Township of Livingston, New Jersey
Biopower Feasibility Study
Water Pollution Control Facility

April 2013

HMM Project No. 305750

Hatch Mott MacDonald

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April 18, 2013

Mr. Ronald H. Reisman
Renewable Energy Incentive Program
New Jersey's Clean Energy Program
75 Lincoln Highway, Suite 100
Iselin, New Jersey 08830

Re: Livingston Township, Essex County, New Jersey
Water Pollution Control Facility (WPCF)
Combined Heat and Power Feasibility Study
New Jersey Clean Energy Program – 2012 Renewable Energy Incentive Program
No. REIPR - 12227
HMM Job No. 305750

Dear Mr. Reisman:

On behalf of the Township of Livingston, Hatch Mott MacDonald (HMM) is submitting herewith a Biopower Feasibility Study for the above referenced project.

We trust that the enclosed document meets the requirements of the New Jersey Clean Energy Program. Should you have any questions regarding this matter, please do not hesitate to contact me.

Very truly yours,

Hatch Mott MacDonald

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DLK:mi

Enclosures

cc: Richard Calbi, Jr., PE, PP, Township Engineer
Joseph Greco, WPCF Superintendent
John Schneekloth, PE, HMM

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Executive Summary

The Township of Livingston (Township) owns, operates and maintains a sanitary sewer collection system and Water Pollution Control Facility (WPCF) located at 81 Naylon Avenue that serve the residents of the Township as well as the commercial properties. The wastewater treatment plant includes the anaerobic digestion of sludges generated from the wastewater treatment process. Anaerobic digestion generates methane gas. A portion of the methane gas is currently used to provide heat for proper digester operations. The remaining gas is disposed of by burning in a flare. The Township has requested that Hatch Mott MacDonald (HMM) study the feasibility of using digester gas to generate electricity and hot water on site.

The results of this Feasibility Study demonstrate that a CHP system project at the Livingston Township WPCF would be technically, economically and legally feasible. The project also provides an environmental benefit by reducing the WPCF's overall carbon footprint, reducing air emissions and fulfilling the Township's desire to implement green projects at the WPCF. It is HMM's recommendation that the Township proceed with the design and construction of a CHP system.

1.0 Introduction

1.1 Background

The Township of Livingston (Township) owns and operates a sanitary sewer collection system and Water Pollution Control Facility (WPCF) located at 81 Naylon Avenue. The Township is charged with the responsibility of managing the WPCF and sanitary sewer collection system and continuing to provide adequate and reliable sewer service to its many customers and the public. The Township retained the services of Hatch Mott MacDonald (HMM) to complete the preparation of a Feasibility Study for the installation of a combined heat and power (CHP) system at the WPCF, utilizing methane gas produced by on site digesters. This study will evaluate the technical, economic and legal feasibility of a potential CHP project and make a recommendation as to whether the Township should proceed.

The Township's WPCF was originally constructed in 1938. Over the years, the WPCF has been expanded and upgraded to meet the needs of the growing Township and to comply with more stringent discharge permit requirements. The WPCF capacity was increased from 2.0 million gallons per day (MGD) to 4.2 MGD in 1979 and the facility was upgraded to provide Level 4 (Tertiary) Treatment beginning in 1987 and completed in 1992. In 2000, the Township completed modifications and upgrades to the WPCF to allow the plant uprating from 4.2 MGD to 4.62 MGD.

During 2011, the Township completed two (2) projects at the WPCF. One project included installation of submersible mixers in the first pass of each of the two (2) Nitrification Aeration Tanks to meet the new monthly average nitrate limits. The other project replaced the Main Aeration Blowers Motor Control Centers.

1.2 Purpose of the Study

Based on the evaluation conducted as part of the Township's Wastewater Master Plan (WMP), it appears that the construction of a combined heat and power (CHP) engine/generator set may be beneficial to the Township. The existing facilities can be modified to improve methane gas production and anaerobic digester gas can be used to produce electricity and heat, offsetting the plant's operating costs. This Feasibility Study will analyze the technical, economic and legal feasibility of installing a CHP system at the Township's WPCF.

The goals of the Feasibility Study and the proposed CHP project are as follows:

- Evaluate the economic and technical engineering feasibility of a CHP system at the Livingston WPCF;
- Determine permitting requirements;
- Pending results of feasibility study, design and install CHP system to generate electricity and heat from Livingston WPCF's two (2) anaerobic digesters; and,
- CHP system will provide electricity and heat to the WPCF.

This report is arranged to include specific requirements established by the New Jersey Clean Energy Program.

2.0 Technical Feasibility

2.1 Existing Facility

The Livingston Township WPCF utilizes sewage grinder/augers and grit removal followed by primary settling tanks, first stage aeration tanks, first stage secondary settling tanks, intermediate pumping, and a second stage activated sludge system to achieve nitrification. The second stage consists of aeration tanks and nitrification settling tanks. Advanced treatment of the 2nd stage nitrification effluent includes microscreens and disinfection using chlorine. Sludge from the primary settling tanks and thickened waste activated sludge from the first stage nitrification activated sludge processes is anaerobically digested and disposed of off-site.

Sludge processing consists of anaerobically digesting primary sludge and air floatation thickened first and second stage waste activated sludge. The digestion process is a conventional two-stage system consisting of a complete mix first stage in the Primary Sludge Digester and a solids-liquid separation second stage in the Secondary Sludge Digester.

2.1.1 Problems Noted

The Livingston WPCF produced on average about 40,000 cubic feet per day of digester gas. A portion of the digester gas generated is used for sludge heating and generating hot water or is burned in a flare at the site. The digester flare (waste gas burner) currently operates 24 hours per day. Approximately 21,000 cubic feet per day of digester gas is wasted to flaring. Since flared gas is a wasted source of energy, it may be advantageous to use the digester gas to produce electric power and heat.

2.1.2 Proposed Modifications

The Township has retained the services of Hatch Mott MacDonald (HMM) to conduct this CHP Feasibility Study to evaluate the beneficial use of the methane gas generated by the WPCF's anaerobic digesters to produce electricity and hot water. Electricity would be used to offset utility power cost and hot water could offset natural gas consumed for heating.

2.2 Combined Heat and Power System Overview

One proven means for reducing electric power consumption at wastewater treatment plants is to use digester gas produced from anaerobic digestion as a fuel for the combined production of heat and electrical power. Systems that couple electric generation with thermal energy for process heating are defined as combined heat and power

(CHP), or "cogeneration." At the Livingston Township WPCF, thermal energy can be used to provide the heat required to operate the two (2) anaerobic digesters. Electrical power can be used to operate treatment plant equipment. Excess heat can be used to heat other onsite facilities. In summary, advantages of a CHP system include:

- Anaerobic digestion processes provide a "free" source of fuel for CHP systems
- CHP systems can supply all of the heat required by the anaerobic digestion process as well as heat for other on-site buildings
- CHP systems can offset a significant portion of the plant's electric power demand (electrical energy represents one of the largest costs associated with operating a wastewater treatment plant)
- Generated electricity is available for immediate use
- Digester gas serves as a no cost long term fuel supply

The following figure illustrates the advantages of operating a CHP system.

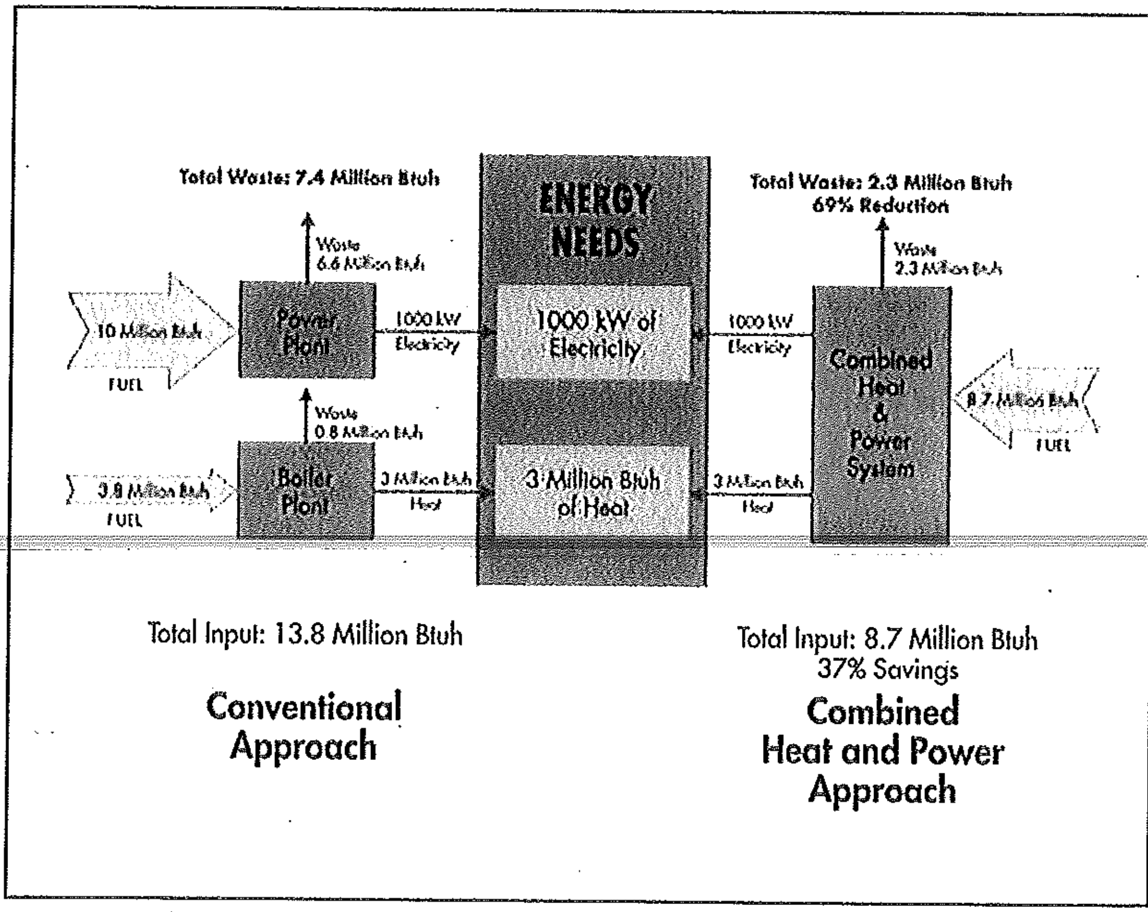

Figure 2-1 Comparison of CHP and Conventional Approaches to Energy Production (EPA, 2010)

2.2.1 Components of a CHP System

CHP Systems typically include an engine-generator~~/CHP unit along with~~ a digester gas conditioning system. The engine-generator is used to produce electricity and heat to be used at the facility. The CHP unit will burn available digester gas. Heat from the engine jacket water and exhaust is recovered as hot water and used to heat digester contents and buildings through a heat recovery system. When heat recovery is not required, the CHP unit is cooled by a remote mounted radiator. Combustion and cooling air for the engine is drawn from the surrounding outdoor area. The digester gas conditioning system is used to clean and dry raw digester gas to meet the gas quality requirements of the engine-generator, generally provided by the engine-generator manufacturer.

2.3 Source of Feedstock Material

The Livingston Township WPCF will utilize digester gas produced from two (2) onsite anaerobic digesters to fuel the proposed CHP system. Currently, the average quantity of gas produced is about 40,000 cu ft/day, which results in an annual production of about 14,600,000 cu ft/year. The digester gas from the onsite primary anaerobic digester was tested and the heating value is about 612 Btu/ft^2 (gross heat of combustion).

2.3.1 Biosolids Generation

Table 2.1 shows the 2012 biosolids generation data at the Township's WPCF. Biosolids generated on site include digested primary settling tank sludge and thickened waste activated sludge (WAS). Currently digested sludge is trucked off site for disposal. A summary of the sludge production is provided below.

Table 2.1 – Biosolids Generation

Primary Sludge	
Annual average daily flow	22,250 gpd
Peak day	27,519 gpd
Average percent total solids	2.82%
Average pounds per day total solids	5,499.2 lbs/day
Average percent total volatile solids	84.05%
Average pounds per day volatile solids	4,622.2 lbs/day
Thickened Waste Activated Sludge	
Annual average daily flow	2,522 gpd
Peak day	5,565 gpd

Average percent total solids	5.10%
Average pounds per day total solids	1,577.6 lbs/day
Average percent total volatile solids	81.28%
Average pounds per day volatile solids	1,282.2 lbs/day

2.3.2 Digester Design

The sludge digestion process includes one (1) primary digester and one (1) secondary digester. A summary of design parameters for the digesters is provided below.

Primary Digester

Diameter	65.0 feet
Operating liquid level	212.2 feet
Bottom of tank level	181.0 feet
Liquid volume	107,181 ft^3 = 801,817 gallons
Cover	Fixed
Mixing	Perth Mixing (not operational)

Secondary Digester

Diameter	65.0 feet
Operating liquid level	210.2 feet
Bottom of tank level	181.0 feet
Liquid volume	97,226 ft^2 = 727,252 gallons
Cover	Floating
Mixing	None

2.4 Anaerobic Digester Biogas Generation

Historical gas production data was provided by Livingston Township. The gas production rates used as a design basis for this study are shown in Table 2.2. The plant operator has indicated that the existing perth mixing system, installed in the Primary Digester in 1975, may not be operating properly. Consequentially, the Primary Digester may receive little to no mixing, likely resulting in reduced gas production. HMM developed calculations to determine the volume of gas that could theoretically be produced under optimal conditions. Appendix A contains a summary of 2012 plant data which was used for the purposes of this study.

Table 2.2 – 2012 Biogas Generation

Description	Volume (cu ft/day)[1]
2012 Average	38,380
2012 Minimum	33,916
2012 Maximum	42,390
Theoretical (expected)	60,224[2]

[1]Measured 62% methane dry gas, flow is wet gas at 95 deg. F at approximately 15.7 psia.
[2]See Table 2.3 for Theoretical calculation

In general, volatile solids are the source of gas production in the digesters. Primary sludges normally contain more volatile solids and therefore generate more gas per pound of sludge treated compared to waste activated sludge. Calculated/Theoretical gas production is based on the following:

Cubic feet of methane:

$$V_{CH4} = 5.62\,(S_0 - S)(Q)(8.24) - 1.42P_x$$

Where:
V_{CH4} = Cubic feet of methane/day
S_0 = Influent BOD_L or COD
S = Effluent BOD_L or COD
Q = Flow Mgal/day
P_x = net mass of cells produced per day, lb/day

$$P_x = \frac{Y\,[(S_0 - S)(Q)(8.24)}{1 + k_d\theta_c}$$

Where:
Y = yield coefficient, lb/lb (0.05)
k_d = endogenous coefficient d^{-1} (0.02)
Q_c = mean cell residence time or hydraulic retention time

Other design assumptions:

- Digester gas is 65% methane

Using current primary sludge data and WAS the following gas production rates can be calculated.

Using
Y = yield coefficient, lb/lb (0.05)
k_d = endogenous coefficient d^{-1} (0.02)
Θ_c = mean cell residence time or hydraulic retention time of 20.22 days
S_0 = Influent BOD_L or COD of 42,825.6 mg/L
S = Effluent BOD_L or COD of 14,28.8 mg/L
Q = Flow Mgal/day in table below

P_x = net mass of cells produced per day, lb/day.

The cubic feet of methane produced per day, V, can be calculated and is shown in the table below.

Table 2.3 – Calculated Digester Gas Production

	Primary Sludge Flow (gpd)	Thickened WAS Flow (gpd)	Total Flow (gpd)	Px Solids (lbs/day)	V Methane (cu ft/day)	V Gas (cu ft/day)[1]	V Gas (cu ft/day)[2]
Sludge Flow	22,250	2,522	25,782	160	22,101	52,288	60,224

[1]Assumed 65% methane, dry gas at 32 deg. F and 14.7 psia.
[2]Assumed 65% methane, dry gas at 95 deg. F and 14.7 psia.

As noted above, the volume of gas created is directly related to the reduction of volatile solids (volatile solids are the portion of the sludge that is consumed by the anaerobic bacteria to produce methane). An analysis of volatile solids reduction shows the digester is performing near to theoretical performance. Based on the volatile solids reduction it would be expected that gas production should be closer to the theoretical flow of 60,224 cu fit/day. The discrepancy between actual gas flow and expected could be caused by gas leaks, inaccurate gas flow measurement or some other process related issue such as poor mixing.

The Township may want to consider digester improvements, such as a new mixing system, membrane covers and finding and fixing leaks in order to optimize digester gas production. The CHP system will be sized with future improved gas production in mind.

2.5 Analysis of CHP System Type

Alternatives for cogeneration with the quantities of digester gas generated at the WPCF are limited. Options for CHP technology would include either an internal combustion engine or a microturbine.

2.5.1 Internal Combustion Engine

Internal combustion engines are the most widely used time-tested CHP technology for use with digester gas. Spark ignition engines, as opposed to compression ignition engines, are most commonly used for digester gas applications. Figure 2-2 shows a process diagram of a typical internal combustion engine based CHP system. Table 2.4 shows typical internal combustion engine performance characteristics (Lean Burn Engine).

Table 2-4 Internal Combustion Engine Performance Characteristics (Lean Burn Engine) (EPA 2010)

Performance Characteristics	Lean Burn Engine
Size (kW)	110 – 2,700
Electrical Efficiency (%)	30 -38
Thermal Efficiency (%)	41 – 49
Equipment Cost ($/kW)	465 -1,600
Maintenance Cost ($/kWh)	0.01 – 0.025
Availability (%)	90 – 96
Overhaul Frequency (hours)	28,000 – 90,000
NOx Emissions (lb/million Btu)	0.015 – 0.870
CO Emissions (lb/million Btu)	0.163 – 2.160

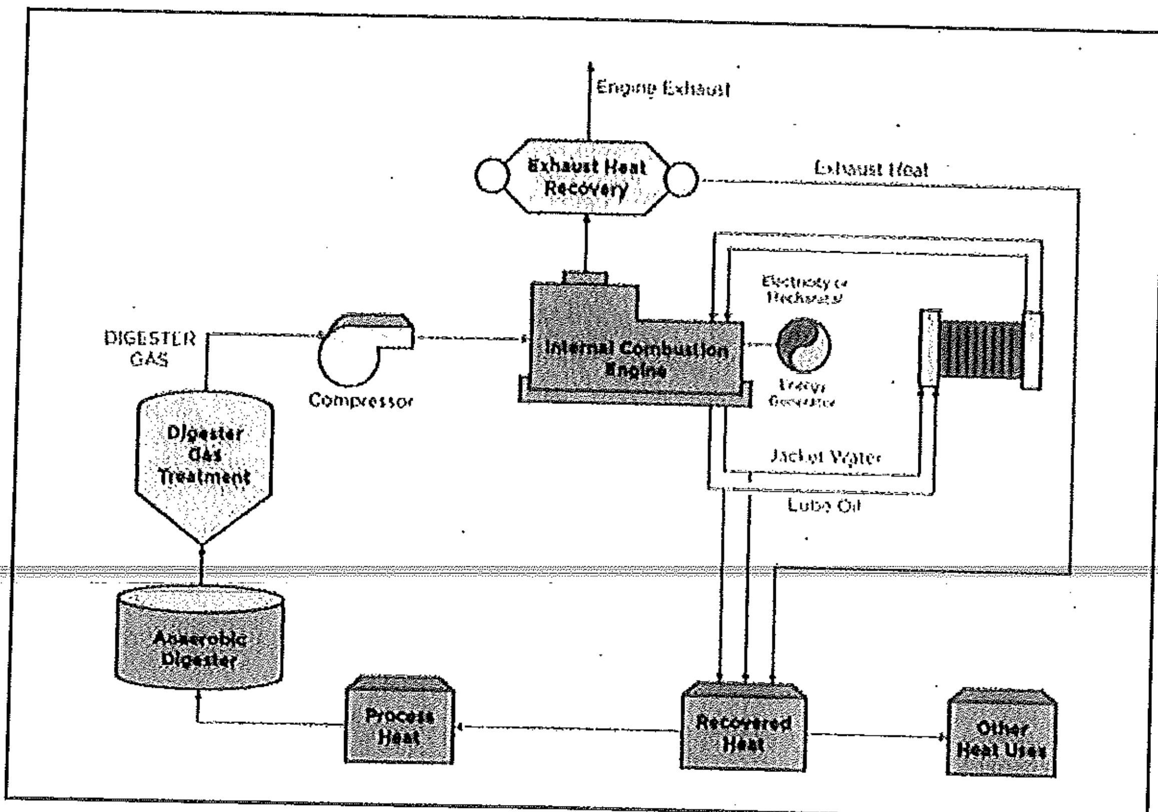

Figure 2-2 Process Flow Diagram of Typical Internal Combustion Engine CHP System (EPA, 2010)

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Advantages to using Internal Combustion Engines for CHP include:

- Availability in a wide range of fuel input requirements
- Reliable, well-proven technology
- Available from several reputable manufacturers
- Greatest combined electrical and thermal efficiency of all CHP technologies
- Less sensitive to siloxanes and hydrogen sulfide in fuel than other CHP technologies
- Easy maintenance
- Requires fuel pressurized to only 3 – 5 psig

Disadvantages to using Internal Combustion Engines for CHP include:

- Requires fuel pretreatment to avoid potential engine damage or efficiency loss
- Requires continual cooling

2.5.2 Microturbine

Microturbines are a relatively new CHP technology, first introduced in 1995. They have become more popular in recent years due to their clean emissions and relatively small sizes. Microturbines are essentially small high-speed recuperated combustion gas turbines and comprise the smallest capacity CHP units available. Exceptionally clean fuel is required for effective operation of these units. Figure 2-3 shows a process diagram of a typical microturbine system. Table 2.5 shows typical microturbine performance characteristics.

Table 2-5 Microturbine Performance Characteristics (EPA 2010)

Performance Characteristics	Microturbine
Size (kW)	30 - 250
Electrical Efficiency (%)	26 - 30
Thermal Efficiency (%)	30 - 37
Equipment Cost ($/kW)	800 – 1,650
Maintenance Cost ($/kWh)	0.012 – 0.025
Availability (%)	85 - 90
Overhaul Frequency (hours)	30,000 – 50,000
NOx Emissions (lb/million Btu)	0.12 – 0.190
CO Emissions (lb/million Btu)	0.520 – 1.760

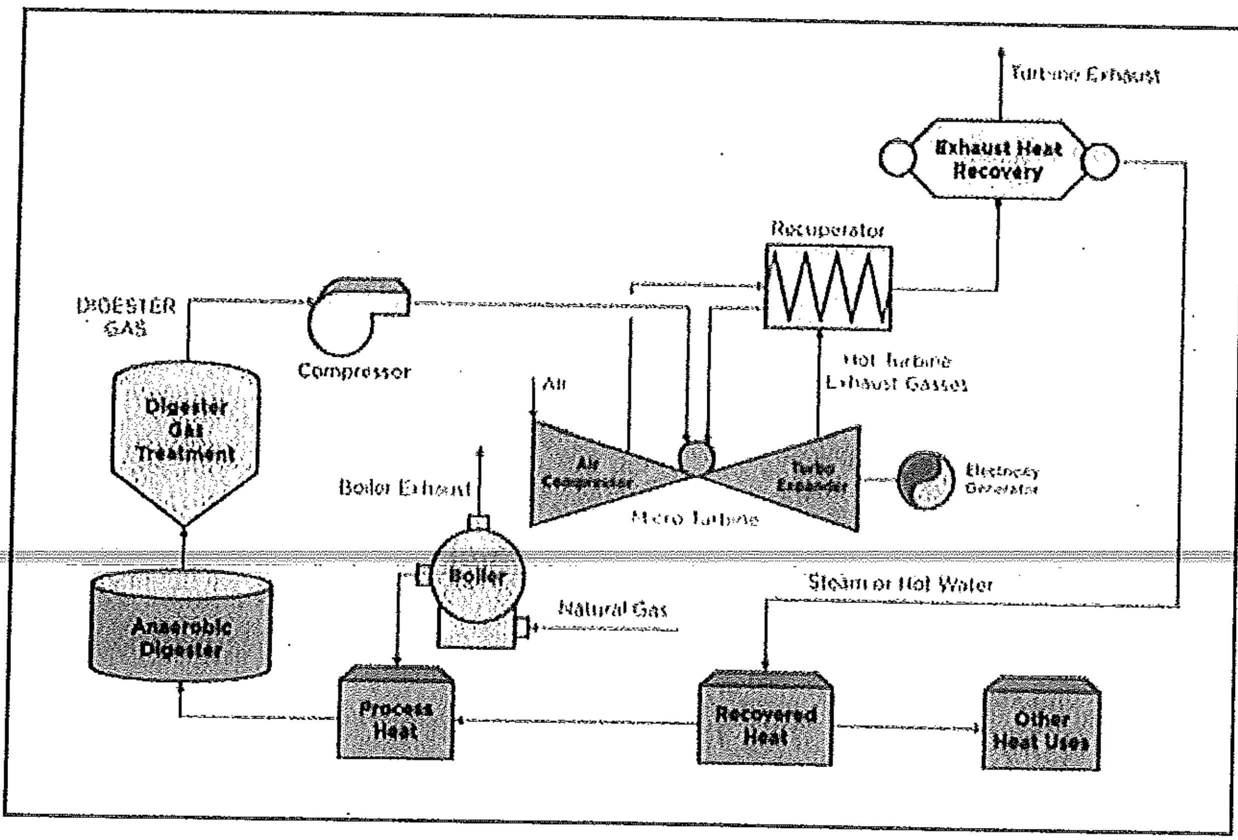

Figure 2-3 Process Flow Diagram of Typical Microturbine System (EPA, 2010)

Advantages to using Microturbines for CHP include:

- Available in smaller size ranges (30 to 250 kW) for smaller gas flows
- Produce low levels of NOx and CO exhaust emissions
- Relatively quiet and suitable for outdoor installation

Disadvantages to using Microturbines for CHP include:

- Low electrical and thermal efficiencies compared to other CHP technologies
- Require significant fuel gas cleanup
- High pressure fuel (75 to 100 psig), requiring compression
- Warm weather (above 59°F) and high elevation reduce power generation and fuel efficiency
- Due to issues with fuel treatment, have not demonstrated a long service life
- Competition is limited

2.5.3 CHP Type Recommendation

It is HMM's recommendation that internal combustion engine technology is the best fit for the Livingston Township WPCF's CHP system. A combustion engine is a well-proven and reliable technology, providing higher energy and thermal production efficiencies than the microturbine at a lower cost. The internal combustion engine will be more reliable, perform better, cost less and deliver a longer service life than the microturbine technology. Appendix B shows a process flow diagram for an internal combustion engine CHP system to be installed at the WPCF.

2.6 Analysis of CHP System Size

The engine-generator will generate electricity and hot water for onsite heating by burning conditioned digester gas. Heat from the engine jacket and exhaust will be recovered as hot water and used to heat digester contents and/or onsite buildings through a heat recovery system.

In order to size the CHP system, the average energy production was calculated for each of the monthly flow scenarios: 2012 minimum, 2012 average, 2012 maximum and theoretical. The results are summarized in Table 2.6 below. Based on experience and communication with various CHP system manufacturers, most engines need to consume between 9,200 – 9,600 Btu/kWhe to run most efficiently. HMM recommends that the CHP system be sized for future improved gas production and therefore, as per Table 2.6, it should be rated between 106 kW and 150 kW.

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Table 2.6 – CHP System Sizing

Monthly Gas Production	Available Volume	Available Energy	Possible Electricity Production [1,2]	Possible Heat Recovery [3]
	cu ft/day	Btu/hr	kW	Btu/hr
2012 Minimum	33,916	794,200	85	420,926
2012 Average	38,380	898,732	96	476,328
2012 Maximum	42,390	992,633	106	526,096
Theoretical	60,224	1,410,245	150	747,430

[1] Required Feedstock = 9,200 - 9,600 Btu/kWhe (9,400 Btu/kWhe average)
[2] 562 Btu/cu ft at 95° F and 14.7 psia
[3] Thermal efficiency = 53%

See Appendix C for a summary of proposal performance characteristics received for various engine options within the recommended size range.

2.7 Digester Gas Composition

Table 2.7 summarizes the results of a digester gas analysis performed by Atlantic Analytical Laboratory (AAL) in November 2012. Gas samples were taken from the Primary Digester and a Gas Composition Report was submitted, summarizing the findings. Appendix D contains the Gas Composition Report prepared by AAL. Also included in Table 2.7 are typical gas sample results that would be expected for an anaerobic digester servicing this area. The gas composition analysis shows siloxane levels much lower than what would typically be expected. For this study, HMM assumed that siloxane levels are within the typical range and siloxane treatment will be required. Additional gas sampling is required to confirm siloxane and other gas properties.

Table 2.7 – Digester Gas Analysis Lab Results for Detected Parameters

Parameter	Unit	Nov-2012 Result	Typical Result
Nitrogen	% v/v	0.64	0.2 – 2.5
Carbon Dioxide	% v/v	27.6	20 - 45
Methane	% v/v	61.7	60 -70
Carbon Content	% w/w	44.8	
Hydrogen Content	% w/w	9.29	
Oxygen Content	% w/w	45.2	
Nitrogen Content	% w/w	0.67	
Gross Heat of Combustion (SAT)	Btu/ft^2	612	
Net Heat of Combustion LHV	Btu/ft^2	561	520 - 580
Gross Heat of Combustion HHV	Btu/ft^2	624	600 - 650
Hydrogen Sulfide	ppm v/v	877	200 – 2,500
Carbonyl Sulfide	ppm v/v	1.46	

Toulene	ppm v/v	0.47	
Octamethylcyclotetrasiloxane	ppm v/v	0.021	0.41[1]
Decamethylcyclopentasiloxane	ppm v/v	0.042	2.51[1]

[1] Typical siloxane levels listed are average values found in digester gas at the Hanover Sewerage Authority (HSA) WWTP. It is expected that the WPCF's digester gas would be similar in composition to the HSA WWTP's digester gas.

Table 2.8 summarizes typical biogas quality requirements that need to be met for use in most internal combustion cogeneration engines. These requirements were provided by Kraft Power in February 2013. The characteristics and requirements presented in Tables 2.7 and 2.8 were used as a design basis for this report.

Table 2.8 – Minimum Requirements to Gas Quality for Biogas Cogeneration Engines

Parameter	Value	Unit
Methane number	>80	N/A
Calorific value	>5	kWh/Nm^2
Chlorine content	< 80	mg/Nm^2_{CH4}
Fluorine content	< 40	mg/Nm^2_{CH4}
Total-Fluorine-Chloriner	<80	mg/Nm^2_{CH4}
Dust Content	<10	mg/Nm^2_{CH4}
Oil vapour	<400	mg/Nm^2_{CH4}
VOCs	<25	mg/Nm^2_{CH4}
Silicon content	<2	mg/Nm^2_{CH4}
Sulphur content	<200	mg/Nm^2
Hydrogen sulphide	<150 / <228	ppm
Hydrogen sulphide	<228	mg/Nm^2
Ammonia content	<40	ppm
Ammonia content	<20	mg/Nm^2
Relative humidity	<60	%
Temperature gas mixer outlet	10 – 20	°C

2.8 Waste Materials

Digested sludge is currently trucked off site in liquid form to the Passaic Valley Sewerage Commissioners (PVSC) facility in Newark, New Jersey for further treatment and final disposal. Liquid waste streams are discharged to the head of the WPCF for treatment. No additional digester waste material will be generated due to installation of a CHP system.

Siloxane and sulfur removal media used in the biogas conditioning system will need to be changed out about once every six months. The gas conditioning manufacturer will likely dispose of and replace waste media under a service contract.

2.9 Site Utility Demands

2.9.1 Electrical Demands

The following Table 2.9 shows the current WPCF monthly electricity demands based on electricity bills that were provided to HMM by the WPCF Superintendent.

Table 2.9 Electricity Demand Summary

Description	kWh
Monthly Average	288,294
Monthly Maximum	351,677
Monthly Minimum	235,000

Electricity produced from the CHP system can be used to offset the cost of utility power. A 150 kW engine-generator can produce up to 86,400 kWh per month, assuming it operates 80% of the time (20% maintenance down time). This represents approximately 30 percent of the average plant demand.

2.9.2 Site Heating Demands

Table 2.10 below shows approximate heat demands for the WPCF.

Table 2.10 2012 Site Heating Demands

Description	2012 Heat Demand Annual Average (Btu/hr)	2012 Winter Heat Demand (Btu/hr)	Current Fuel Source
Digester Influent Sludge Heating	303,000	545,300	Raw digester gas
Advanced Treatment Building (ATB) boilers (ATB building heat and hot water)	60,500	122,200	Natural gas
Other (Lab Building)	91,800	91,800	Natural gas
Total 2012 Heat Demand	455,300	759,305	

A 150 kW CHP engine can produce up to 800,000 Btu/hour of heat, recovered as hot water. Hot water generated by the CHP will primarily be used to heat the anaerobic digesters. Hot water from the CHP system can also be tied into the existing hot water loop, located inside of the Advanced Treatment Building, replacing up to 122,200 Btu/hour of natural gas currently being used for building heat.

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Hot water produced from the CHP system can be used to offset the cost of natural gas. The existing sludge boiler/heat exchanger used for sludge heating is nearing the end of its useful life. The CHP system would allow the existing boiler to be taken out of service. Hot water from the CHP would be fed directly into the existing sludge heat exchanger. Alternatively, a new sludge heat exchanger could be installed with hot water provided by the CHP. In both cases, the existing boilers, located in the Advanced Treatment Building, could be used as backup to the CHP for sludge heating.

Note that the "other" heat demands shown in Table 2-10 cannot be replaced by CHP hot water.

Any remaining CHP produced heat may potentially be used to heat existing buildings that are not currently heated.

2.10 Electrical System Upgrades

Electrical system upgrades associated with this project include new electrical conduit runs, tying the CHP system into the existing on-site substation and installing a new electrical switch gear. There will also be work related to complying with electrical utility company, JCP&L, connection requirements. It is recommended that existing conduits be investigated in order to determine if they can be used for the substation tie in.

2.11 Other Issues

2.11.1 Digester Mixing

The WPCF Superintendent has indicated that the existing "Perth" sludge mixing system in the Primary Digester has not worked for years. Proper mixing is an important consideration in achieving optimum process performance. As previously discussed, methane gas produced as a by-product of anaerobic digestion will be used to fuel the CHP system. Effective mixing of digester contents is important for process stability and maximizing gas production. A lack of adequate mixing in the Primary Digester may be leading to underperformance and accumulation of solids in the digester. Installation of a new mixing system in the Primary Digester would increase biogas production and consequentially lead to greater energy generation through the CHP system.

Various systems for digester mixing are in use today. The most common types involve the use of gas injection and/or mechanical pumping. Unconfined gas mixing systems are designed to collect gas at the top of the digester, compress the gas, and then discharge the gas through a pattern of bottom diffusers or through a series of radially placed top-mounted lances (pipe). Digester contents are mixed by releasing unconfined gas bubbles that rise to the surface, carrying and moving the sludge. In confined gas mixing systems (i.e. gas lifter system, gas piston system) gas is collected at the top of the digesters, compressed, and then discharged through confined tubes. For example, in a gas piston system, gas bubbles are released intermittently at the bottom of a cylindrical tube. The confined gas bubbles rise, acting like a piston, pushing sludge to the surface. Mechanical pumping systems consist of propeller-type pumps mounted in internal or external draft tubes, or axial flow or centrifugal pumps and piping installed externally. Mixing is promoted by the circulation of sludge.

The following mixing systems, or equal, are recommended for use at the Livingston WPCF:

- JetMix™ Vortex Mixing System manufactured by Siemens (external mechanical pumping system)
- Infilco Cannon® Mixer manufactured by Degremont Technologies Ltd. (gas piston mixing system)
- Turbomixer manufactured by JDV Equipment Corporation (gas piston mixing system)

2.11.2 Digester Gas Piping Repairs

During HMM's site visit on February 20, 2013, it was noted that existing digester piping inside of the Digestion Control Building was in need of replacement and/or repair. Drip traps and sediment trap drain piping is missing in multiple locations and should be replaced.

2.11.3 Digester Sludge Heating Boiler/Heat Exchanger

The existing sludge heating unit is nearing the end of its useful life and will need to be removed and/or replaced in the near future. The unit, located in the Digester Control Building, is a heat exchanger and boiler combination. It was installed in 1975. Currently, the boiler is fueled by raw digester gas and produces hot water for sludge heating through the heat exchanger. The WPCF Superintendent has indicated that the boiler is not performing efficiently and is in need of replacement. Alternatives for boiler/heat exchanger replacement under this project are discussed in paragraph 2.12.2.

2.11.4 Fats, Oils and Grease (FOG)

Alternate feed stocks include fats, oils, and grease (FOG), food waste, and process waste from beverage industries. The addition of FOG and other highly digestible waste streams to the anaerobic digestion process can increase digester gas production, making CHP systems more cost effective. The Township should evaluate the potential to add FOG and/or other digester feed stocks to the anaerobic digestion process. The increased digester gas production translates directly into cost offsets for electric power and greater heat production for use as process heat.

2.11.5 Building Heat

The WPCF Superintendent has reported that the Digester Control building and Nitrification Control building heating systems are not in operation. As a result, some of the hot water generated by the CHP system would not be used for heating.

2.12 Alternatives Evaluated

2.12.1 CHP System Location

There are two (2) suitable locations for installation of the CHP system. Location #1 is on the grassy area located adjacent to and northeast of the primary digestion tank. Location # 2 is in the parking area southeast of the Advanced Treatment Building. Both locations offer enough space for the entire system including gas conditioning and cogeneration. Appendix E shows site plans for both locations. Table 2.11 presents the positives and negative associated with each location.

Table 2.11 Location #1 vs. Location #2

Location # 1	Location #2
Advantages: - Close to anaerobic digesters and Digestion Control Building - Minimize gas piping to CHP System - Minimize hot water piping to and from sludge heat exchanger/boiler	**Advantages:** - Close to Advanced Treatment Building boiler room - Minimize hot water supply and return piping to Advanced Treatment Building boilers - Minimize electrical run to existing conduit tie-in - Plant drain located nearby
Disadvantages: - Long hot water supply and return pipe runs to Advanced Treatment Building boiler room. - Long electrical run to connect with existing conduit. - Noise may be an issue as it is closer to the treatment plant entrance and street	**Disadvantages:** - Long hot water supply and return pipe runs to sludge heat exchanger/boiler - Long digester gas supply run to CHP system. - May be in the flood hazard area

- Location to connect drain piping may be an issue. - Traffic in and out of the plant.	

2.12.2 Sludge Heating

As previously discussed, the existing sludge heating boiler/heat exchanger is nearing the end of its useful life. The following is a list of alternatives to be considered in conjunction with the installation of a CHP system:

- Alternative 1 – Replace the entire boiler/heat exchanger unit in kind with a new sludge heater and boiler unit. Use CHP as the primary source of hot water with the new boiler as backup.
- Alternative 2 – Replace the entire boiler/heat exchanger with a new sludge heater (without boiler) to be fed with hot water produced by the new CHP unit for sludge heating. This may require additional piping to allow the use of Advanced Treatment Building boilers for backup heating.
- Alternative 3 – Abandon the existing boiler and feed the existing heat exchanger with hot water produced by the new CHP unit for sludge heating. This may require additional piping to allow the use of Advanced Treatment Building boilers for backup heating.

Alternative 1 is the most expensive option and will not utilize any benefits produced by the installation of a new CHP system. Alternatives 2 or 3 are the most practical in combination with the use of the CHP system. Hot water from the CHP system can be used for sludge heating in place of the existing boiler. Alternative 3 is appropriate should the existing heat exchanger remain in good condition; however, replacement of the heater may be required sometime in the near future.

As noted above, Alternatives 2 and 3 provide the Township with the advantage of eliminating the sludge heating boiler. Without cogeneration, the cost to replace the boiler/heat exchanger would be approximately $750,000. This cost can be avoided if the cogeneration system is installed and used for sludge heating. Also as previously noted, a new sludge heat exchanger may be required. The cost for just a new heat exchanger is approximately $302,000. Under this scenario, the avoided cost would be $448,000. See project expenses Section 3.1 below for further details.

SECTION 3

3.0 Economic Feasibility

3.1 Project Expenses

3.1.1 Project Cost Estimate

Appendix F presents project cost estimates based on quotes that were received from various manufacturers for CHP equipment (gas conditioning equipment and engine-generator). Table 3-1 below summarizes the estimates.

Table 3-1 CHP Project Cost Estimate Summary

Supplier	Type	Rating (kW)	Estimate	$/kWh
2G-Cenergy (Gas cleaning & CHP unit)	Combustion Engine	150	$2,153,400	$14,356
Robinson Group (Gas cleaning & CHP unit)	Combustion Engine	137	$2,324,900	$16,970
Robinson Group (Gas cleaning & CHP unit)	Microturbine	130	$2,534,900	$19,499
Tech 3 Solutions (CHP unit), Unison (Gas cleaning)	Combustion Engine	150	$2,606,900	$17,379
Kraft Power (CHP unit), Unison (Gas cleaning)	Combustion Engine	180	$2,704,400	$15,024
Kraft Power (CHP unit), Unison (Gas cleaning)	Combustion Engine	100	$2,277,600	$22,776

As per Appendix F, the cost estimates presented above include equipment and installation costs, site preparation cost, engineering, legal and permitting fees. Based on these estimates, the entire CHP project is expected to cost between $2.15 million and $2.75 million. Cost varies based on the equipment supplier, CHP size and CHP type. The 100 kW internal combustion engine option has the greatest cost per kWh ($22,776) while the average cost per kWh for a 150 kW internal combustion engine project is about $15,868.

The above estimates do not include previously discussed alternatives related to digester mixing or sludge heating. Table 3-2 presents the estimated costs of various additional options.

Table 3-2 Additional Cost of Alternatives

Description	Additional Cost
Sludge Heater (without boiler)	$302,000
Sludge Heater (including boiler)	$750,000
JDV Turbomixer Mixing System	$1,100,000

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3.1.2 Operation and Maintenance Costs

Operation and maintenance costs for this project have been determined on an annual basis. Based on the fourth edition of *Plant Design and Economic for Engineers* (Peters & Temmerhaus, 1991) it is estimated that the annu maintenance cost of the CHP system would be about 2.5 percent of the total capital cost. No additional labor co is incurred based on the assumption that existing WPCF employees will maintain the system. For a 150 kW internal combustion engine CHP system, the average expected capital cost (based on per kWh estimates summarized in Table 3-1) is about \$2,381,000. Therefore, the expected annual maintenance cost is about \$59,525.

$$\$2{,}381{,}000 \times 0.025 = \$59{,}525$$

The cost to operate the CHP system is limited to the gas conditioning components. The engine-generator is essentially free to operate as it is fueled by digester gas. The gas conditioning chiller and compressor are about 5 horsepower each and will utilize about 179 kWh per day total. The hot water pump and heat dump radiator are about 1 and 2 horsepower, respectively, and will utilize and additional 36 kWh per day (assuming the heat dump radiator only operates for about 12 hours per day). Assuming that the system operates 80 percent of the time and that utility electric costs about \$0.12 per kWh, the total annual operational cost of the system is about \$7,533.

$$(179\ kWh + 36\ kWh) \times 0.80 \times 365\ days \times \$0.12 = \$7{,}533$$

Combining the two costs calculated above, total annual operation and maintenance cost for the CHP system is about \$67,058.

3.2 Potential Revenue Sources

3.2.1 Value of Electricity Produced for On-Site Utilization

The value of electricity produced for on-site utilization is dependent on the amount of digester gas produced by the anaerobic digesters. If theoretical gas production is achieved (60,224 cfd) a 150 kW engine-generator will be able to produce up to 3,600 kWh per day. At the current average gas production (38,380 cfd) a 150 kW generator will only produce about 2,295 kWh per day. The value of electricity produced in each scenario is presented in the following Table 3-3.

Table 3-3 Value of Electricity Produced for On-Site Utilization

Description	Daily gas production (cuft/day)	150 kW Engine Electricity production (kWh/day)	Days in Operation (%)	Value of Electricity ($/kWh)	Annual Value of Electricity ($)
Theoretical	60,224	3,600	80%	$0.12	$126,144
2012 Average	38,380	2,295	80%	$0.12	$80,417

3.2.2 Value of Thermal Energy Produced for On-Site Utilization

The value of thermal energy produced for on-site utilization is also dependent on the amount of digester gas produced by the anaerobic digesters. However, as discussed in Section 2.9.2, digester gas is already being used for sludge heating at the WPCF (303,000 Btu/hour annual average). According to the plant Superintendent, about $16,000 is spent per year on natural gas for plant building heat (152,300 Btu/hour annual average). Less than half of that cost is allocated to the Advanced Treatment Building heat (60,500 Btu/hour annual average). As a result, if CHP hot water was used for heating the Advanced Treatment Building, the maximum value of that thermal energy would be about $6,000 to $8,000 per year.

A 150 kW CHP unit is expected to produce about 800,000 Btu/hour in hot water to be used for on-site heating. About 303,000 Btu/hour (annual average) will be used for sludge heating. About 60,500 Btu/hour (annual average) will be used to heat the Advanced Treatment Building. When running at full capacity, the remaining 436,500 Btu/hour could be used to heat other on-site buildings that are currently not being heated. The following Table 3-4 summarizes the value of thermal energy produced from the CHP system for on-site utilization.

Table 3-4 Value of Thermal Energy Produced for On-Site Utilization

Description	Current Source of Thermal Energy	CHP Produced Hot Water (Btu/hr)	Winter CHP Produced Hot Water (Btu/hr)	Annual Value of Thermal Energy ($)
Sludge Heating	Digester Gas	303,000	545,300	$0
Advanced Treatment Building heat	Natural Gas	60,500	122,200	$8,000
Other	N/A	436,500	132,500	$0
Total		800,000	800,000	$8,000

Note that the above values are annual averages. In the winter almost all of the heat generated by the CHP would be used to meet digester and Advanced Treatment Building heating. In warmer months, most CHP heat would be wasted to ambient air.

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3.2.3 Renewable Energy Certificates

Livingston Township does not plan to contribute electricity to the grid.

3.2.4 Acceptance of Feedstock

Livingston Township is not planning to accept feedstock from an outside source at this time. Sludge is generated as a result of the wastewater treatment process. The production of sludge will be stable over the life of the CHP system.

3.2.5 Cost of Sludge Disposal

No additional cost of sludge disposal will be incurred as a result of this project. Digested sludge is currently trucked off site in liquid form to the Passaic Valley Sewerage Commissioners (PVSC) facility in Newark, New Jersey for further treatment and final disposal.

3.2.6 Renewable Energy Incentive Program (REIP) Incentive

New Jersey's Clean Energy Program Renewable Energy Incentive Program (REIP) offers an incentive for combined heat and power projects. The Township would be eligible to apply for this incentive under the scope of this project. The value of the incentive will be based on the total CHP system rated output. The REIP program is currently offering $3.00 per watt of system rated output for Tier I projects (0 to 500,000 watts). Consequentially, for a 150 kW unit, the Township could request up to $450,000 under the REIP.

3.3 Financial Analysis

3.3.1 Economic Viability

The economic viability of this project is determined based on the project expenses and potential revenue sources described in Sections 3.1 and 3.2 above. Appendix G presents the total project costs, annual savings and total payback time for six different 150 kW CHP project scenarios. The scenarios are as follows:

- Scenario 1 – Total payback time in years assuming theoretical gas production (60,224 cu ft/day) and no REIP incentive.
- Scenario 2 – Total payback time in years assuming 2012 average gas production (38,380 cu ft/day) and no REIP incentive.
- Scenario 3 – Total payback time in years assuming theoretical gas production (60,224 cu ft/day) and including the REIP incentive.
- Scenario 4 – Total payback time in years assuming 2012 average gas production (38,380 cu ft/day) and including the REIP incentive.

- Scenario 5 – Total payback time in years assuming theoretical gas production, including the REIP incentive and cost saved should the sludge heater not have to be replaced in the future.
- Scenario 6 – Total payback time in years assuming 2012 average gas production, including the REIP incentive and cost saved should the sludge heater not have to be replaced in the future.

Scenarios 5 and 6 include the cost saved should the Township avoid the replacement of the heat exchanger/boiler used for sludge heating, described in Section 2.11.3. These scenarios point to Alternative 3 described in Section 2.12.2. This alternative would allow the existing heat exchanger/boiler to remain in service by discontinuing use of the boiler and using CHP produced hot water for sludge heating instead. This alternative would allow the Township to continue to use the existing heat exchanger without incurring any additional future costs. The project cost for Scenarios 5 and 6 also include annual maintenance savings associated with discontinued use of the existing sludge heating boiler. Table 3-5 below summarizes the payback information presented in Appendix G.

Table 3-5 Economic Viability Summary – 150 kW CHP System

Scenario	Total Project Cost	Annual Savings	Payback Time (years)
Scenario 1	$2,381,000	$67,086	35
Scenario 2	$2,381,000	$21,359	111
Scenario 3	$1,931,000	$67,086	29
Scenario 4	$1,931,000	$21,359	90
Scenario 5	$1,181,000	$78,286	15
Scenario 6	$1,181,000	$32,559	36

As made obvious in the above table, digester gas production and the REIP incentive have a huge impact on the economic viability of the CHP system project.

It should be noted that payback periods are also hampered by the current steps taken by the Township to reduce heating costs in the Advanced Treatment, Digester and Nitrification Control Buildings. As a result of these actions, natural gas use for heating is low and hot water generated by the CHP system cannot be used to offset significant natural gas usage.

Scenario 5 above shows the fastest payback period of 15 years. Appendix H presents the project costs, annual savings and total payback time for two different sized engines (150 kW and 180 kW) under the following conditions (similar to Scenario 5):

- It is assumed that the anaerobic digesters will produce enough gas to fuel each of the units, 80% of the time. The 180 kW unit would require gas production above theoretical.

- Total project costs listed include the REIP incentive.
- Total project costs listed include cost savings for avoiding future replacement of sludge heating boiler/heat exchanger.
- Electricity cost $0.12/kWh.

Table 3-6 below summarizes the payback information presented in Appendix H.

Table 3-6 Economic Viability Summary – Size Variation

Scenario	Total Project Cost	Annual Savings	Payback Time (years)
150 kW	$1,181,000	$78,286	15
180 kW	$1,414,400	$107,871	13

As shown in Table 3-6 above, the 180 kW unit shows a faster payback period than the 150 kW unit. However; order to realize this payback the anaerobic digesters would have to produce 76 % more gas than they do current (2012 Average) and 12 % more gas than what is theoretically predicted. Therefore, the 150 kW option is more economically viable.

Appendix I presents the project costs, annual savings and total payback time for varying electrical costs ($0.12/kWh, $0.13/kWh, $0.14/kWh and $0.15/kWh) under the following conditions (similar to Scenario 5):

- 150 kW CHP system
- Total project costs listed include REIP incentive.
- Total project costs listed include cost saving for avoiding future replacement of sludge heating boiler/heat exchanger.
- Theoretical gas production.

Table 3-7 below summarized the payback information presented in Appendix H.

Table 3-7 Economic Viability Summary – Electrical Cost Variation

Scenario	Total Project Cost	Annual Savings	Payback Time (years)
$0.12/kWh	$1,181,000	$78,286	15
$0.13/kWh	$1,181,000	$88,170	13
$0.14/kWh	$1,181,000	$98,054	12
$0.15/kWh	$1,181,000	$107,938	11

As per the above table, should the cost of electricity increase over the life of the CHP system, the payback time could be as fast as 11 years.

3.3.2 Access to Capital Through Financing or Bonding Authority

The New Jersey Environmental Infrastructure Trust (NJEIT) administers low interest rate loans to New Jersey's municipalities, counties and regional authorities for the purpose of financing water quality infrastructure projects that improve the State's natural resources and protect public health. Should the Township of Livingston decide to move forward with the CHP project it will be eligible to apply for a NJEIT loan. This loan would assist the Township in funding the construction of this project.

3.3.3 Investment Analysis

An investment analysis was performed using Scenario 5 conditions described in Section 3.3.1 in order to take inflation and returns into account. For the purposes of this analysis, it was assumed that the project would be financed through the NJEIT. The following assumptions were made:

- NJEIT loan interest rate of 1.0 %
- Long term inflation rate of 3.0 %

The analysis revealed that a Scenario 5 CHP project would have a payback period of fifteen (15) years and a Net Present Value (NPV) of $699,116 after 20 years. The Internal Rate of Return (IRR) on the investment is estimated to be about 3.9 %. Appendix J contains the net present value calculations. Cost savings associated with avoiding sludge heater replacement was incorporated by deducting an estimated annual loan payment associated with a boiler replacement project.

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4.0 Legal Feasibility

4.1 Required Permits and Approvals

The Livingston Township WPCF site is within the 100-year flood plain of the Passaic River. As a result, the following permits will have to be obtained for this project:

- Flood Hazard Area Verification
- Flood Hazard Area Individual Permit
- Local Building Permits

The WPCF's current air permit will also have to be updated as the CHP is considered a new emissions source. The following will be required for this project:

- Air Permit update

4.2 Compliance with EDC Interconnection Requirements

The Township must obtain approval to install the CHP system from the Electric Distribution Company (EDC), Jersey Central Power and Light (JCP&L). In order to be granted approval an interconnection application/agreement will need to be submitted. Construction must be in accordance with the Interconnection Application/Agreement.

4.3 Bidding Requirements for Public Entities

Bidding requirements shall be as per the Local Public Contracts Law (LPCL), N.J.S.A. 40A:11-1 et seq. The LPCL ensures that public contracts are awarded through a fair, open and competitive process.

4.4 Prevailing Wage Rules

Prevailing wage rules shall be as per the New Jersey State and Federal Wage Rates and applicable provisions of the New Jersey Prevailing Wage Act, N.J.S.A. 34:11-56.25 et seq., as amended, governing the prevailing rates of wages for workmen who would be employed on this project. All workmen engaged in the performance of services directly under a public work contract shall be paid not less than the prevailing rate of wages. The Contractor will be obligated to pay the higher of the State or Federal wage rates.

4.5 Bonding/Financing Restrictions

The Township does not currently have any bonding and/or financing restrictions.

4.6 Determination

Compliance with the above mentioned legal requirements will not adversely impact Livingston Township's ability to complete this project within 18 months of REIP Application approval.

5.0 Recommendation

Construction of a combined heat and power (CHP) system at the Livingston Township WPCF would be beneficial to the Township. The WPCF's anaerobic digesters currently produce about 40,000 cubic feet of digester gas per day. Each day, approximately 21,000 cubic feet of digester gas is wasted to flaring. A CHP system would enable the Township to use digester gas to produce electric power and heat, offsetting its utility power and natural gas costs and lower air emissions. Over the life span of the CHP system, the Township will realize an economic advantage.

CHP is a proven means for reducing electric power consumption at WWTPs using digester gas as a fuel for the combined production of heat and electrical power. The WPCF's on-site anaerobic digesters are capable of producing up to 60,000 cubic feet of digester gas per day. Once installed, a 150 kW CHP system will be able to supply all of the heat required by the anaerobic digestion process as well as heat for the Advanced Treatment Building. Additionally, a 150 kW engine can supply up to 86,400 kWh of electricity per month. This represents approximately one third (1/3) of the WPCF's average electricity demand.

The total capital cost for the design and construction of a 150 kW CHP system at the WPCF would be about $2,381,000. This cost includes equipment and installation costs, site preparation cost, engineering, legal and permitting fees. Should the Township receive an REIP incentive of $450,000 and avoid the replacement of the existing sludge heating boiler/heat exchanger ($750,000), the total project cost would be approximately $1,181,000. Once installed, annual revenue for the CHP system would include utility power savings of $126,144 per year (at $0.12/kWh), natural gas savings of $8,000 per year and sludge heating boiler maintenance cost savings of $11,200 per year. Combined with an annual cost of operation and maintenance of $67,058, the total annual revenue/savings associated with the CHP system could be up to $78,286. Consequentially, the expected payback period for the design and construction of a CHP system could be as little as 15 years. The detailed investment analysis, incorporating inflation and returns, also shows a 15 year payback period with a NPV of $699,116 over 20 years and an IRR of 3.9 %. Based on the investment analysis the NPV of the Township's investment over the lifespan of the CHP system (40 years) could be up to $3,480,000.

It is important to note that the economics discussed above are based on the assumption that the Township will implement digester enhancements (i.e. improved mixing, chemical addition, etc.) for increased gas production. As per Appendix G, 2012 average gas production will not realize the same economic benefit. Based on calculations described in Section 2.4, the anaerobic digesters are theoretically capable of producing up to 34%

more gas. Also note, as described in Section 2.4, the volatile solids reduction is near theoretical. Based on this, gas production should also be close to theoretical. Therefore, we suspect that gas leaks or inaccurate gas flow measurement may be the cause of low gas readings. It is recommended that the Township proceed with digester mixing improvements regardless of whether or not a CHP system is installed.

Should the Township decide to undertake this project, HMM recommends that the following actions be taken prior to and/or during design:

- Additional digester gas testing should be performed in order to get a more accurate description of digester gas composition.
- Digester mixing improvements should be considered in order to increase digester gas production.
- Other digester enhancements should be considered such as chemical addition to increase digester gas production
- Investigate and reduce any gas leaks and confirm gas metering accuracy.

The results of this Feasibility Study demonstrate that a CHP system project at the Livingston Township WPCF would be technically, economically and legally feasible. The project also provides an environmental benefit by reducing the WPCF's overall carbon footprint, reducing air emissions and fulfilling the Township's desire to implement green projects at the WPCF. It is HMM's recommendation that the Township proceed with the design and construction of a CHP system.