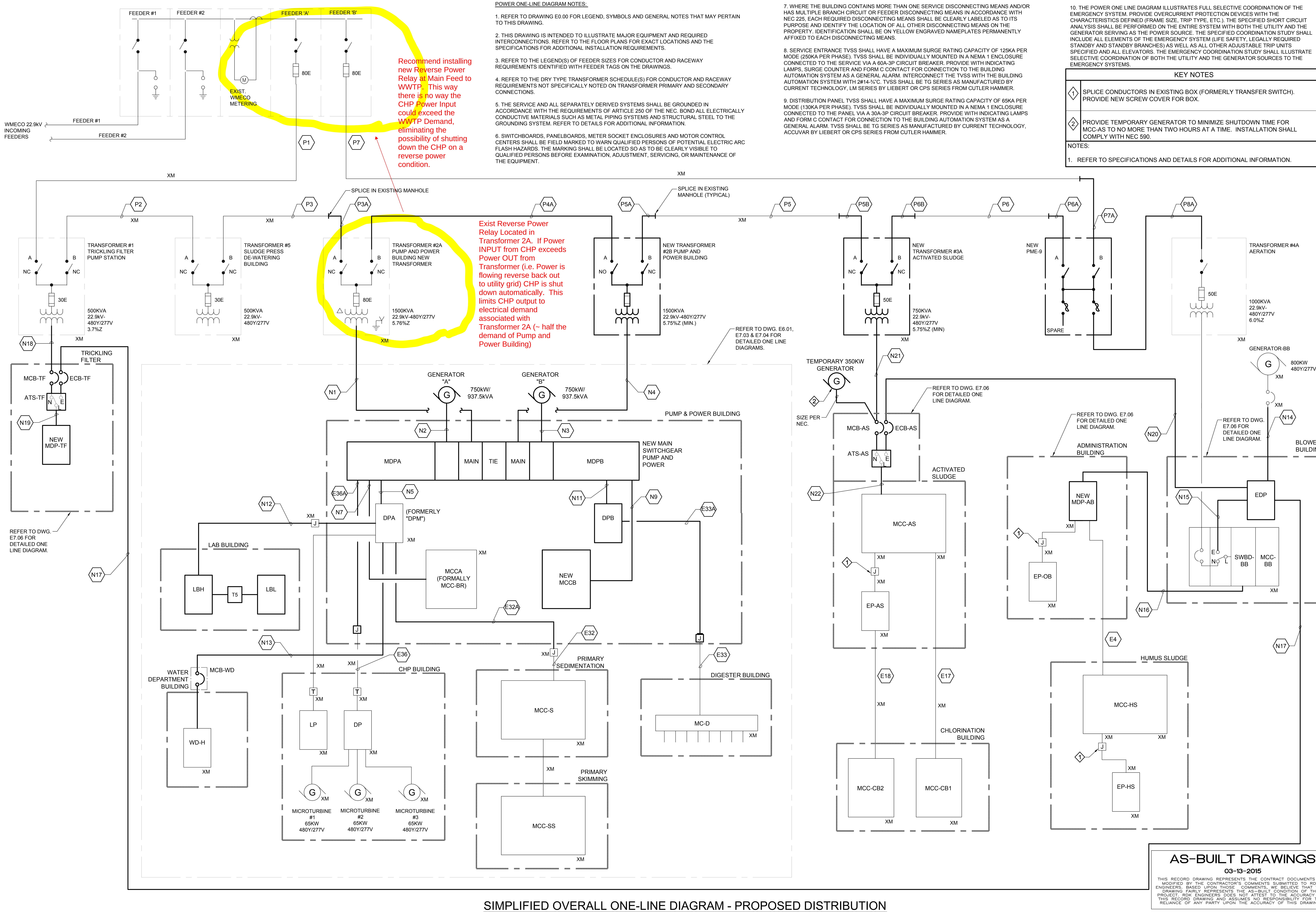
Client: CITY OF PITTSFIELD

Project: WWTP CHP FINAL DESIGN

Drawing: PIPING AND INSTRUMENTATION DIAGRAM CHP AND PUMP AND POWER BUILDINGS

Sheet: D3-1

Appendix 2: Reverse Power Relay



POWER ONE-LINE DIAGRAM NOTES:

1. REFER TO DRAWING E0.00 FOR LEGEND, SYMBOLS AND GENERAL NOTES THAT MAY PERTAIN TO THIS DRAWING.

2. THIS DRAWING IS INTENDED TO ILLUSTRATE MAJOR EQUIPMENT AND REQUIRED INTERCONNECTIONS. REFER TO THE FLOOR PLANS FOR EXACT LOCATIONS AND THE SPECIFICATIONS FOR ADDITIONAL INSTALLATION REQUIREMENTS.

3. REFER TO THE LEGEND(S) OF FEEDER SIZES FOR CONDUCTOR AND RACEWAY REQUIREMENTS IDENTIFIED WITH FEEDER TAGS ON THE DRAWINGS.

4. REFER TO THE DRY TYPE TRANSFORMER SCHEDULE(S) FOR CONDUCTOR AND RACEWAY REQUIREMENTS NOT SPECIFICALLY NOTED ON TRANSFORMER PRIMARY AND SECONDARY CONNECTIONS.

5. THE SERVICE AND ALL SEPARATELY DERIVED SYSTEMS SHALL BE GROUNDED IN ACCORDANCE WITH THE REQUIREMENTS OF ARTICLE 250 OF THE NEC. BOND ALL ELECTRICALLY CONDUCTIVE MATERIALS SUCH AS METAL PIPING SYSTEMS AND STRUCTURAL STEEL TO THE GROUNDING SYSTEM. REFER TO DETAILS FOR ADDITIONAL INFORMATION.

6. SWITCHBOARDS, PANELBOARDS, METER SOCKET ENCLOSURES AND MOTOR CONTROL CENTERS SHALL BE FIELD MARKED TO WARN QUALIFIED PERSONS OF POTENTIAL ELECTRIC ARC FLASH HAZARDS. THE MARKING SHALL BE LOCATED SO AS TO BE CLEARLY VISIBLE TO QUALIFIED PERSONS BEFORE EXAMINATION, ADJUSTMENT, SERVICING, OR MAINTENANCE OF THE EQUIPMENT.

7. WHERE THE BUILDING CONTAINS MORE THAN ONE SERVICE DISCONNECTING MEANS AND/OR HAS MULTIPLE BRANCH CIRCUIT OR FEEDER DISCONNECTING MEANS IN ACCORDANCE WITH NEC 225, EACH REQUIRED DISCONNECTING MEANS SHALL BE CLEARLY LABELED AS TO ITS PURPOSE AND IDENTIFY THE LOCATION OF ALL OTHER DISCONNECTING MEANS ON THE PROPERTY. IDENTIFICATION SHALL BE ON YELLOW ENGRAVED NAMEPLATES PERMANENTLY AFFIXED TO EACH DISCONNECTING MEANS.

8. SERVICE ENTRANCE TVSS SHALL HAVE A MAXIMUM SURGE RATING CAPACITY OF 125KA PER MODE (250KA PER PHASE). TVSS SHALL BE INDIVIDUALLY MOUNTED IN A NEMA 1 ENCLOSURE CONNECTED TO THE SERVICE VIA A 60A-3P CIRCUIT BREAKER. PROVIDE WITH INDICATING LAMPS, SURGE COUNTER AND FORM C CONTACT FOR CONNECTION TO THE BUILDING AUTOMATION SYSTEM AS A GENERAL ALARM. INTERCONNECT THE TVSS WITH THE BUILDING AUTOMATION SYSTEM WITH 2#14-¾"C. TVSS SHALL BE TG SERIES AS MANUFACTURED BY CURRENT TECHNOLOGY, LM SERIES BY LIEBERT OR CPS SERIES FROM CUTLER HAMMER.

9. DISTRIBUTION PANEL TVSS SHALL HAVE A MAXIMUM SURGE RATING CAPACITY OF 65KA PER MODE (130KA PER PHASE). TVSS SHALL BE INDIVIDUALLY MOUNTED IN A NEMA 1 ENCLOSURE CONNECTED TO THE PANEL VIA A 30A-3P CIRCUIT BREAKER. PROVIDE WITH INDICATING LAMPS AND FORM C CONTACT FOR CONNECTION TO THE BUILDING AUTOMATION SYSTEM AS A GENERAL ALARM. TVSS SHALL BE TG SERIES AS MANUFACTURED BY CURRENT TECHNOLOGY, ACCUVAR BY LIEBERT OR CPS SERIES FROM CUTLER HAMMER.

10. THE POWER ONE LINE DIAGRAM ILLUSTRATES FULL SELECTIVE COORDINATION OF THE EMERGENCY SYSTEM. PROVIDE OVERCURRENT PROTECTION DEVICES WITH THE CHARACTERISTICS DEFINED (FRAME SIZE, TRIP TYPE, ETC.). THE SPECIFIED SHORT CIRCUIT ANALYSIS SHALL BE PERFORMED ON THE ENTIRE SYSTEM WITH BOTH THE UTILITY AND THE GENERATOR SERVING AS THE POWER SOURCE. THE SPECIFIED COORDINATION STUDY SHALL INCLUDE ALL ELEMENTS OF THE EMERGENCY SYSTEM (LIFE SAFETY, LEGALLY REQUIRED STANDBY AND STANDBY BRANCHES) AS WELL AS ALL OTHER ADJUSTABLE TRIP UNITS SPECIFIED AND ALL ELEVATORS. THE EMERGENCY COORDINATION STUDY SHALL ILLUSTRATE SELECTIVE COORDINATION OF BOTH THE UTILITY AND THE GENERATOR SOURCES TO THE EMERGENCY SYSTEMS.

KEY NOTES	
1	SPLICE CONDUCTORS IN EXISTING BOX (FORMERLY TRANSFER SWITCH). PROVIDE NEW SCREW COVER FOR BOX.
2	PROVIDE TEMPORARY GENERATOR TO MINIMIZE SHUTDOWN TIME FOR MCC-AS TO NO MORE THAN TWO HOURS AT A TIME. INSTALLATION SHALL COMPLY WITH NEC 590.

NOTES:

1. REFER TO SPECIFICATIONS AND DETAILS FOR ADDITIONAL INFORMATION.

SIMPLIFIED OVERALL ONE-LINE DIAGRAM - PROPOSED DISTRIBUTION

SCALE: NONE

AS-BUILT DRAWINGS

03-13-2015

THIS RECORD DRAWING REPRESENTS THE CONTRACT DOCUMENTS AS MODIFIED BY THE CONTRACTOR'S COMMENTS SUBMITTED TO RDK ENGINEERS. BASED UPON THOSE COMMENTS, WE BELIEVE THAT THIS DRAWING FAIRLY REPRESENTS THE AS-BUILT CONDITION OF THE PROJECT. RDK ENGINEERS DOES NOT ATTEST TO THE ACCURACY OF THIS RECORD DRAWING AND ASSUMES NO RESPONSIBILITY FOR THE RELIANCE OF ANY PARTY UPON THE ACCURACY OF THIS DRAWING.

S E A
SE A CONSULTANTS INC.
KLEINFELDER Bright People. Right Solutions.
RDK ENGINEERS
Andover, MA - Boston, MA - Amherst, MA
Durham, NC - Charlotte, NC
380 Russell St. Hadley, MA 01035
T. 413-387-4640

Scale	N.T.S.
Date	JUN-22-2012
Job No.	
Designed by	DLE
Drawn by	FN
Checked by	GEM
Approved by	GEM

No.	Description	Date
1	AS-BUILT DRAWINGS	03-13-15

REVISIONS

Client: CITY OF PITTSFIELD, MASSACHUSETTS

Project: WWTP PUMP & POWER & EMERGENCY ELECTRICAL UPGRADES

Drawing: ELECTRICAL-SIMPLIFIED OVERALL ONE LINE DIAGRAM-NEW WORK

Sheet: E7.01

PLOT DATE=3/13/2015 3:16:12 PM USER=NIEVES, FELIX FILENAME=Z:\2011\20110507 - Pittsfield WWT Pump and Power Electrical Upgrades\Electrical\Plot Sheets\20110507.00 E7.01 ELECTRICAL SIMPLIFIED OVERALL ONE LINE DIAGRAM - NEW WORK.dwg

Appendix 3: Heat Balance

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #1 - CURRENT CONDITIONS
CURRENT CONDITIONS
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Estimate heat exchanger capacity (***Q***) needed to warm sludge from winter condition (45 deg F) to sludge design temperature (97 deg F)

Assume:

Only the Primary Digester is Heated
Heating occurs 24 hrs / day
Heat loss from recirculation piping is negligible
Do not consider efficiencies of boiler or heat exchanger

Specific Heat Sludge, ***C*** :	1.0	BTU/lb-F

Sludge Feed Rate, ***m*** (incl. mass of water and sludge):

- Average 5-Day Sludge Rate	239,658	lb/d
- Peak 5-Day Sludge Rate	297,288	lb/d

Heat Transfer Coef, ***U*** :

- Cover	0.25	BTU/SF-h-F
- Walls above grade	0.4	BTU/SF-h-F
- Walls below grade (<4ft)	0.1	BTU/SF-h-F
- Walls below grade (>4ft)	0.1	BTU/SF-h-F
- Floor	0.2	BTU/SF-h-F

Temperatures, ***T*** :	Winter	Summer	
- Ambient, ***To***	10	80	F
- Below Grade (<4ft), ***To***	32	55	F
- Below Grade (>4ft), ***To***	41	55	F
- Incoming Sludge, ***Ti***	45	60	F
- Design Sludge, ***Tf***	97	97	F

Dimensions / Elevations:

Top of Digester Wall	998.0
Normal Sludge Elevation	993.5
Grade Elevation	981.0
Frost Line	977.0
Bottom of Digester	970.0

Digester Diameter 80 FT

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #1 - CURRENT CONDITIONS
CURRENT CONDITIONS
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

CALCULATION:

A - Heat Requirement for Incoming Sludge

Qs = C**m** (Tf - Ti)

Qs =

	Winter	Summer	
Average Loading	12,462,228	8,867,355	BTU/d
Max. Loading	15,458,957	10,999,643	BTU/d

B - Heat Lost Through Digester

Qhl = U*Area*(Tf - To)

Qhl = Cover

Winter	Summer	
2,623,858	512,708	BTU/d

Walls Above Grade

Winter	Summer	
3,568,447	697,283	BTU/d

Walls <4ft Below Grade

Winter	Summer	
156,828	101,335	BTU/d

Walls >4ft Below Grade

Winter	Summer	
236,449	177,337	BTU/d

Floor

Winter	Summer	
1,351,136	1,013,352	BTU/d

C - Heating Requirement (Qs + Qhl)

	Winter	Summer	
Average Loading	20,398,947	11,369,370	BTU/d
Max. Loading	23,395,676	13,501,657	BTU/d

	Winter	Summer	
Average Loading	849,956	473,724	BTU/hr
Max. Loading	974,820	562,569	BTU/hr

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #2 - MAXIMUM FUTURE CAPACITY
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Estimate heat exchanger capacity (***Q***) needed to warm sludge from winter condition (45 deg F) to sludge design temperature (97 deg F)

Assume:

Only the Primary Digester is Heated
Heating occurs 24 hrs / day
Heat loss from recirculation piping is negligible
Do not consider efficiencies of boiler or heat exchanger

Specific Heat Sludge, ***C*** :	1.0	BTU/lb-F

Sludge Feed Rate, ***m*** (incl. mass of water and sludge):

- Average 5-Day Sludge Rate	784,394	lb/d
- Peak 5-Day Sludge Rate	842,023	lb/d

Heat Transfer Coef, ***U*** :

- Cover	0.25	BTU/SF-h-F
- Walls above grade	0.4	BTU/SF-h-F
- Walls below grade (<4ft)	0.1	BTU/SF-h-F
- Walls below grade (>4ft)	0.1	BTU/SF-h-F
- Floor	0.2	BTU/SF-h-F

Temperatures, ***T*** :	Winter	Summer	
- Ambient, ***To***	10	80	F
- Below Grade (<4ft), ***To***	32	55	F
- Below Grade (>4ft), ***To***	41	55	F
- Incoming Sludge, ***Ti***	45	60	F
- Design Sludge, ***Tf***	97	97	F

Dimensions / Elevations:

Top of Digester Wall	998.0
Normal Sludge Elevation	993.5
Grade Elevation	981.0
Frost Line	977.0
Bottom of Digester	970.0
Digester Diameter	80 FT

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #2 - MAXIMUM FUTURE CAPACITY
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

CALCULATION:

A - Heat Requirement for Incoming Sludge

Qs = C**m** (Tf - Ti)

Qs =

	Winter	Summer	
Average Loading	40,788,473	29,022,567	BTU/d
Max. Loading	43,785,202	31,154,855	BTU/d

B - Heat Lost Through Digester

Qhl = U*Area*(Tf - To)

Qhl =

Cover

Winter	Summer	
2,623,858	512,708	BTU/d

Walls Above Grade

Winter	Summer	
3,568,447	697,283	BTU/d

Walls <4ft Below Grade

Winter	Summer	
156,828	101,335	BTU/d

Walls >4ft Below Grade

Winter	Summer	
236,449	177,337	BTU/d

Floor

Winter	Summer	
1,351,136	1,013,352	BTU/d

C - Heating Requirement (Qs + Qhl)

	Winter	Summer	
Average Loading	48,725,191	31,524,582	BTU/d
Max. Loading	51,721,920	33,656,870	BTU/d

	Winter	Summer	
Average Loading	2,030,216	1,313,524	BTU/hr
Max. Loading	2,155,080	1,402,370	BTU/hr

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #3 - ALTERNATIVE 2B.1 AEGIS
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Estimate heat exchanger capacity (***Q***) needed to warm sludge from winter condition (45 deg F) to sludge design temperature (97 deg F)

Assume:

Only the Primary Digester is Heated
Heating occurs 24 hrs / day
Heat loss from recirculation piping is negligible
Do not consider efficiencies of boiler or heat exchanger

Specific Heat Sludge, ***C*** :	1.0	BTU/lb-F
Sludge Feed Rate, ***m*** (incl. mass of water and sludge):		
- Average 5-Day Sludge Rate	412,713	lb/d
- Peak 5-Day Sludge Rate	470,343	lb/d
Heat Transfer Coef, ***U*** :		
- Cover	0.25	BTU/SF-h-F
- Walls above grade	0.4	BTU/SF-h-F
- Walls below grade (<4ft)	0.1	BTU/SF-h-F
- Walls below grade (>4ft)	0.1	BTU/SF-h-F
- Floor	0.2	BTU/SF-h-F

Temperatures, ***T*** :	Winter	Summer	
- Ambient, ***To***	10	80	F
- Below Grade (<4ft), ***To***	32	55	F
- Below Grade (>4ft), ***To***	41	55	F
- Incoming Sludge, ***Ti***	45	60	F
- Design Sludge, ***Tf***	97	97	F

Dimensions / Elevations:

Top of Digester Wall	998.0
Normal Sludge Elevation	993.5
Grade Elevation	981.0
Frost Line	977.0
Bottom of Digester	970.0
Digester Diameter	80 FT

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #3 - ALTERNATIVE 2B.1 AEGIS
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

CALCULATION:

A - Heat Requirement for Incoming Sludge

Qs = C**m** (Tf - Ti)

Qs =

	Winter	Summer	
Average Loading	21,461,088	15,270,390	BTU/d
Max. Loading	24,457,817	17,402,678	BTU/d

B - Heat Lost Through Digester

Qhl = U*Area*(Tf - To)

Qhl =

Cover

Winter	Summer	
2,623,858	512,708	BTU/d

Walls Above Grade

Winter	Summer	
3,568,447	697,283	BTU/d

Walls <4ft Below Grade

Winter	Summer	
156,828	101,335	BTU/d

Walls >4ft Below Grade

Winter	Summer	
236,449	177,337	BTU/d

Floor

Winter	Summer	
1,351,136	1,013,352	BTU/d

C - Heating Requirement (Qs + Qhl)

	Winter	Summer	
Average Loading	29,397,807	17,772,405	BTU/d
Max. Loading	32,394,536	19,904,692	BTU/d

	Winter	Summer	
Average Loading	1,224,909	740,517	BTU/hr
Max. Loading	1,349,772	829,362	BTU/hr

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #3 - ALTERNATIVE 2B.2 NES
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Estimate heat exchanger capacity (***Q***) needed to warm sludge from winter condition (45 deg F) to sludge design temperature (97 deg F)

Assume:

Only the Primary Digester is Heated
Heating occurs 24 hrs / day
Heat loss from recirculation piping is negligible
Do not consider efficiencies of boiler or heat exchanger

Specific Heat Sludge, ***C*** :	1.0	BTU/lb-F
Sludge Feed Rate, ***m*** (incl. mass of water and sludge):		
- Average 5-Day Sludge Rate	594,108	lb/d
- Peak 5-Day Sludge Rate	651,738	lb/d
Heat Transfer Coef, ***U*** :		
- Cover	0.25	BTU/SF-h-F
- Walls above grade	0.4	BTU/SF-h-F
- Walls below grade (<4ft)	0.1	BTU/SF-h-F
- Walls below grade (>4ft)	0.1	BTU/SF-h-F
- Floor	0.2	BTU/SF-h-F

Temperatures, ***T*** :	Winter	Summer	
- Ambient, ***To***	10	80	F
- Below Grade (<4ft), ***To***	32	55	F
- Below Grade (>4ft), ***To***	41	55	F
- Incoming Sludge, ***Ti***	45	60	F
- Design Sludge, ***Tf***	97	97	F

Dimensions / Elevations:

Top of Digester Wall	998.0
Normal Sludge Elevation	993.5
Grade Elevation	981.0
Frost Line	977.0
Bottom of Digester	970.0
Digester Diameter	80 FT

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #3 - ALTERNATIVE 2B.2 NES
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

CALCULATION:

A - Heat Requirement for Incoming Sludge

Qs = C**m** (Tf - Ti)

Qs =

	Winter	Summer	
Average Loading	30,893,628	21,982,005	BTU/d
Max. Loading	33,890,357	24,114,293	BTU/d

B - Heat Lost Through Digester

Qhl = U*Area*(Tf - To)

Qhl =

Cover

Winter	Summer	
2,623,858	512,708	BTU/d

Walls Above Grade

Winter	Summer	
3,568,447	697,283	BTU/d

Walls <4ft Below Grade

Winter	Summer	
156,828	101,335	BTU/d

Walls >4ft Below Grade

Winter	Summer	
236,449	177,337	BTU/d

Floor

Winter	Summer	
1,351,136	1,013,352	BTU/d

C - Heating Requirement (Qs + Qhl)

	Winter	Summer	
Average Loading	38,830,347	24,484,020	BTU/d
Max. Loading	41,827,076	26,616,307	BTU/d

	Winter	Summer	
Average Loading	1,617,931	1,020,167	BTU/hr
Max. Loading	1,742,795	1,109,013	BTU/hr

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #3 - ALETRNATIVE 2B.3 Tech3Soln
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Estimate heat exchanger capacity (***Q***) needed to warm sludge from winter condition (45 deg F) to sludge design temperature (97 deg F)

Assume:

Only the Primary Digester is Heated
Heating occurs 24 hrs / day
Heat loss from recirculation piping is negligible
Do not consider efficiencies of boiler or heat exchanger

Specific Heat Sludge, ***C*** :	1.0	BTU/lb-F
Sludge Feed Rate, ***m*** (incl. mass of water and sludge):		
- Average 5-Day Sludge Rate	506,538	lb/d
- Peak 5-Day Sludge Rate	564,168	lb/d
Heat Transfer Coef, ***U*** :		
- Cover	0.25	BTU/SF-h-F
- Walls above grade	0.4	BTU/SF-h-F
- Walls below grade (<4ft)	0.1	BTU/SF-h-F
- Walls below grade (>4ft)	0.1	BTU/SF-h-F
- Floor	0.2	BTU/SF-h-F

Temperatures, ***T*** :	Winter	Summer	
- Ambient, ***To***	10	80	F
- Below Grade (<4ft), ***To***	32	55	F
- Below Grade (>4ft), ***To***	41	55	F
- Incoming Sludge, ***Ti***	45	60	F
- Design Sludge, ***Tf***	97	97	F

Dimensions / Elevations:

Top of Digester Wall	998.0	
Normal Sludge Elevation	993.5	
Grade Elevation	981.0	
Frost Line	977.0	
Bottom of Digester	970.0	
Digester Diameter	80	FT

DIGESTION / BIOGAS HEAT REQUIREMENTS
HEAT BALANCE #3 - ALETRNATIVE 2B.3 Tech3Soln
ADDITION OF ORGANIC WASTE
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

CALCULATION:

A - Heat Requirement for Incoming Sludge

Qs = C**m** (Tf - Ti)

Qs =

	Winter	Summer	
Average Loading	26,339,988	18,741,915	BTU/d
Max. Loading	29,336,717	20,874,203	BTU/d

B - Heat Lost Through Digester

Qhl = U*Area*(Tf - To)

Qhl =

<u>Cover</u>

Winter	Summer	
2,623,858	512,708	BTU/d

<u>Walls Above Grade</u>

Winter	Summer	
3,568,447	697,283	BTU/d

<u>Walls <4ft Below Grade</u>

Winter	Summer	
156,828	101,335	BTU/d

<u>Walls >4ft Below Grade</u>

Winter	Summer	
236,449	177,337	BTU/d

<u>Floor</u>

Winter	Summer	
1,351,136	1,013,352	BTU/d

C - Heating Requirement (Qs + Qhl)

	Winter	Summer	
Average Loading	34,276,707	21,243,930	BTU/d
Max. Loading	37,273,436	23,376,217	BTU/d

	Winter	Summer	
Average Loading	1,428,196	885,164	BTU/hr
Max. Loading	1,553,060	974,009	BTU/hr

Appendix 4: Cost-Benefit Analysis for Alternative 1

ALTERNATIVE 1 - Repair Microturbines – Existing Gas Production COST - BENEFIT ANALYSIS:
REPLACING ONE MICROTURBINE AND SKID, NO ADDITIONAL ORGANIC WASTE
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index: 10,958.78

Assumptions:

- Three C-65kW microturbines total
- One microturbine power head, two repaired
- One new pre-conditioning skid
- Total fuel gas requirement - 65.5 SCFM
- Minimum gas requirement for all three CHP units is met at all times
- No additional organic waste or septic

CHP Electricity Gain:		195	kW total	65*3	
CHP Recoverable Heat Gain:		675,000	BTU/hr total	225,000 BTU/hr	
Maximum Heat Available to Sludge Heat Exchanger		634,500	BTU/hr total		
				Assume 6% total heat loss in buried piping to and from Digester Building	
Increased Biogas Production		0	cf/d		
Sludge Disposal Costs:	$	97.35	/wet ton		
Average Electricity Cost	$	0.1057	/kWh		
Transmission Cost			/kWh		
Demand Charge	$	15.24	/kW		
Standby Rate			/kW per month		
Inflation		3.00%			
Capital Costs:					
CHP System Equipment Purchase:	$	401,150			
Microturbine repairs	$	22,000			
Automation of gas bleeding valves	$	50,000			
System Installation (35%)	$	165,603	Basis:		
Electrical and Instrumentation (15%)	$	71,000		Estimate does not reflect:	
Construction Contingency (30%)	$	213,000		demolition, building, heat, any specialized civil site, geotech	
Undefined Work Items (25%)	$	231,000			
Construction Sub-total	*$*	*1,153,753*			
20% OH&P	$	231,000			
Total construction	*$*	*1,384,753*			
Engineering Design, CA & RE Services (25%)	$	231,000			
Total Capital Investment	$	1,616,000		~+/- 30% for the report	
Annual O&M Costs:					
Cost per unit per hour	$	3.90		$0.02/kWh of electricity generated (from PDR report)	
Units		3			
Hours of operation per unit		8,760			
Total O&M	$	103,000			
Annual O&M Costs (Additional Over Existing System):					
Standby Rate Charge	$	-			
Sludge Disposal Volume Increase		0	Annual Wet Tons		
Cost of Additional Sludge Disposal		0	Annually		
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	20,000			
Annual O&M Cost	$	20,000			
	$	**123,000**			
Annual Benefits (Additional Over Existing System):					
Increased biogas production		0	Annual SCF additional		
Reduction in kWh for compressors		-			
Reduction in kWh From Grid		1,684,800	kWh/YR		
Value of Electricity Savings	$	214,000			
Reduction in Sludge Heating Requirements		53%		Assume 1,200,000 BTU/hr	
Reduction in Total Heating Requirements		49%		Assume 1,305,000 BTU/hr	
Fuel Oil #2 Savings	$	150,000		Assume 141,000 BTU/gal, $1.842/gal (Dec. 2017)	
Total Annual Savings	$	364,000	Annually		
Sludge Disposal Volume Reduced		0	Annual Wet Tons		
Value of Sludge Disposal Savings		$0.00	Annually		
Total Annual Savings	**$**	**364,000**			
Current Estimated Annual Electric Utility Bill	$	634,020		500,000 kWh/month *12 months	500000
	$	137,160		750 kW/month * 12 months	750
TOTAL	**$**	**771,180**			
% Reduction in Electric Utility Bill		**27.7%**			

NET PRESENT WORTH CALCULATION
ALTERNATIVE 1: Repair Microturbines – Existing Gas Production
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

20-City ENR CCI Index

Assumumptions

Inflation		3.00%
O&M Cost Factor		3.00%
Electrical Rate Cost Factor		3.00%
Annual O&M Cost	$	123,000
Annual Benefit	$	364,000
Initial Capital Invesment	$	1,616,000

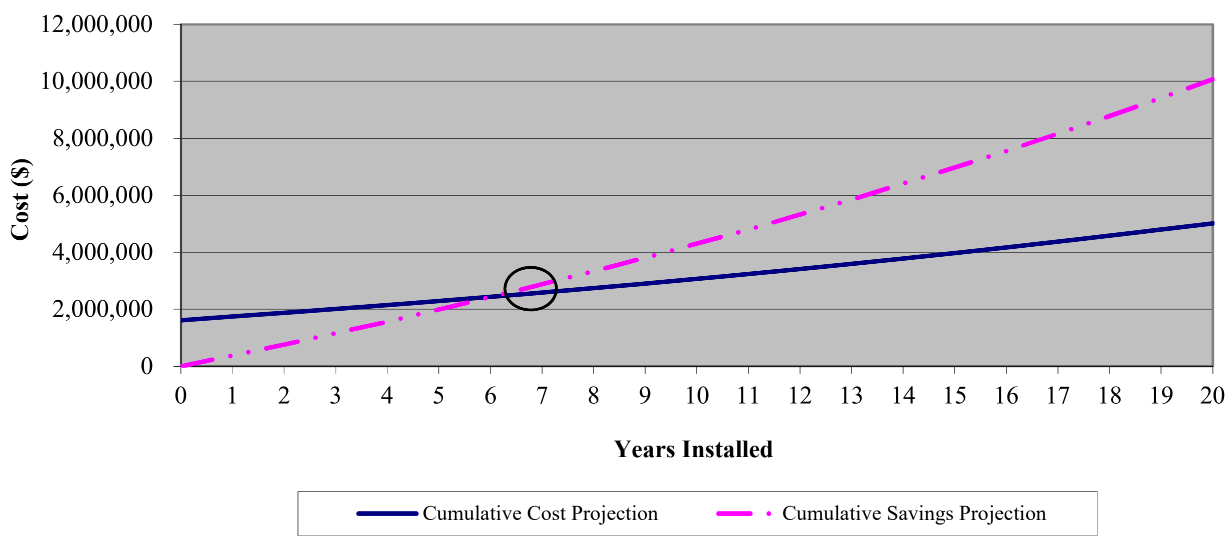
	BENEFIT	COSTS	
Year	**Annual Benefits**	**CHP System Capital Cost**	**Annual O&M Cost**
0	$0	(1,616,000)	0
1	$375,000	0	(127,000)
2	$386,000	0	(130,000)
3	$398,000	0	(134,000)
4	$410,000	0	(138,000)
5	$422,000	0	(143,000)
6	$435,000	0	(147,000)
7	$448,000	0	(151,000)
8	$461,000	0	(156,000)
9	$475,000	0	(160,000)
10	$489,000	0	(165,000)
11	$504,000	0	(170,000)
12	$519,000	0	(175,000)
13	$535,000	0	(181,000)
14	$551,000	0	(186,000)
15	$567,000	0	(192,000)
16	$584,000	0	(197,000)
17	$602,000	0	(203,000)
18	$620,000	0	(209,000)
19	$638,000	0	(216,000)
20	$657,000	0	(222,000)
Present Worth	**$7,281,000**	**(1,616,000)**	**(2,458,000)**

Net Present Worth	**$3,207,000**

PAYBACK PERIOD ANALYSIS
ALTERNATIVE 1: Repair Microturbines – Existing Gas Production
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	1,616,000	0	1,616,000	0	1,616,000
1	127,000	375,000	1,743,000	375,000	1,368,000
2	130,000	386,000	1,873,000	761,000	1,112,000
3	134,000	398,000	2,007,000	1,159,000	848,000
4	138,000	410,000	2,145,000	1,569,000	576,000
5	143,000	422,000	2,288,000	1,991,000	297,000
6	147,000	435,000	2,435,000	2,426,000	9,000
7	151,000	448,000	2,586,000	2,874,000	(288,000)
8	156,000	461,000	2,742,000	3,335,000	(593,000)
9	160,000	475,000	2,902,000	3,810,000	(908,000)
10	165,000	489,000	3,067,000	4,299,000	(1,232,000)
11	170,000	504,000	3,237,000	4,803,000	(1,566,000)
12	175,000	519,000	3,412,000	5,322,000	(1,910,000)
13	181,000	535,000	3,593,000	5,857,000	(2,264,000)
14	186,000	551,000	3,779,000	6,408,000	(2,629,000)
15	192,000	567,000	3,971,000	6,975,000	(3,004,000)
16	197,000	584,000	4,168,000	7,559,000	(3,391,000)
17	203,000	602,000	4,371,000	8,161,000	(3,790,000)
18	209,000	620,000	4,580,000	8,781,000	(4,201,000)
19	216,000	638,000	4,796,000	9,419,000	(4,623,000)
20	222,000	657,000	5,018,000	10,076,000	(5,058,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
ALTERNATIVE 1: Repair Microturbines – Existing Gas Production
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Exchange Requirement to Sludge Heat Exchanger	1,200,000	800,000	BTU/hr	
Units operating	3			
Heat Output per unit	225,000		BTU/hr	
Total Heat Output from Engines	675,000		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

Maximum amount of heat available to be supplied to sludge heat exchanger	634,500		BTU/hr	
Additional heat required to meet maximum heat exchange requirement	565,500	125,000	BTU/hr	
Gallons of #2 Fuel Oil Saved	9.00	9.57	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	1,269,000	1,350,000	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil Saved	72,612	77,246	**149,858**	$/year

Appendix 5: Cost-Benefit Analysis for Alternative 2A.1

Alternative 2A.1 - Aegis Reciprocating Engines COST - BENEFIT ANALYSIS:
INSTALLATION OF AEGIS RECIPROCATING ENGINES, NO ADDITIONAL ORGANIC WASTE
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index: 10,958.78

Assumptions:

Three Aegis 75kW reciprocating engines installed
Total fuel gas requirement - 46.5 SCFM
Minimum gas requirement for all three CHP units is met at all times
No additional organic waste or septic

CHP Electricity Gain:		225	kW total		
CHP Recoverable Heat Gain:		972,780	BTU/hr total	324,260 BTU/hr*3 units	
Maximum Heat Available to Sludge Heat Exchanger		914,413	BTU/hr total		
				Assume 6% total heat loss in buried piping to and from Digester Building	
Increased Biogas Production		0	cf/d		
Sludge Disposal Costs:	$	97.35	/wet ton		
Average Electricity Cost	$	0.1057	/kWh		
Transmission Cost			/kWh		
Demand Charge	$	15.24	/kW		
Standby Rate			/kW per month		
Inflation		3.00%			
Capital Costs:					
CHP System Equipment Purchase:	$	700,000		Three engines plus pre-conditioning skid	
Automation of gas bleeding valves	$	50,000			
System Installation (35%)	$	262,500	Basis:		
Electrical and Instrumentation (15%)	$	113,000		Estimate does not reflect:	
Construction Contingency (30%)	$	338,000		demolition, building, heat, any specialized civil site, geotech	
Undefined Work Items (25%)	$	366,000			
Construction Sub-total	*$*	*1,829,500*			
20% OH&P	$	366,000			
Total construction	*$*	*2,195,500*			
Engineering Design, CA & RE Services (25%)	$	366,000			
Total Capital Investment	$	2,562,000		~+/- 30% for the report	
Annual O&M Costs:					
Cost per unit per hour	$	2.50		Quote from vendor	
Units		3			
Hours of operation per unit		8,760			
Total O&M	$	65,700			
Annual O&M Costs (Additional Over Existing System):					
Standby Rate Charge	$	-			
Sludge Disposal Volume Increase		0	Annual Wet Tons		
Cost of Additional Sludge Disposal		0	Annually		
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	25,000		Includes: oil, filters, labor	
Annual O&M Cost	$	25,000			
	$	**90,700**			
Annual Benefits (Additional Over Existing System):					
Increased biogas production		0	Annual SCF additional		
Reduction in kWh for compressors		192,720		22kW running 24 hours everyday	
Reduction in kWh From Grid		1,944,000	kWh/YR		
Value of Electricity Savings	$	270,959			
Reduction in Sludge Heating Requirements		76%		Assume 1,200,000 BTU/hr	
Reduction in Total Heating Requirements		70%		Assume 1,305,000 BTU/hr	
Fuel Oil #2 Savings	$	196,196		Assume 141,000 BTU/gal, $1.842/gal (Dec. 2017)	
Total Annual Savings	$	467,155	Annually		
Sludge Disposal Volume Reduced		0	Annual Wet Tons		
Value of Sludge Disposal Savings		$0.00	Annually		
Total Annual Savings	**$**	**467,155**			
Current Estimated Annual Electric Utility Bill	$	634,020		500,000 kWh/month *12 months	500000
	$	137,160		750 kW/month * 12 months	750
TOTAL	**$**	**771,180**			
% Reduction in Electric Utility Bill		**35.1%**			

NET PRESENT WORTH CALCULATION

e 2A.1 - Aegis Reciprocating Engines

CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

20-City ENR CCI Index

Assumumptions

Inflation		3.00%
O&M Cost Factor		3.00%
Electrical Rate Cost Factor		3.00%
Annual O&M Cost	$	90,700
Annual Benefit	$	467,155
Initial Capital Invesment	$	2,562,000

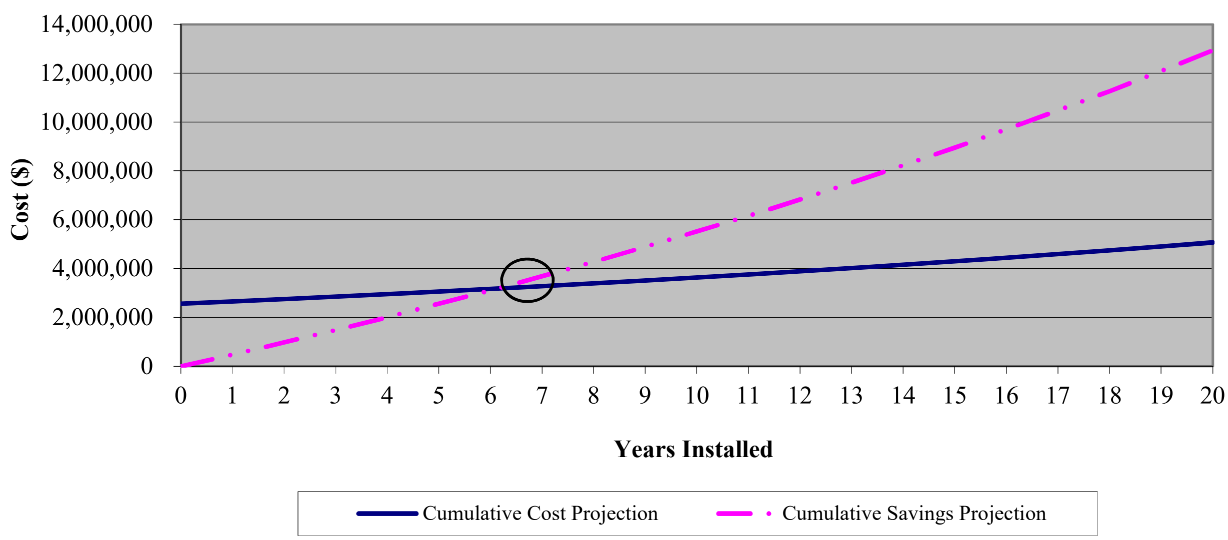
Year	BENEFIT Annual Benefits	COSTS CHP System Capital Cost	 Annual O&M Cost
0	$0	(2,562,000)	0
1	$481,000	0	(93,000)
2	$496,000	0	(96,000)
3	$510,000	0	(99,000)
4	$526,000	0	(102,000)
5	$542,000	0	(105,000)
6	$558,000	0	(108,000)
7	$575,000	0	(112,000)
8	$592,000	0	(115,000)
9	$610,000	0	(118,000)
10	$628,000	0	(122,000)
11	$647,000	0	(126,000)
12	$666,000	0	(129,000)
13	$686,000	0	(133,000)
14	$707,000	0	(137,000)
15	$728,000	0	(141,000)
16	$750,000	0	(146,000)
17	$772,000	0	(150,000)
18	$795,000	0	(154,000)
19	$819,000	0	(159,000)
20	$844,000	0	(164,000)
Present Worth	**$9,345,000**	**(2,562,000)**	**(1,813,000)**

Net Present Worth	**$4,970,000**

PAYBACK PERIOD ANALYSIS
Alternative 2A.1 - Aegis Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	2,562,000	0	2,562,000	0	2,562,000
1	93,000	481,000	2,655,000	481,000	2,174,000
2	96,000	496,000	2,751,000	977,000	1,774,000
3	99,000	510,000	2,850,000	1,487,000	1,363,000
4	102,000	526,000	2,952,000	2,013,000	939,000
5	105,000	542,000	3,057,000	2,555,000	502,000
6	108,000	558,000	3,165,000	3,113,000	52,000
7	112,000	575,000	3,277,000	3,688,000	(411,000)
8	115,000	592,000	3,392,000	4,280,000	(888,000)
9	118,000	610,000	3,510,000	4,890,000	(1,380,000)
10	122,000	628,000	3,632,000	5,518,000	(1,886,000)
11	126,000	647,000	3,758,000	6,165,000	(2,407,000)
12	129,000	666,000	3,887,000	6,831,000	(2,944,000)
13	133,000	686,000	4,020,000	7,517,000	(3,497,000)
14	137,000	707,000	4,157,000	8,224,000	(4,067,000)
15	141,000	728,000	4,298,000	8,952,000	(4,654,000)
16	146,000	750,000	4,444,000	9,702,000	(5,258,000)
17	150,000	772,000	4,594,000	10,474,000	(5,880,000)
18	154,000	795,000	4,748,000	11,269,000	(6,521,000)
19	159,000	819,000	4,907,000	12,088,000	(7,181,000)
20	164,000	844,000	5,071,000	12,932,000	(7,861,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
Alternative 2A.1 - Aegis Reciprocating Engines
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Exchange Requirement to Sludge Heat Exchanger	1,200,000	800,000	BTU/hr	
Units operating	3			
Heat Output per unit	324,260		BTU/hr	
Total Heat Output from Engines	972,780		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

Maximum amount of heat available to be supplied to sludge heat exchanger	914,413		BTU/hr	
Additional heat required to meet maximum heat exchange requirement	285,587	-172,780	BTU/hr	
Gallons of #2 Fuel Oil Saved	12.97	11.35	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	1,828,826	1,600,000	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil Saved	104,645	91,551	**196,196**	$/year

Extra heat available all in the summer that could be used for other purposes

Appendix 6: Cost-Benefit Analysis for Alternative 2A.2

Alternative 2A.2 - NES Reciprocating Engines COST - BENEFIT ANALYSIS:
INSTALLATION OF NES RECIPROCATING ENGINES, NO ADDITIONAL ORGANIC WASTE
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index: 10,958.78

Assumptions:

One 160 kW and one 50 KW reciprocating engine
The 50kW unit will run at full load all the time
The 160kW unit will run at 65% load all the time
Total fuel gas requirement - 45.6SCFM — 14.7 and 47.6
No additional organic waste or septic

CHP Electricity Gain:		154	kW total	
CHP Recoverable Heat Gain:		624,700	BTU/hr total	249,000 and 578,000
Maximum Heat Available to Sludge Heat Exchanger		587,218	BTU/hr total	Assume 6% total heat loss in buried piping to and from Digester Building
Increased Biogas Production		0	cf/d	
Sludge Disposal Costs:	$	97.35	/wet ton	
Average Electricity Cost	$	0.1057	/kWh	
Transmission Cost			/kWh	
Demand Charge	$	15.24	/kW	
Standby Rate			/kW per month	
Inflation		3.00%		

Capital Costs:

CHP System Equipment Purchase:	$	757,360		Two engines plus one pre-conditioning skid
Automation of gas bleeding valves	$	50,000		
System Installation (35%)	$	282,576	Basis:	
Electrical and Instrumentation (15%)	$	121,000		Estimate does not reflect:
Construction Contingency (30%)	$	363,000		demolition, building, heat, any specialized civil site, geotech
Undefined Work Items (25%)	$	393,000		
Construction Sub-total	*$*	*1,966,936*		
20% OH&P	$	393,000		
Total construction	*$*	*2,359,936*		
Engineering Design, CA & RE Services (25%)	$	393,000		
Total Capital Investment	$	2,753,000		~+/- 30% for the report

Annual O&M Costs:

Cost per unit per hour	$	3.70	Quote from vendor
Units		2	
Hours of operation per unit		8,700	
Total O&M	$	64,380	

Annual O&M Costs (Additional Over Existing System):

Standby Rate Charge	$	-		
Sludge Disposal Volume Increase		0	Annual Wet Tons	
Cost of Additional Sludge Disposal		0	Annually	
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	25,000		Includes: oil, filters, labor
Annual O&M Cost	$	25,000		
	$	**89,380**		

Annual Benefits (Additional Over Existing System):

Increased biogas production		0	Annual SCF additional	
Reduction in kWh for compressors		192,720		22kW running 24 hours everyday
Reduction in kWh From Grid		1,330,560	kWh/YR	
Value of Electricity Savings	$	193,152		
Reduction in Sludge Heating Requirements		49%		
Reduction in Total Heating Requirements		45%		Assume 1,305,000 BTU/hr
Fuel Oil #2 Savings	$	138,691		Assume 141,000 BTU/gal, $1.842/gal (Dec. 2017)
Total Annual Savings	$	331,843	Annually	
Sludge Disposal Volume Reduced		0	Annual Wet Tons	
Value of Sludge Disposal Savings		$0.00	Annually	
Total Annual Savings	**$**	**331,843**		

Current Estimated Annual Electric Utility Bill	$	634,020	500,000 kWh/month *12 months	500000
	$	137,160	750 kW/month * 12 months	750
TOTAL	**$**	**771,180**		
% Reduction in Electric Utility Bill		**25.0%**		

NET PRESENT WORTH CALCULATION

Alternative 2A.2 - NES Reciprocating Engines

CHP AND AD UPGRADES STUDY

PITTSFIELD WWTP

March 2018

20-City ENR CCI Index 10,958.78

Assumumptions

Inflation		3.00%	
O&M Cost Factor		3.00%	
Electrical Rate Cost Factor		3.00%	
Annual O&M Cost	$	89,380	
Annual Benefit	$	331,843	
Initial Capital Invesment	$	2,753,000	$825,900.00

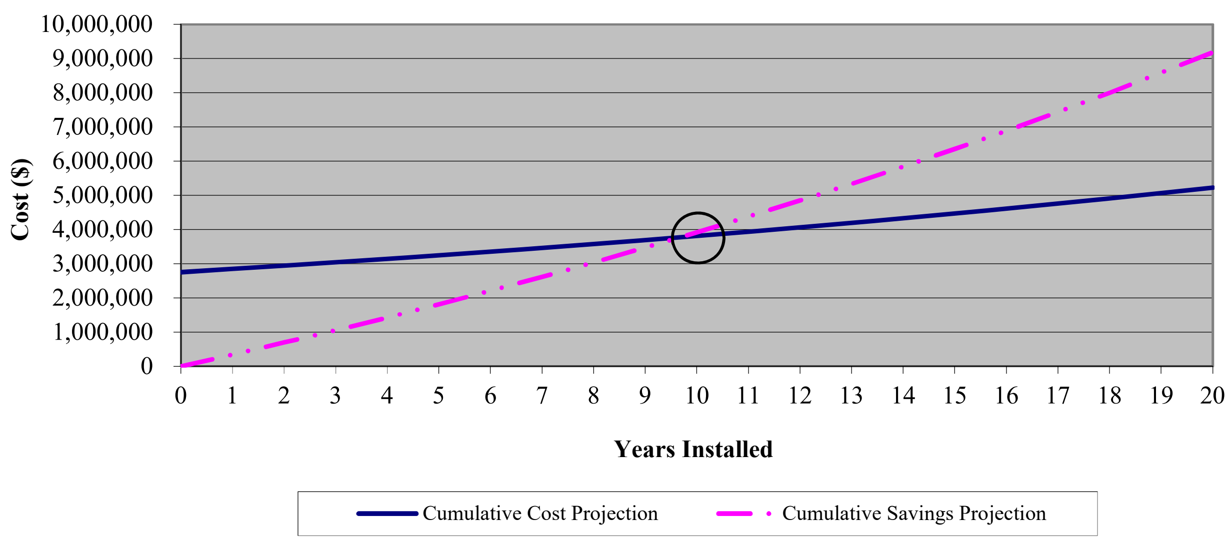
Year	BENEFIT Annual Benefit	COSTS CHP System Capital Cost	 Annual O&M Cost
0	$0	(2,753,000)	0
1	$342,000	0	(92,000)
2	$352,000	0	(95,000)
3	$363,000	0	(98,000)
4	$373,000	0	(101,000)
5	$385,000	0	(104,000)
6	$396,000	0	(107,000)
7	$408,000	0	(110,000)
8	$420,000	0	(113,000)
9	$433,000	0	(117,000)
10	$446,000	0	(120,000)
11	$459,000	0	(124,000)
12	$473,000	0	(127,000)
13	$487,000	0	(131,000)
14	$502,000	0	(135,000)
15	$517,000	0	(139,000)
16	$533,000	0	(143,000)
17	$548,000	0	(148,000)
18	$565,000	0	(152,000)
19	$582,000	0	(157,000)
20	$599,000	0	(161,000)
Present Worth	**$6,636,000**	**(2,753,000)**	**(1,788,000)**

Net Present Worth	**$2,095,000**

PAYBACK PERIOD ANALYSIS
Alternative 2A.2 - NES Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	2,753,000	0	2,753,000	0	2,753,000
1	92,000	342,000	2,845,000	342,000	2,503,000
2	95,000	352,000	2,940,000	694,000	2,246,000
3	98,000	363,000	3,038,000	1,057,000	1,981,000
4	101,000	373,000	3,139,000	1,430,000	1,709,000
5	104,000	385,000	3,243,000	1,815,000	1,428,000
6	107,000	396,000	3,350,000	2,211,000	1,139,000
7	110,000	408,000	3,460,000	2,619,000	841,000
8	113,000	420,000	3,573,000	3,039,000	534,000
9	117,000	433,000	3,690,000	3,472,000	218,000
10	120,000	446,000	3,810,000	3,918,000	(108,000)
11	124,000	459,000	3,934,000	4,377,000	(443,000)
12	127,000	473,000	4,061,000	4,850,000	(789,000)
13	131,000	487,000	4,192,000	5,337,000	(1,145,000)
14	135,000	502,000	4,327,000	5,839,000	(1,512,000)
15	139,000	517,000	4,466,000	6,356,000	(1,890,000)
16	143,000	533,000	4,609,000	6,889,000	(2,280,000)
17	148,000	548,000	4,757,000	7,437,000	(2,680,000)
18	152,000	565,000	4,909,000	8,002,000	(3,093,000)
19	157,000	582,000	5,066,000	8,584,000	(3,518,000)
20	161,000	599,000	5,227,000	9,183,000	(3,956,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
Alternative 2A.2 - NES Reciprocating Engines
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Exchange Requirement to Sludge Heat Exchanger	1,200,000	800,000	BTU/hr	
Units operating	2			
Total Heat Output from Engine	624,700		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

Maximum amount of heat available to be supplied to sludge heat exchanger	587,218		BTU/hr	
Additional heat required to meet maximum heat exchange requirement	612,782	175,300	BTU/hr	
Gallons of #2 Fuel Oil Saved	8	9	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	1,174,436	1,249,400	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil saved	67,201	71,490	**138,691**	$/year

Appendix 7: Cost-Benefit Analysis for Alternative 2A.3

Alternative 2A.3 - Tech3Solutions Reciprocating Engines COST - BENEFIT ANALYSIS:
INSTALLATION OF TECH 3 SOLUTIONS RECIPROCATING ENGINES, NO ADDITIONAL ORGANIC WASTE
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index: 10,958.78

Assumptions:

One 150 kW and one 90kW reciprocating engine installed
The 90kW unit will run at full load all the time
The 150kW unit will run at 65% load all the time
Total fuel gas requirement - 45.4 SCFM — 22 and 36
No additional organic waste or septic

CHP Electricity Gain:		188	kW total	
CHP Recoverable Heat Gain:		976,554	BTU/hr total	470,875 and 777,968
Maximum Heat Available to Sludge Heat Exchanger		917,961	BTU/hr total	Assume 6% total heat loss in buried piping to and from Digester Building
Increased Biogas Production		0	cf/d	
Sludge Disposal Costs:	$	97.35	/wet ton	
Average Electricity Cost	$	0.1057	/kWh	
Transmission Cost			/kWh	
Demand Charge	$	15.24	/kW	
Standby Rate			/kW per month	
Inflation		3.00%		

Capital Costs:

CHP System Equipment Purchase:	$	760,000		Pre-conditioning skid cost estimate $100,000
Automation of gas bleeding valves	$	50,000		
System Installation (35%)	$	283,500	Basis:	
Electrical and Instrumentation (15%)	$	122,000		Estimate does not reflect:
Construction Contingency (30%)	$	365,000		demolition, building, heat, any specialized civil site, geotech
Undefined Work Items (25%)	$	395,000		
Construction Sub-total	*$*	*1,975,500*		
20% OH&P	$	395,000		
Total construction	*$*	*2,370,500*		
Engineering Design, CA & RE Services (25%)	$	395,000		
Total Capital Investment	$	2,766,000		~+/- 30% for the report

Annual O&M Costs:

Cost per unit per hour	$	3.00		Quote from vendor
Units		2		
Hours of operation per unit		8,700		
Total O&M	$	52,200		

Annual O&M Costs (Additional Over Existing System):

Standby Rate Charge	$	-	
Sludge Disposal Volume Increase		0	Annual Wet Tons
Cost of Additional Sludge Disposal		0	Annually
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	25,000	
Annual O&M Cost	$	25,000	
	$	**77,200**	

Annual Benefits (Additional Over Existing System):

Increased biogas production		0	Annual SCF additional	
Reduction in kWh for compressors		192,720		22kW running 24 hours everyday
Reduction in kWh From Grid		1,620,000	kWh/YR	
Value of Electricity Savings	$	229,863		
Reduction in Sludge Heating Requirements		76%		
Reduction in Total Heating Requirements		70%		Assume 1,305,000 BTU/hr
Fuel Oil #2 Savings	$	196,602		Assume 141,000 BTU/gal, $1.842/gal (Dec. 2017)
Total Annual Savings	$	426,465	Annually	
Sludge Disposal Volume Reduced		0	Annual Wet Tons	
Value of Sludge Disposal Savings		$0.00	Annually	
Total Annual Savings	**$**	**426,465**		
Current Estimated Annual Electric Utility Bill	$	634,020		500,000 kWh/month *12 months — 500000
	$	137,160		750 kW/month * 12 months — 750
TOTAL	**$**	**771,180**		
% Reduction in Electric Utility Bill		**29.8%**		

NET PRESENT WORTH CALCULATION
Alternative 2A.3 - Tech3Solutions Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018

20-City ENR CCI Index 10,958.78

Assumumptions

Inflation		3.00%
O&M Cost Factor		3.00%
Electrical Rate Cost Factor		3.00%
Annual O&M Cost	$	77,200
Annual Benefit	$	426,465
Initial Capital Invesment	$	2,766,000

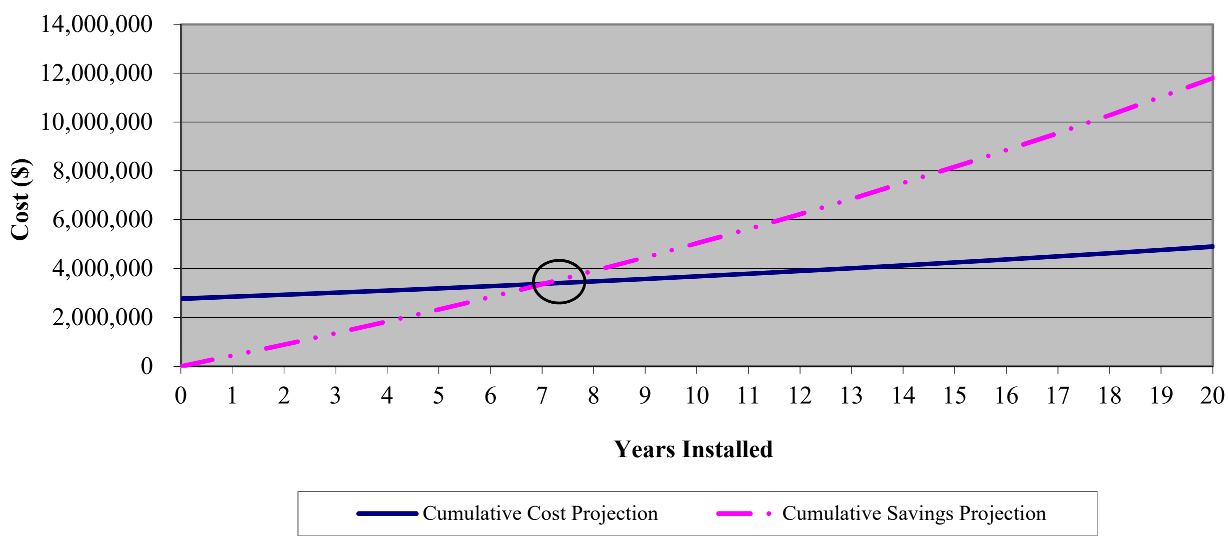
	BENEFIT	COSTS	
Year	Annual Benefit	CHP System Capital Cost	Annual O&M Cost
0	$0	(2,766,000)	0
1	$439,000	0	(80,000)
2	$452,000	0	(82,000)
3	$466,000	0	(84,000)
4	$480,000	0	(87,000)
5	$494,000	0	(89,000)
6	$509,000	0	(92,000)
7	$524,000	0	(95,000)
8	$540,000	0	(98,000)
9	$556,000	0	(101,000)
10	$573,000	0	(104,000)
11	$590,000	0	(107,000)
12	$608,000	0	(110,000)
13	$626,000	0	(113,000)
14	$645,000	0	(117,000)
15	$664,000	0	(120,000)
16	$684,000	0	(124,000)
17	$705,000	0	(128,000)
18	$726,000	0	(131,000)
19	$748,000	0	(135,000)
20	$770,000	0	(139,000)
Present Worth	**$8,526,000**	**(2,766,000)**	**(1,544,000)**

Net Present Worth	**$4,216,000**

PAYBACK PERIOD ANALYSIS
Alternative 2A.3 - Tech3Solutions Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	2,766,000	0	2,766,000	0	2,766,000
1	80,000	439,000	2,846,000	439,000	2,407,000
2	82,000	452,000	2,928,000	891,000	2,037,000
3	84,000	466,000	3,012,000	1,357,000	1,655,000
4	87,000	480,000	3,099,000	1,837,000	1,262,000
5	89,000	494,000	3,188,000	2,331,000	857,000
6	92,000	509,000	3,280,000	2,840,000	440,000
7	95,000	524,000	3,375,000	3,364,000	11,000
8	98,000	540,000	3,473,000	3,904,000	(431,000)
9	101,000	556,000	3,574,000	4,460,000	(886,000)
10	104,000	573,000	3,678,000	5,033,000	(1,355,000)
11	107,000	590,000	3,785,000	5,623,000	(1,838,000)
12	110,000	608,000	3,895,000	6,231,000	(2,336,000)
13	113,000	626,000	4,008,000	6,857,000	(2,849,000)
14	117,000	645,000	4,125,000	7,502,000	(3,377,000)
15	120,000	664,000	4,245,000	8,166,000	(3,921,000)
16	124,000	684,000	4,369,000	8,850,000	(4,481,000)
17	128,000	705,000	4,497,000	9,555,000	(5,058,000)
18	131,000	726,000	4,628,000	10,281,000	(5,653,000)
19	135,000	748,000	4,763,000	11,029,000	(6,266,000)
20	139,000	770,000	4,902,000	11,799,000	(6,897,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
Alternative 2A.3 - Tech3Solutions Reciprocating Engines
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Exchange Requirement to Sludge Heat Exchanger	1,200,000	800,000	BTU/hr	
Units operating	2			
Total Heat Output from Engines	976,554		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

	Winter	Summer		
Maximum amount of heat available to be supplied to sludge heat exchanger	917,961		BTU/hr	
Additional heat required to meet maximum heat exchange requirement	282,039	-176,554	BTU/hr	
Gallons of #2 Fuel Oil Saved	13.02	11.35	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	1,835,922	1,600,000	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil Saved	105,051	91,551	**196,602**	$/year

Extra heat available in the summer that could be used for other purposes

Appendix 8: Cost-Benefit Analysis for Alternative 2B.1

ALTERNATIVE 2B.1 - Aegis Energy Services Reciprocating Engines COST - BENEFIT ANALYSIS:
INSTALLATION OF AEGIS RECIPROCATING ENGINES, MAXIMIZE DESIGN
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018

20-City ENR CCI Index 10,958.78

Assumptions:

Five Aegis 75kW reciprocating engines installed
Five engines is the maximum number of Aegis units that can fit in the space now
Total fuel gas requirement - 77.5 SCFM
Minimum gas requirement for all five CHP units is met at all times
Engines will run full load all the time
Additional sludge in the digester of 20,750 gallons of day
Assume additional sludge source is septic waste

CHP Electricity Gain:		375	kW total		
CHP Recoverable Heat Gain:		1,623,000	BTU/hr total	324,600 BTU/hr/unit	
Maximum Heat Available to Sludge Heat Exchanger		1,525,620	BTU/hr total	Assume 6% total heat loss in buried piping to and from Digester Building	
Increased Biogas Production		44,600	cf/d		
Sludge Disposal Costs:	$	97.35	/wet ton		
Average Electricity Cost	$	0.1057	/kWh		
Transmission Cost			/kWh		
Demand Charge	$	15.24	/kW		
Sludge Receiving Rate	$	121.00	/1,000 gallons		
Inflation		3.00%			

Capital Costs:

CHP System Equipment Purchase:	$	1,100,000		Five engines plus pre-conditioning skid	
Automation of gas bleeding valves	$	50,000			
System Installation (35%)	$	402,500	Basis:	Purchase cost includes installation	
Electrical and Instrumentation (15%)	$	173,000		Estimate does not reflect:	
Construction Contingency (30%)	$	518,000		demolition, building, heat, any specialized civil site, geotech	
Undefined Work Items (25%)	$	561,000			
Construction Sub-total	*$*	*2,804,500*			
20% OH&P	$	561,000			
Total construction	*$*	*3,365,500*			
Engineering Design, CA & RE Services (25%)	$	561,000			
Total Capital Investment	$	3,927,000		~+/- 30% for the report	

Annual O&M Costs:

Cost per unit per hour	$	2.50	
Units		5	
Hours of operation per unit		8,700	
Total O&M	$	108,750	

Annual O&M Costs (Additional Over Existing System):

Sludge Disposal Volume Increase		1514.9	Annual Wet Tons	
Cost of Additional Sludge Disposal	$	147,477	Annually	
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	25,000		Includes oil, filters, labor, parts
Annual O&M Cost	$	172,477		
	$	**281,000**		

Annual Benefits (Additional Over Existing System):

Increased biogas production		16,279,000		Annual additional SCF digester gas	
Reduction in kWh for compressors		192,720		22kW running 24 hours everyday	
Reduction in kWh From Grid		3,240,000	kWh/YR		
Value of Electricity Savings	$	435,000			
Reduction in Sludge Heating Requirements		120%			1,349,772
Reduction in Digester Heating Requirements		110%		Additional digester demand	122,150
Fuel Oil #2 Savings	$	249,000		From Fuel Savings sheet	
Total Annual Savings	$	684,000	Annually		

Total Annual Savings	**$**	**684,000**		
Current Estimated Annual Electric Utility Bill	$	634,020	500,000 kWh/month *12 months	500000
	$	137,160	750 kW/month * 12 months	750
TOTAL	**$**	**771,180**		
% Reduction in Electric Utility Bill		**56.4%**		

NET PRESENT WORTH CALCULATION
Alternative 2B.1 Aegis Energy Services Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018

20-City ENR CCI Index 10,958.78

Assumumptions

Inflation		3.00%
O&M Cost Factor		3.00%
Electrical Rate Cost Factor		3.00%
Annual O&M Cost	$	281,000
Annual Benefit	$	684,000
Initial Capital Invesment	$	3,927,000

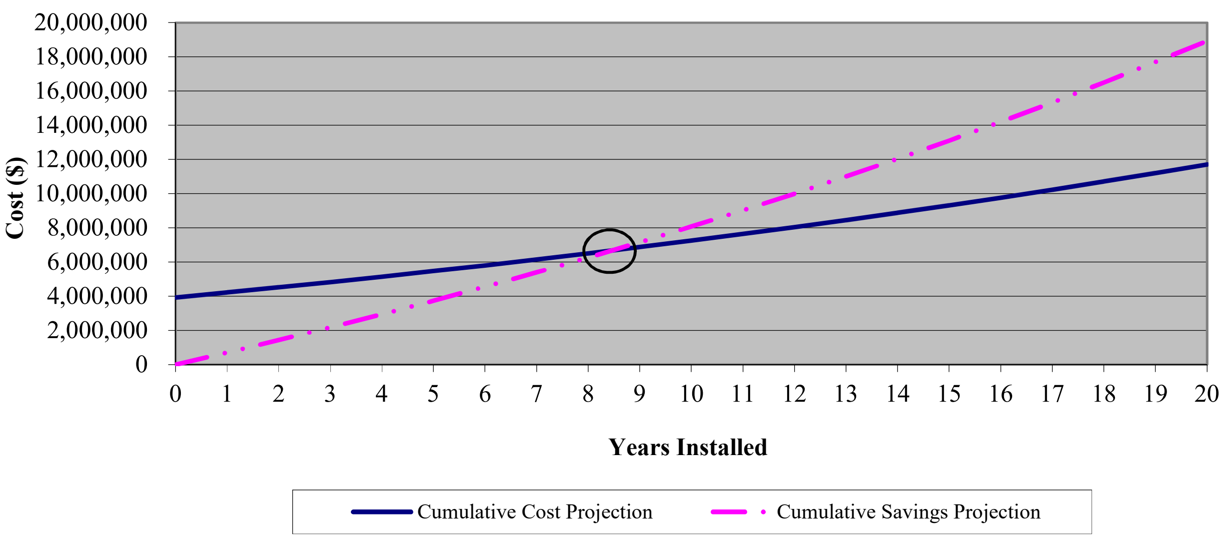
Year	BENEFIT Annual Electric Benefit	COSTS CHP System Capital Cost	 Annual O&M Cost
0	$0	(3,927,000)	0
1	$705,000	0	(289,000)
2	$726,000	0	(298,000)
3	$747,000	0	(307,000)
4	$770,000	0	(316,000)
5	$793,000	0	(326,000)
6	$817,000	0	(336,000)
7	$841,000	0	(346,000)
8	$866,000	0	(356,000)
9	$892,000	0	(367,000)
10	$919,000	0	(378,000)
11	$947,000	0	(389,000)
12	$975,000	0	(401,000)
13	$1,004,000	0	(413,000)
14	$1,035,000	0	(425,000)
15	$1,066,000	0	(438,000)
16	$1,098,000	0	(451,000)
17	$1,131,000	0	(464,000)
18	$1,164,000	0	(478,000)
19	$1,199,000	0	(493,000)
20	$1,235,000	0	(508,000)
Present Worth	**$13,680,000**	**(3,927,000)**	**(5,621,000)**

Net Present Worth	**$4,132,000**

PAYBACK PERIOD ANALYSIS
Alternative 2B.1 Aegis Energy Services Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	3,927,000	0	3,927,000	0	3,927,000
1	289,000	705,000	4,216,000	705,000	3,511,000
2	298,000	726,000	4,514,000	1,431,000	3,083,000
3	307,000	747,000	4,821,000	2,178,000	2,643,000
4	316,000	770,000	5,137,000	2,948,000	2,189,000
5	326,000	793,000	5,463,000	3,741,000	1,722,000
6	336,000	817,000	5,799,000	4,558,000	1,241,000
7	346,000	841,000	6,145,000	5,399,000	746,000
8	356,000	866,000	6,501,000	6,265,000	236,000
9	367,000	892,000	6,868,000	7,157,000	(289,000)
10	378,000	919,000	7,246,000	8,076,000	(830,000)
11	389,000	947,000	7,635,000	9,023,000	(1,388,000)
12	401,000	975,000	8,036,000	9,998,000	(1,962,000)
13	413,000	1,004,000	8,449,000	11,002,000	(2,553,000)
14	425,000	1,035,000	8,874,000	12,037,000	(3,163,000)
15	438,000	1,066,000	9,312,000	13,103,000	(3,791,000)
16	451,000	1,098,000	9,763,000	14,201,000	(4,438,000)
17	464,000	1,131,000	10,227,000	15,332,000	(5,105,000)
18	478,000	1,164,000	10,705,000	16,496,000	(5,791,000)
19	493,000	1,199,000	11,198,000	17,695,000	(6,497,000)
20	508,000	1,235,000	11,706,000	18,930,000	(7,224,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
Alternative 2B.1 Aegis Energy Services Reciprocating Engines
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Required to Heat Sludge	1,350,000	829,000	BTU/hr	
Units operating	5			
Total Heat Output from Engines	1,623,000		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum amount of heat available	1,525,620		BTU/hr	
Additional heat required to meet maximum heat requirement	-175,620	-794,000	BTU/hr	
Gallons of #2 Fuel Oil Saved	19	12	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	2,700,000	1,658,000	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil saved	154,493	94,870	**249,363**	$/year

Between 0.2 and 0.8 MMBtu heat available to be used for other Plant demands

Appendix 9: Cost-Benefit Analysis for Alternative 2B.2

Alternative 2B.2 - Northeast Energy Systems (NES) Reciprocating Engines COST - BENEFIT ANALYSIS:
INSTALLATION OF NES RECIPROCATING ENGINES, MAXIMIZE DESIGN
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

Assumptions:

Three NES reciprocating engines installed: one 50kw and two 160 kw
Three units can fit in the space now 47.6
Total fuel gas requirement - 109.9 SCFM
All three engines will run at 100% load
Additional sludge in the digesterof 42,500 gallons per day
Assume additional sludge source is septic waste

CHP Electricity Gain:		370	kW total	160	
CHP Recoverable Heat Gain:		1,405,000	BTU/hr total	578,000	
Maximum Heat Available to Sludge Heat Exchanger		1,320,700	BTU/hr total	Assume 6% total heat loss in buried piping to and from Digester Building	
Increased Biogas Production		91,000	cf/d		
Sludge Disposal Costs:	$	97.35	/wet ton		
Average Electricity Cost	$	0.1057	/kWh		
Transmission Cost			/kWh		
Demand Charge	$	15.24	/kW		
Standby Rate			/kW per month		
Inflation		3.00%			
Capital Costs:					
CHP System Equipment Purchase:	$	1,158,870		Three engines plus one conditioning skid	
Automation of gas bleeding valves	$	50,000			
System Installation (35%)	$	423,105	Basis:		
Electrical and Instrumentation (15%)	$	181,000		Estimate does not reflect:	
Construction Contingency (30%)	$	544,000		demolition, building, heat, any specialized civil site, geotech	
Undefined Work Items (25%)	$	589,000			
Construction Sub-total	*$*	*2,945,975*			
20% OH&P	$	589,000			
Total construction	*$*	*3,534,975*			
Engineering Design, CA & RE Services (25%)	$	589,000			
Total Capital Investment	$	4,124,000		~+/- 30% for the report	
Annual O&M Costs:					
Cost per unit per hour	$	3.70			
Units		3			
Hours of operation per unit		8,700			
Total O&M	$	96,570			
Annual O&M Costs (Additional Over Existing System):					
Standby Rate Charge	$	-			
Sludge Disposal Volume Increase		3102.8	Annual Wet Tons		
Cost of Additional Sludge Disposal	$	302,061	Annually		
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	25,000			
Annual O&M Cost	$	327,061			
	$	**424,000**			
Annual Benefits (Additional Over Existing System):					
Increased biogas production		33,215,000	Annual SCF additional		
Reduction in kWh for compressors		192,720		22kW running 24 hours everyday	
Reduction in kWh From Grid		3,196,800	kWh/YR		
Value of Electricity Savings	$	429,860			
Reduction in Sludge Heating Requirements		81%			1742794.829
Reduction in Total Heating Requirements		75%			122,150
Fuel Oil #2 Savings	$	229,725		Assume 141,000 BTU/gal, $1.842/gal (Dec. 2017)	
Total Annual Savings	$	659,585	Annually		
Sludge Disposal Volume Reduced		0	Annual Wet Tons		
Value of Sludge Disposal Savings		$0.00	Annually		
Total Annual Savings	**$**	**659,585**			
Current Estimated Annual Electric Utility Bill	$	634,020		500,000 kWh/month *12 months	500000
	$	137,160		750 kW/month * 12 months	750
TOTAL	**$**	**771,180**			
% Reduction in Electric Utility Bill		**55.7%**			

NET PRESENT WORTH CALCULATION
Alternative 2B.2 - Northeast Energy Systems (NES) Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

Assumumptions

Inflation		3.00%
O&M Cost Factor		3.00%
Electrical Rate Cost Factor		3.00%
Annual O&M Cost	$	424,000
Annual Benefit	$	659,585
Initial Capital Invesment	$	4,124,000

Year	BENEFIT	COSTS	
	Annual Electric Benefit	CHP System Capital Cost	Annual O&M Cost
0	$0	(4,124,000)	0
1	$679,000	0	(437,000)
2	$700,000	0	(450,000)
3	$721,000	0	(463,000)
4	$742,000	0	(477,000)
5	$765,000	0	(492,000)
6	$788,000	0	(506,000)
7	$811,000	0	(521,000)
8	$836,000	0	(537,000)
9	$861,000	0	(553,000)
10	$886,000	0	(570,000)
11	$913,000	0	(587,000)
12	$940,000	0	(605,000)
13	$969,000	0	(623,000)
14	$998,000	0	(641,000)
15	$1,028,000	0	(661,000)
16	$1,058,000	0	(680,000)
17	$1,090,000	0	(701,000)
18	$1,123,000	0	(722,000)
19	$1,157,000	0	(743,000)
20	$1,191,000	0	(766,000)
Present Worth	**$13,192,000**	**(4,124,000)**	**(8,480,000)**

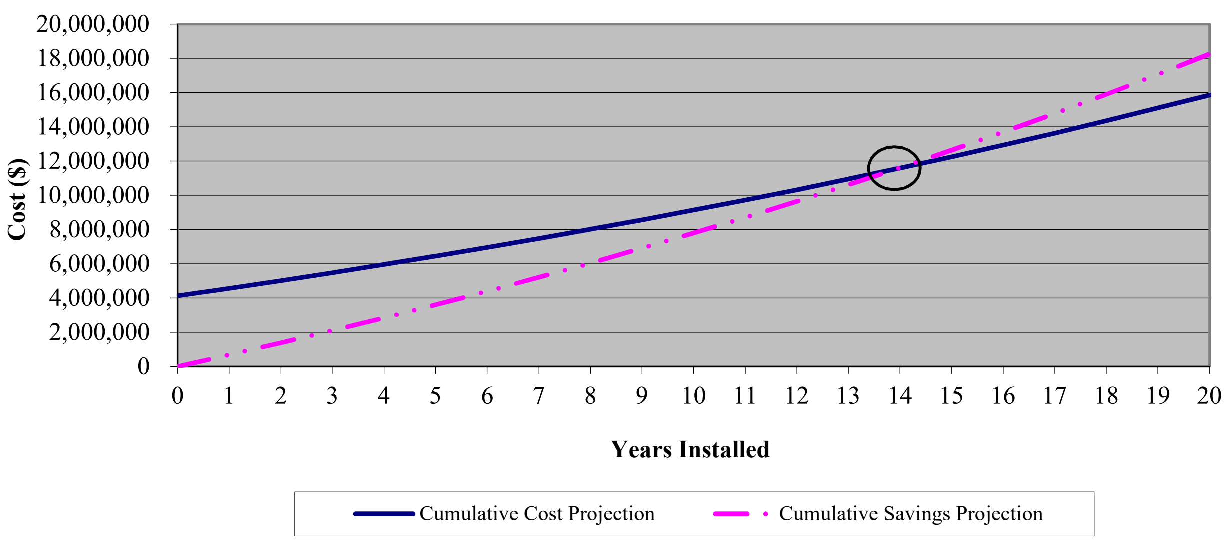
Net Present Worth	**$588,000**

PAYBACK PERIOD ANALYSIS
Alternative 2B.2 - Northeast Energy Systems (NES) Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018

20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	4,124,000	0	4,124,000	0	4,124,000
1	437,000	679,000	4,561,000	679,000	3,882,000
2	450,000	700,000	5,011,000	1,379,000	3,632,000
3	463,000	721,000	5,474,000	2,100,000	3,374,000
4	477,000	742,000	5,951,000	2,842,000	3,109,000
5	492,000	765,000	6,443,000	3,607,000	2,836,000
6	506,000	788,000	6,949,000	4,395,000	2,554,000
7	521,000	811,000	7,470,000	5,206,000	2,264,000
8	537,000	836,000	8,007,000	6,042,000	1,965,000
9	553,000	861,000	8,560,000	6,903,000	1,657,000
10	570,000	886,000	9,130,000	7,789,000	1,341,000
11	587,000	913,000	9,717,000	8,702,000	1,015,000
12	605,000	940,000	10,322,000	9,642,000	680,000
13	623,000	969,000	10,945,000	10,611,000	334,000
14	641,000	998,000	11,586,000	11,609,000	(23,000)
15	661,000	1,028,000	12,247,000	12,637,000	(390,000)
16	680,000	1,058,000	12,927,000	13,695,000	(768,000)
17	701,000	1,090,000	13,628,000	14,785,000	(1,157,000)
18	722,000	1,123,000	14,350,000	15,908,000	(1,558,000)
19	743,000	1,157,000	15,093,000	17,065,000	(1,972,000)
20	766,000	1,191,000	15,859,000	18,256,000	(2,397,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
Alternative 2B.2 - Northeast Energy Systems (NES) Reciprocating E
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Required to Heat Sludge	1,743,000	1,109,000	BTU/hr	
Units operating	3			
Total Heat Output from Engine	1,405,000		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

Maximum amount of heat available	1,320,700		BTU/hr	
Additional heat required to meet maximum heat requirement	422,300	-296,000	BTU/hr	
Gallons of #2 Fuel Oil Saved	19	16	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	2,641,400	2,218,000	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil saved	151,140	126,913	**229,725**	$/year
Deduct # Fuel Oil Cost	48,328			

Appendix 10: Cost-Benefit Analysis for Alternative 2B.3

Alternative 2B.3 - Tech3Solutions Reciprocating EnginesCOST - BENEFIT ANALYSIS:

INSTALLATION OF TECH 3 SOLUTIONS RECIPROCATING ENGINES, MAXIMIZE DESIGN

CHP AND AD UPGRADES STUDY

PITTSFIELD WWTP

	March 2018
20-City ENR CCI Index	10,958.78

Assumptions:

Three Tech3Solutions eciprocating engines installed: one 90kW and two 150kW
Three engines is the maximum number of units that can fit in the space now
Total fuel gas requirement - 94 SCFM
Engines will run full load all the time
Additional sludge in the digester of 32,000 gallons of day
Assume additional sludge source is septic waste

CHP Electricity Gain:		390	kW total		
CHP Recoverable Heat Gain:		2,026,811	BTU/hr total	777,968 BTU/Hr/unit	
Maximum Heat Available to Sludge Heat Exchanger		1,905,202	BTU/hr total	Assume 6% total heat loss in buried piping to and from Digester Building	
Increased Biogas Production		68,000	cf/d		
Sludge Disposal Costs:	$	97.35	/wet ton		
Average Electricity Cost	$	0.1057	/kWh		
Transmission Cost			/kWh		
Demand Charge	$	15.24	/kW		
Standby Rate			/kW per month		
Inflation		3.00%			
Capital Costs:					
CHP System Equipment Purchase:	$	1,135,000		Three engines plus one pre-conditioning skid ($100,000 estimate for the skid)	
Automation of gas bleeding valves	$	50,000			
System Installation (35%)	$	414,750	Basis:		
Electrical and Instrumentation (15%)	$	178,000		Estimate does not reflect:	
Construction Contingency (30%)	$	533,000		demolition, building, heat, any specialized civil site, geotech	
Undefined Work Items (25%)	$	578,000			
Construction Sub-total	*$*	*2,888,750*			
20% OH&P	$	578,000			
Total construction	*$*	*3,466,750*			
Engineering Design, CA & RE Services (25%)	$	578,000			
Total Capital Investment	$	4,045,000		~+/- 30% for the report	
Annual O&M Costs:					
Cost per unit per hour	$	3.00			
Units		3			
Hours of operation per unit		8,700			
Total O&M	$	78,300			
Annual O&M Costs (Additional Over Existing System):					
Standby Rate Charge	$	-			
Sludge Disposal Volume Increase		2336.3	Annual Wet Tons		
Cost of Additional Sludge Disposal	$	227,435	Annually		
Maintenance, Expendable Mat'ls, Gas Analysis Costs	$	25,000			
Annual O&M Cost	$	252,435			
	$	**331,000**			
Annual Benefits (Additional Over Existing System):					
Increased biogas production		24,820,000	Annual SCF additional		
Reduction in kWh for compressors		192,720		22kW running 24 hours everyday	
Reduction in kWh From Grid		3,369,600	kWh/YR		
Value of Electricity Savings	$	451,777			
Reduction in Sludge Heating Requirements		123%			1,553,060
Reduction in Total Heating Requirements		114%			122,150
Fuel Oil #2 Savings	$	289,188		Assume 141,000 BTU/gal, $1.842/gal (Dec. 2017)	
Total Annual Savings	$	740,965	Annually		
Sludge Disposal Volume Reduced		0	Annual Wet Tons		
Value of Sludge Disposal Savings		$0.00	Annually		
Total Annual Savings	**$**	**740,965**			
Current Estimated Annual Electric Utility Bill	$	634,020		500,000 kWh/month *12 months	500000
	$	137,160		750 kW/month * 12 months	750
TOTAL	**$**	**771,180**			
% Reduction in Electric Utility Bill		**58.6%**			

NET PRESENT WORTH CALCULATION
Alternative 2B.3 - Tech3Solutions Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

Assumumptions

Inflation		3.00%
O&M Cost Factor		3.00%
Electrical Rate Cost Factor		3.00%
Annual O&M Cost	$	331,000
Annual Benefit	$	740,965
Initial Capital Invesment	$	4,045,000

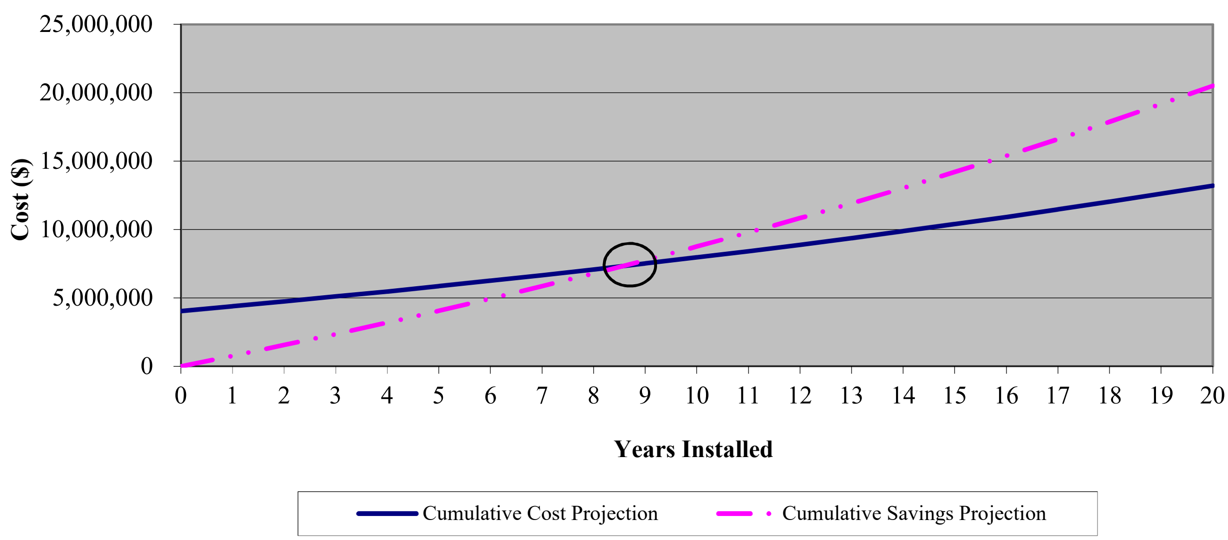
Year	BENEFIT Annual Electric Benefit	COSTS CHP System Capital Cost	 Annual O&M Cost
0	$0	(4,045,000)	0
1	$763,000	0	(341,000)
2	$786,000	0	(351,000)
3	$810,000	0	(362,000)
4	$834,000	0	(373,000)
5	$859,000	0	(384,000)
6	$885,000	0	(395,000)
7	$911,000	0	(407,000)
8	$939,000	0	(419,000)
9	$967,000	0	(432,000)
10	$996,000	0	(445,000)
11	$1,026,000	0	(458,000)
12	$1,056,000	0	(472,000)
13	$1,088,000	0	(486,000)
14	$1,121,000	0	(501,000)
15	$1,154,000	0	(516,000)
16	$1,189,000	0	(531,000)
17	$1,225,000	0	(547,000)
18	$1,261,000	0	(564,000)
19	$1,299,000	0	(580,000)
20	$1,338,000	0	(598,000)
Present Worth	**$14,819,000**	**(4,045,000)**	**(6,621,000)**

Net Present Worth	**$4,153,000**

PAYBACK PERIOD ANALYSIS
Alternative 2B.3 - Tech3Solutions Reciprocating Engines
CHP AND AD UPGRADES STUDY
PITTSFIELD WWTP

March 2018
20-City ENR CCI Index 10,958.78

YEAR	Cost	Benefit	Cumulative Cost	Cumulative Benefit	Cumulative Cost-Benefit
0	4,045,000	0	4,045,000	0	4,045,000
1	341,000	763,000	4,386,000	763,000	3,623,000
2	351,000	786,000	4,737,000	1,549,000	3,188,000
3	362,000	810,000	5,099,000	2,359,000	2,740,000
4	373,000	834,000	5,472,000	3,193,000	2,279,000
5	384,000	859,000	5,856,000	4,052,000	1,804,000
6	395,000	885,000	6,251,000	4,937,000	1,314,000
7	407,000	911,000	6,658,000	5,848,000	810,000
8	419,000	939,000	7,077,000	6,787,000	290,000
9	432,000	967,000	7,509,000	7,754,000	(245,000)
10	445,000	996,000	7,954,000	8,750,000	(796,000)
11	458,000	1,026,000	8,412,000	9,776,000	(1,364,000)
12	472,000	1,056,000	8,884,000	10,832,000	(1,948,000)
13	486,000	1,088,000	9,370,000	11,920,000	(2,550,000)
14	501,000	1,121,000	9,871,000	13,041,000	(3,170,000)
15	516,000	1,154,000	10,387,000	14,195,000	(3,808,000)
16	531,000	1,189,000	10,918,000	15,384,000	(4,466,000)
17	547,000	1,225,000	11,465,000	16,609,000	(5,144,000)
18	564,000	1,261,000	12,029,000	17,870,000	(5,841,000)
19	580,000	1,299,000	12,609,000	19,169,000	(6,560,000)
20	598,000	1,338,000	13,207,000	20,507,000	(7,300,000)



DIGESTION / BIOGAS HEAT REQUIREMENTS
Alternative 2B.3 - Tech3Solutions Reciprocating Engines
PITTSFIELD WWTP
CITY OF PITTSFIELD, MA

TASK - Evaluate savings of #2 Fuel Oil to heat sludge

Basis:

	Winter Loading Conditions	Summer Loading Conditions		
Maximum Heat Required to Heat Sludge	1,553,000	974,000	BTU/hr	
Units operating	3			
Total Heat Output from Engine	2,026,811		BTU/hr	
Assume 6% total heat loss in buried piping to and from Digester Building				

Calculations:

Maximum amount of heat available to be supplied to sludge heat exchanger	1,905,202		BTU/hr	
Additional heat required to meet maximum heat requirement	-352,202	-1,052,811	BTU/hr	
Gallons of #2 Fuel Oil Saved	22	14	gal/hr	#2 Fuel Oil
Average Heating Value of #2 Fuel Oil	141,000	141,000	BTU/gal	
Maximum Heat Input To Boiler	3,106,000	1,948,000	BTU/hr	
Assume 50% efficiency of transfer of heat to steam heat exchanger				
Cost of #2 Fuel Oil saved	177,724	111,464	**289,188**	$/year

Between 0.35 and 1.1 MMBtu heat available to be used for other demands at the Plant