Energy Plan for MMSD Facilities

Planning Report

Milwaukee Metropolitan Sewerage District
Contract M03109P01

Final – March 2024

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Background

The Milwaukee Metropolitan Sewerage District (MMSD) is a leading regional government agency that provides water reclamation and flood management services for approximately 1.1 million people in 28 municipalities in the Greater Milwaukee area. The wastewater collected within MMSD's service area through the conveyance and storage asset system is sent to two water reclamation facilities, Jones Island Water Reclamation Facility (JIWRF) and South Shore Water Reclamation Facility (SSWRF).

MMSD adopted the 2035 Vision in 2010, which focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency and includes the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal, renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Purpose

The purpose of this Planning Report is to summarize opportunities for energy reduction improvements, renewable energy production and greenhouse gas (GHG) reduction to meet the 2035 Vision. The following technical memorandums (TM) and reports were used to develop this Planning Report:

- TM-1: Energy Review and Renewables
- TM-2: Administration Buildings and Conveyance System
- TM-3: JIWRF Energy Plan
- TM-4: SSWRF Energy Plan
- TM-5: Carbon Neutrality Needs Assessment
- **Planning Report**

Energy Baseline and Planned and Recommended Energy Reduction Improvements,

MMSD provided total energy consumption data for 2018 – 2020 to calculate the baseline energy usage for the Conveyance System, Administration Facilities, JIWRF, and SSWRF. This data was used to develop an Energy Baseline and is presented in Metric Million British Thermal Units (MMBTU) to compare gas and electricity usage. MMSD's 2018-2020 average annual energy usage was 2,632,800 MMBTU and is the baseline used for energy comparison and project planning in this report.

MMSD has a number of planned facility improvements that are in various stages of development, from planning to construction. These Planned Improvements are projects that will influence energy demand and consumption. These planned improvement projects are part of the 2023 budget. This report incorporates the energy improvements as the planned project impacts are not included in the baseline, but this plan wants to account for their impact on energy. Additionally, the costs associated with these planned improvements are not included in this plan's opinion of probable construction costs for recommended projects as funding has already been allocated to these planned projects.

In addition to the Planned Improvements, TM-2, TM-3, and TM-4 included Recommended Improvements to replace equipment with new, higher efficiency equipment and modifying processes to further reduce energy usage. With the Planned and Recommended Improvements:

- The total energy demand is reduced by 198,400 MMBTU, an 11.1% reduction from the 2018-2020 baseline.
- The renewable gas energy increased by 963,480 MMBTU, a 141% increase from the 2018-2020 baseline.

Recommendation

Three alternatives were developed that each can achieve the 2035 Vision goals. Each alternative differs in how energy is consumed and generated to meet the 2035 Vision. The three alternatives and the recommended improvements to generate additional energy are summarized below. Additional information including quantities, capacities, and costs are included in the main body of this report.

- Alternative 1 prioritizes landfill and digester gas generation.
  - JIWRF
    - Install two new Solar Turbines
    - Install 158,400 SF or 2,200 kW of photovoltaic (PV) panels
    - Convert one more dryer to LFG fueled
  - SSWRF
    - Install new engine generators
    - Install 1,315,400 SF or 18,300 kW of PV panels
    - Build a 16 tons per day high strength waste receiving station and anaerobic digesters to increase digester gas generation
    - Install a 1,800 SCFM gas cleaning system
    - Install 5,640,000 CF of gas storage serving JIWRF and SSWRF
    - Build a digester gas pipeline connecting JIWRF and SSWRF
  - Conveyance System
    - Install 4,600 kW of PV panels

    - Purchase the remaining renewable electricity and natural gas from We Energies
  - Administration Facilities
    - Installing 36,400 SF or 500 kW of PV panels
    - Purchasing the remaining renewable electricity and renewable natural gas from We Energies
- Alternative 2 prioritizes photovoltaic and wind electricity generation.
  - JIWRF
    - Install 1,165,200 SF or 16,200 kW of PV panels
    - Install 412,800 kWh (3,120 m2 or 33,600 SF) of battery storage for JIWRF at SSWRF
    - Convert three more dryers to LFG fueled
  - SSWRF
    - Install 1,800,800 SF or 25,000 kW of PV panels
    - Install three wind turbines
    - Build five additional wind turbines or an additional 2,351,000 SF or 32,700 kW of PV off-site at other MMSD owned properties if power wheeling is possible
    - Install a 1,500 SCFM gas cleaning system
    - Install 846,000 CF of gas storage serving SSWRF
    - Build an electrical ductbank connecting JIWRF and SSWRF electrically
    - Install 148,800 kWh (1,140 m2 or 12,270 SF) of battery storage for SSWRF
    - Build a digester gas pipeline connecting JIWRF and SSWRF
  - Conveyance System
    - Install 4,600 kW of PV panels
    - Purchasing the remaining renewable electricity and renewable natural gas from We Energies
  - Administration Facilities
    - Install 36,400 SF or 500 kW of PV panels
    - Purchase the remaining renewable electricity and renewable natural gas from We Energies

- Alternative 3 includes a new Milorganite® drying facility at SSWRF per the recommendation from the Biosolids Advanced Facility Plan (BAFP), completed by others and prioritizes the production and utilization of digester gas and utilization of landfill gas.
    - JIWRF
        - Install two new Solar Turbines
        - Install 158,400 SF or 2,200 kW of PV panels
        - Install a 520 SCFM gas cleaning system
    - SSWRF
        - Install new engine generators
        - Install 1,315,400 SF or 18,300 kW of PV panels
        - Install a new thermal hydrolysis process (THP)
        - Build an 11.5 tons per day high strength waste receiving station and anaerobic digesters to increase digester gas generation
        - Install a 1,600 SCFM gas cleaning system
        - Install 2,538,000 CF of gas storage serving JIWRF and SSWRF
        - Build a digester gas pipeline connecting JIWRF and SSWRF
    - Conveyance System
        - Install 4,600 kW of PV panels
        - Purchase the remaining renewable electricity and natural gas from We Energies
    - Administration Facilities
        - Install 36,400 SF or 500 kW of PV panels
        - Purchase the remaining renewable electricity and renewable natural gas from We Energies

The three alternatives were evaluated based on the opinion of probable construction cost (OPCC), 20-year present worth cost, GHG emissions, and total energy consumption. **Table ES-1** summarizes the three alternatives and **Table ES-2** summarizes the alternative's achievement with respect to the 2035 Vision goals.

Table ES-1: Alternative Evaluation Summary

Alternative	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost	Total GHG Emissions (Metric Tons CO2e)	% Reduction from 2005 Baseline	Total Energy Consumption (MMBTU/year)
Alternative 1	$705,012,000	$10,696,000	$153,748,000	$858,760,000	452	99.7%	1,775,693
Alternative 2	$1,048,534,000	$13,517,000	$194,299,000	$1,242,833,000	297	99.8%	1,171,963
Alternative 3	$727,257,000	$9,608,000	$138,111,000	$865,368,000	418	99.7%	1,644,453

Table ES-2: Alternative 2035 Vision Goal Evaluation Summary

Alternative	% Net Energy From Renewable Sources	% Internal, Renewable Energy	% Reduction from 2005 Baseline	Meets All 2035 Vision Goals
Alternative 1	100%	97.8%	99.7%	Yes
Alternative 2	100%	96.6%	99.8%	Yes
Alternative 3	100%	97.6%	99.7%	Yes

Table ES-3 compares alternatives on their evaluation criteria including meeting the 2035 Vision Goals, operational flexibility, and costs and presents them in rankings.

Table ES-3: Evaluation Criteria Alternative Summary

	Meets 2035 Vision Goals	Operational Flexibility	Costs
Alternative 1	Yes	Preferred	Preferred
Alternative 2	Yes	Least Preferred	Least Preferred
Alternative 3	Yes	Most Preferred	Most Preferred

It is recommended that MMSD implement Alternative 3 as the path to achieve the 2035 Vision Goals. Alternative 3 provides MMSD with the most operational flexibility, mitigates impacts, and has the most preferred costs resulting in the largest return on investment. The single largest energy user for MMSD is the biosolids drying process for Milorganite® production. Shifting half of this energy load to SSWRF, where digester gas is generated, puts the largest energy load at the same location as the largest energy producer, the anaerobic digesters. This is why Alternative 3 is considered the most preferred operational flexibility. This and connecting the facilities with a gas pipeline allows for greater redundancy and renewable gas consumption, assisting with minimizing DG flaring.

MMSD is experienced using renewable gases (landfill and digester gas) and will continue to rely on renewable gas to generate electricity for both JIWRF and SSWRF and the biosolids drying process. Renewable electricity generation through solar PV will fill in the electricity gaps at both WRFs. Community impacts are mitigated through not needing large wind turbines at WRF, Greenseams, or conveyance facilities like Alternative 2 requires. The recommendation shows no anticipated energy consumption at the WRFs from We Energies, however we are not recommending islanding the facilities. Coordination with We Energies to be a backup power source is required.

The Conveyance System and Administration Facilities will generate renewable electricity using solar PV and fill in the remaining energy gap at these facilities by purchasing renewable energy through We Energies to meet MMSD’s goal of using 100% renewable energy.

Capital Improvement Plan

Table ES-4 and **Table ES-6** present the Capital Improvement Plan project costs and schedule to meet the 2035 Vision Goals. This is a potential timeline that incorporates BAFP projects and aligns recommended projects with start and completion dates.

Table ES-4: Alternative 3 OPCC Summary

Project Number	Project	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost
1	Energy Reduction Recommended Improvements Total	$109,645,000	$0	$0	$109,645,000
2	JIWRF New Turbine Generators	$71,233,000	$1,939,000	$27,872,000	$99,105,000
3	JIWRF PV Panel Installation	$17,801,000	$45,000	$647,000	$18,448,000
4	JIWRF Landfill Gas Cleaning	$7,848,000	$129,000	$1,854,000	$9,702,000
	JIWRF Subtotal	**$96,882,000**	**$2,113,000**	**$30,373,000**	**$127,255,000**
4	SSWRF New Engine Generators	$48,938,000	$1,591,000	$22,870,000	$71,808,000
5	SSWRF PV Panel Installation	$147,661,000	$366,000	$5,261,000	$152,922,000
6	THP at SSWRF	$98,175,000	$450,000	$6,469,000	$104,644,000
7	SSWRF High Strength Waste	$136,212,000	$2,725,000	$39,171,000	$175,383,000
8	SSWRF DG Cleaning	$20,217,000	$405,000	$5,822,000	$26,039,000
9	SSWRF DG Storage	$18,900,000	$378,000	$5,434,000	$24,334,000
10	SSWRF to JIWRF Gas Pipeline	$44,967,000	$900,000	$12,937,000	$57,904,000
	SSWRF Subtotal	**$515,070,000**	**$6,815,000**	**$97,964,000**	**$613,034,000**
11	Conveyance System Renewable Energy	$1,573,000	$361,000	$5,189,000	$6,762,000
12	Administration Facilities Renewable Energy	$4,087,000	$391,000	$5,620,000	$9,707,000
	Conveyance and Admin Facilities Subtotal	**$5,660,000**	**$752,000**	**$10,810,000**	**$16,470,000**
	TOTAL	**$727,257,000**	**$9,608,000**	**$138,111,000**	**$865,368,000**
	Alternative 3 Total GHG Emissions	418	Metric Tons CO2e		
	Percent Reduction from 2005 Baseline	99.7%			

Table ES-5: Alternative 3 OPCC Summary by Category

Project Category	OPCC	Total 20 Yr PW Cost
Efficiency Improvements	$109,645,000	$109,645,000
PV Generation	$165,462,000	$171,370,000
LFG Generation Improvements	$79,081,000	$108,807,000
HSW Generation	$136,212,000	$175,383,000
DG Generation Improvements	$186,230,000	$225,790,000
Renewable Energy Purchasing	$5,660,000	$16,469,000
JIWRF to SSWRF Pipeline	$44,967,000	$57,904,000
Total	$727,257,000	$865,368,000

Table ES-6: Alternative 3 Schedule

#	Project	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	OPCC	Total 20 Yr PW Cost
MMSD Planned Improvement Projects															
	SSWRF Drying Facility														
	WM - LFG Pipeline														
Alternative 3 Projects															
1	Energy Reduction Recommended Improvements Total													$109,645,000	$109,645,000
12	Conveyance System Renewable Energy													$1,573,000	$6,762,000
6	SSWRF PV Panel Installation													$147,661,000	$152,922,000
3	JIWRF PV Panel Installation													$17,801,000	$18,448,000
11	SSWRF to JIWRF Gas Pipeline													$44,967,000	$57,904,000
2	JIWRF New Turbine Generators													$71,233,000	$99,105,000
5	SSWRF New Engine Generators													$48,938,000	$71,808,000
8	SSWRF High Strength Waste													$136,212,000	$175,383,000
7	THP at SSWRF													$98,175,000	$104,644,000
4	JIWRF Landfill Gas Cleaning													$7,848,000	$9,702,000
9	SSWRF Digester Gas Cleaning													$20,217,000	$25,004,000
10	SSWRF Digester Gas Storage													$18,900,000	$24,334,000
13	Administration Facilities Renewable Energy													$4,087,000	$9,707,000
													Total	**$727,257,000**	**$865,368,000**
	Yearly Cost	$103,549,583	$54,104,083	$80,370,083	$292,462,083	$9,137,083	$9,137,083	$45,993,583	$9,137,083	$95,955,083	$9,137,083	$9,137,083	$9,137,083		
	Cumulative Cash Flow	$103,549,583	$157,653,667	$238,023,750	$530,485,833	$539,622,917	$548,760,000	$594,753,583	$603,890,667	$699,845,750	$708,982,833	$718,119,917	$727,257,000		

O&M and Process Improvements that are good practice	$109,645,000	$109,645,000
MMSD Implements Outside of Energy	$165,138,000	$228,817,000
Energy Plan Specific Improvements	$452,474,000	$526,906,000

Section 1 Introduction

1.1 Background

The Milwaukee Metropolitan Sewerage District (MMSD) is a leading regional government agency that provides water reclamation and flood management services for approximately 1.1 million people in 28 municipalities in the Greater Milwaukee area. The wastewater collected within MMSD's service area through the conveyance and storage asset system is sent to two water reclamation facilities, Jones Island Water Reclamation Facility (JIWRF) and South Shore Water Reclamation Facility (SSWRF).

1.2 MMSD 2035 Vision and Goals

MMSD is an industry leader in protecting the environment and sustainability. MMSD adopted the 2035 Vision in 2010, which focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency and includes the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal, renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

1.3 Purpose

The purpose of this Planning Report is summarizing the opportunities for renewable energy production and greenhouse gas (GHG) reduction, as described in TMs 1 through 4 and proposing a roadmap to meet MMSD's 2035 Vision and make progress towards the Carbon Neutrality Goals. This Planning Report includes greenhouse gas emissions calculations and reductions, as presented in TM 5.

The following technical memorandums (TM) and reports are a part of this project:

- TM-1: Energy Review and Renewables (Appendix A)
- TM-2: Administration Buildings and Conveyance System (Appendix B)
- TM-3: JIWRF Energy Plan (Appendix C)
- TM-4: SSWRF Energy Plan (Appendix D)
- TM-5: Carbon Neutrality Needs Assessment
- **Planning Report**

Section 2 Energy Baseline of Existing Facilities

2.1 Energy Baseline of Existing Facilities

MMSD provided total energy consumption data for 2018 – 2020 to calculate the baseline energy usage for the Conveyance System, Administration Facilities, JIWRF, and SSWRF. This data was summarized in TM-2, TM-3, and TM-4, respectively. The provided energy data includes a variety of energy sources like natural gas (NG), digester gas (DG), landfill gas (LFG), utility electricity, fuel oil, propane, and diesel fuel.

The energy sources are categorized by renewable, non-renewable, internal, and external in **Table 2-1**.

Table 2-1: Energy Source Types

	Renewable	Non-Renewable
Internal	Digester Gas, Landfill Gas, PV	n/a
External	Utility Electricity	Utility Electricity, Natural Gas, Fuel Oil, Propane, Diesel

Figure 2-1, **Table 2-2**, and **Figure 2-2** depict the annual energy consumption by facility and energy source for 2018 through 2020. Additionally, the average total for each energy source from 2018 through 2020 is summarized. All energy totals are in units of MMBTU. The oil column in the charts is the boiler's fuel oil consumption. Propane and diesel consumption at these facilities are negligible.

Energy consumption includes all the energy that a facility uses. The energy consumption includes powering or fueling equipment and wasted energy due to inefficiencies of electricity generation or DG flaring. **Section 2** presents MMSD's energy consumption.

Energy demand is what a facility requires for operation and does not include inefficiencies or DG flaring. **Section 3** presents MMSD's energy demand.

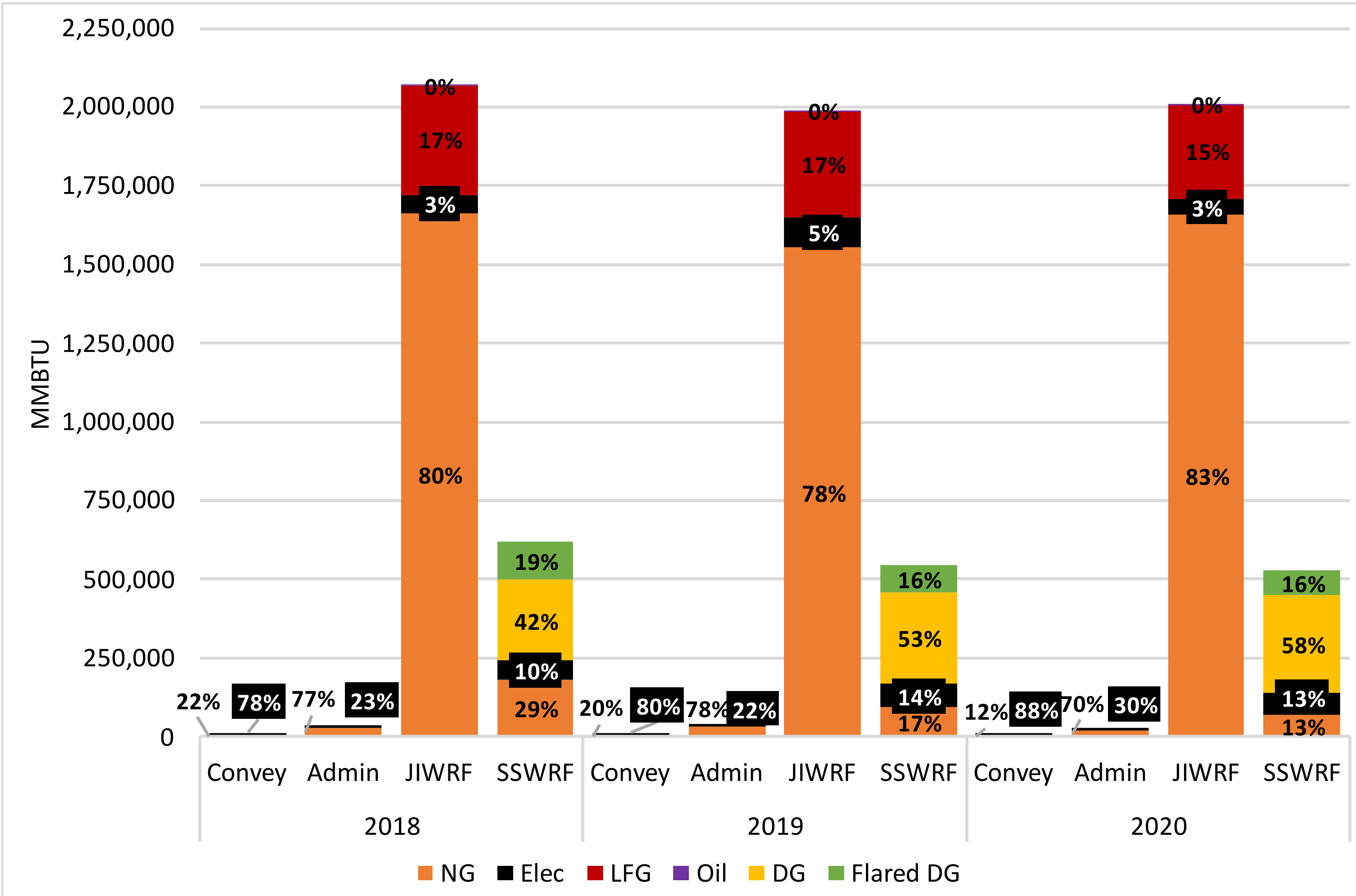

Figure 2-1: Energy Consumption by Facility, 2018-2020 (MMBTU/Year)

Table 2-2: Annual Energy Consumption by Facility (MMBTU)

		NG	Elec	LFG	Oil	DG	Flared DG	Total
2018	Conveyance	2,600	9,400	0	0	0	0	12,000
	Administration	28,600	8,600	0	0	0	0	37,200
	JIWRF	1,664,000	57,900	346,800	60	0	0	2,068,760
	SSWRF	181,500	60,300	0	0	259,700	118,020	619,520
2019	Conveyance	2,400	9,600	0	0	0	0	12,000
	Administration	30,700	8,800	0	0	0	0	39,500
	JIWRF	1,554,000	97,400	335,600	320	0	0	1,987,320
	SSWRF	93,000	75,900	0	0	290,500	87,256	546,656
2020	Conveyance	1,300	9,300	0	0	0	0	10,600
	Administration	19,200	8,100	0	0	0	0	27,300
	JIWRF	1,658,000	51,600	297,600	810	0	0	2,008,010
	SSWRF	70,000	71,000	0	0	307,300	82,351	530,651
Average	Total	1,768,100	156,000	326,600	400	285,800	95,900	2,632,800
	%	67%	12%	6%	0%	11%	4%	100%

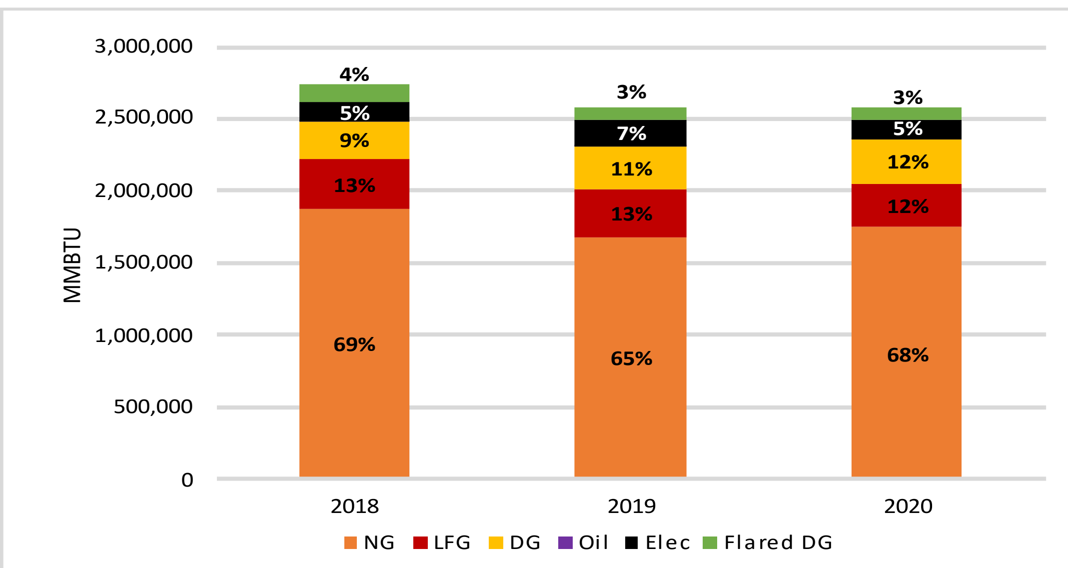

Figure 2-2: Total Energy Consumption by Source, 2018-2020 (MMBTU/Year)

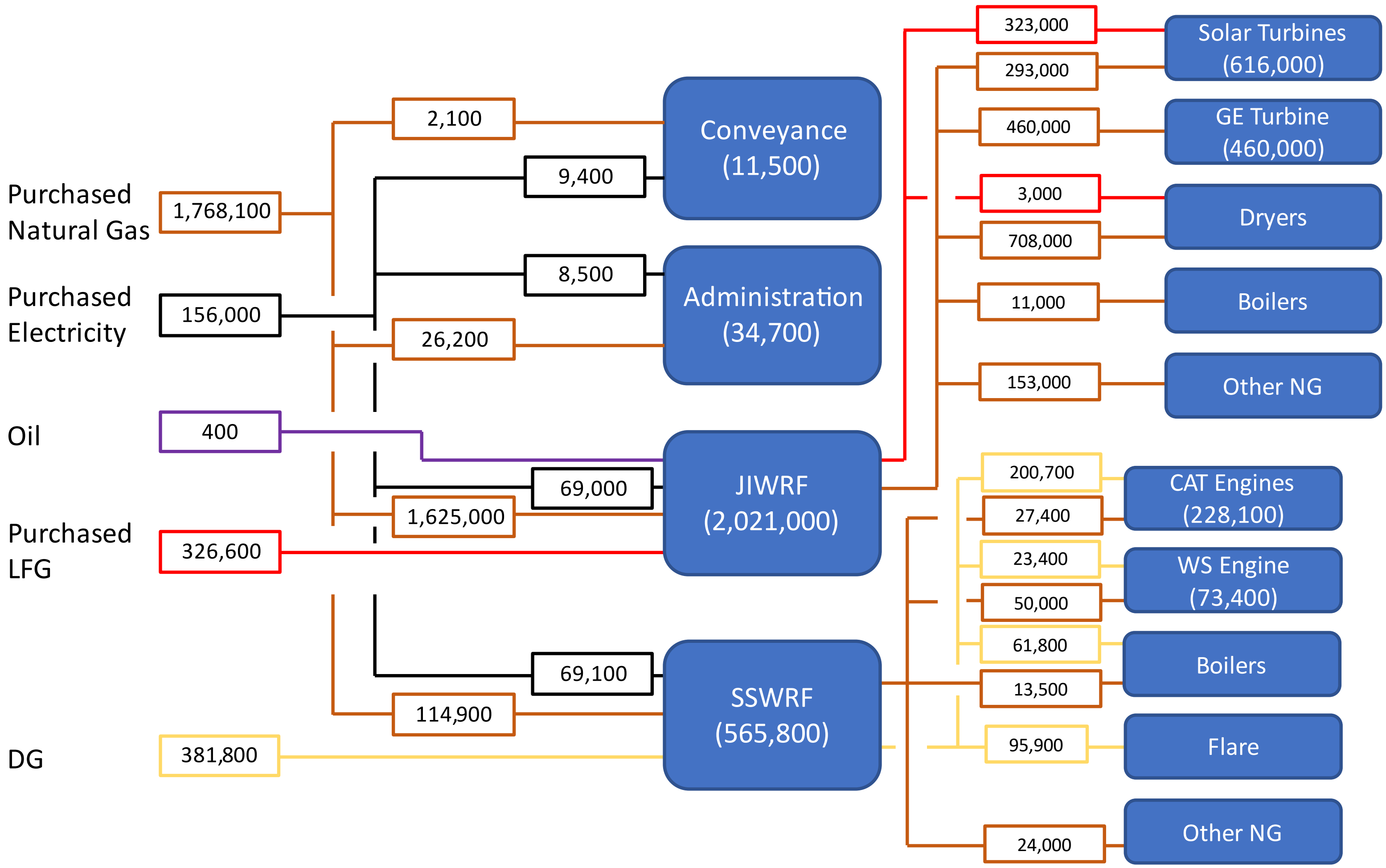

Figure 2-3: Baseline Energy Profile (MMBTU/Year)

2.2 Greenhouse Gas Emissions Calculation and Baseline

One of MMSD's 2035 Vision goals is focused on mitigating climate change by reducing its carbon footprint by 90% from its 2005 baseline. To determine progress towards that goal, as well as the anticipated progress that comes from implementing the improvements outlined in TM-2, TM-3, and TM-4, greenhouse gas emissions calculations were performed.

The major energy sources that MMSD currently uses are NG, LFG, DG, and purchased electricity. These sources account for 99.98% of MMSD's energy usage and 99.99% of MMSD's greenhouse gas (GHG) emissions, based on its 2005 baseline. The greenhouse gas emission baseline was calculated based on the average energy consumption from 2018 through 2020 for these fuels. This baseline was determined for the Conveyance System, Administration Facilities, JIWRF, and SSWRF. The energy consumption data were converted from MMBTU to tons of CO_2 equivalent (CO_2e). CO_2 equivalent accounts for GHG emissions from methane, nitrous oxide, and other GHG emissions gases. This was completed using USEPA conversion factors, provided by MMSD. These are the same as the calculations MMSD uses in the reported emissions to the Wisconsin Department of Natural Resources (DNR), for NG, LFG, DG, and purchased electricity. These resulting calculations are shown in **Table 2-3**.

Table 2-3: 2018 – 2020 AVG Energy Consumption and CO_2e Baseline

Energy Source	Unit	Conveyance	Administration	JIWRF	SSWRF	Total
Natural Gas	MMBTU/year	2,100	26,200	1,625,000	114,900	1,768,100
	Metric Tons CO_2e	112	1,392	86,311	6,098	93,912
Landfill Gas	MMBTU/year	0	0	326,600	0	326,600
	Metric Tons CO_2e	0	0	84	0	84
Digester Gas	MMBTU/year	0	0	0	381,800	381,700
	Metric Tons CO_2e	0	0	0	98	98
Purchased Electricity	MMBTU/year	9,400	8,500	69,000	69,100	156,000
	Metric Tons CO_2e	1,564	1,414	11,479	11,496	25,953
Purchased Oil	MMBTU/year	0	0	400	0	400
	Metric Tons CO_2e	0	0	4	0	4
Total	MMBTU/year	11,500	34,700	2,021,000	565,800	2,633,000
	Metric Tons CO2e	1,675	2,806	97,878	17,691	120,051

MMSD calculated that 130,237 metric tons of CO_2e were emitted in 2005 and serves as the basis for the 90% reduction goal. To achieve the 90% reduction, this number needs to be reduced to 13,000 metric tons of CO_2e by 2035.

This report calculated the average emissions from 2018-2020 to be approximately 120,000 metric tons of CO_2e. This equates about an 8% reduction from the 2005 baseline. The reduction in GHG from 2005 to the 2018-2020 average is mostly from increased renewable energy generated by LFG. This report details a plan to reduce NG and purchases electricity consumption to reduce MMSD's GHG emissions to meet the 2035 Vision.

In addition to the recommended improvements, carbon sequestration options such as planting trees or native prairie grass can be used to offset GHG emissions. A mature tree, for example, can take in 50 pounds of carbon dioxide per year (equivalent to 0.025 tons).

2.2.1 Greenhouse Gas Dashboard

As part of this project, a GHG and energy dashboard using Power BI was created. The GHG accounting includes everything in the emissions calculation in the previous section, as well as additional process emissions from the WRFs and vehicle emissions. The dashboard also has a planning tab that lists planned projects with their estimated impacts on energy and GHG emissions.

2.2.1.1 Dashboard Planned Projects

The planned projects tab is populated by an excel spreadsheet that has planned projects information including estimated start and completion dates and impacts to energy. The impact to electrical emissions impacts at the WRFs are calculated using an emission multiplier from the WRFs previous year's GHG emissions. The emission multiplier is the total WRF GHG emissions divided by the WRF total energy consumption. The dashboard then shows the planned projects projected impacts to GHG emissions are by year.

2.2.1.2 Dashboard Vehicle Emissions

The vehicle emissions are calculated using an excel spreadsheet that the dashboard references for the data. The spreadsheet must be manually updated yearly by MMSD with the total vehicle gasoline, diesel, and CNG consumption for the year. These are included in the GHG emissions dashboard totals, however, were not included in the 2005 baseline.

2.2.1.3 Dashboard Process Emissions

The WRF process emissions are calculated on an excel spreadsheet that the dashboard references. The spreadsheet requires yearly update by MMSD to confirm the WRF service population is accurate and that the consumed digester gas is updated. These are included in the GHG emissions dashboard totals, however, were not included in the 2005 baseline.

2.3 Energy Baseline Demand with Planned Improvements

MMSD has a number of planned facility improvements (PIs) that are in various stages of development, from planning to construction. These planned facility improvements projects will influence energy demand and consumption. The following section summarizes the anticipated energy demand impacts of projects with currently assigned project numbers. The energy baseline consumption of existing facilities summarized in **Section 2.1** plus the anticipated changes due to planned improvements minus the inefficiencies due to electricity generation and flaring, defines the "Energy Baseline Demand with Planned Improvements" that will be used in this report. These planned improvement projects are part of the 2023 budget. This report incorporates the energy improvements, but does not include costs as part of this project, as funding has already been allocated. MMSD has the Commission Policy on Environmental Management, Part IVC Energy and Greenhouse Gas Reduction Matrix that requires projects to achieve a 10% energy and greenhouse gas emissions reduction. This project incorporates this requirement in the planned project's energy reductions where it can be reasonably assumed to be met. Assumptions are made to determine the project's baseline energy use to determine the 10% energy reduction.

Conveyance System

There are no planned projects anticipated to impact Conveyance System energy demand.

Administration Facilities

There is only one planned project that will affect the Administration Facilities Energy baseline. Project M01044 - HQ and Lab Building Remodel is estimated to reduce HVAC energy consumption by 10%.

- Per TM-2 and **Section 2.1**, The administration facilities consume 34,680 MMBTU/year of energy.
- The DOE estimates that 35% of buildings energy consumption is for HVAC[1].
- This results in reductions of 297 MMBTU/year of electricity and 917 MMBTU/year of NG.

The Administration Facilities planned projects are detailed and summarized in Appendix B.

JIWRF

The JIWRF planned projects are detailed and summarized in Appendix E. Major projects include the following:

- J04081 – D&D HVAC Upgrade
- J04066 – Milorganite Dust Suppressant System Upgrades

[1] https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf

- S01013 – Primary Clarification System Improvements
  - There is an energy decrease for drying at JIWRF due to improved dewaterability of sludge.
- P02004 – Landfill Gas System – Waste Management Metro Landfill
  - This project is outside of MMSD's 10-year plan, however, has a large energy impact and can provide an immediate leap towards MMSD's goals. These large impacts are included in the planned projects list. If this project does not happen, additional digester gas generation, equipment electrification, and other initiatives described in Alternative 2 will have to be incorporated.

SSWRF
The SSWRF planned projects are detailed and summarized in TM-4 and summarized in Appendix E. Major projects include the following:

- S01013 – Primary Clarification System Improvements
- S02015 – Aeration System Upgrade
- S02017 – Process Air Header Improvements
- S03005 – Disinfection Process Improvements
- S04039 – Gravity Thickening & Acid Phase Digestion

Total Baseline with Planned Improvements
Table 2-4 summarizes MMSD's energy baseline demand with planned improvements.

Table 2-4: Energy Baseline Demand with Planned Improvements and Renewable Gas Available

Facility	Energy Demand				Renewable Gas Available		
	Electricity		Gas	Total	LFG	DG	Total
	MMBTU	kWh	MMBTU	MMBTU	MMBTU	MMBTU	MMBTU
Conveyance	9,400	2,754,900	2,100	11,500	0	0	0
Administration	8,200	2,400,000	25,300	33,500	0	0	0
JIWRF	356,000	104,330,000	979,200	1,335,200	1,175,000	0	1,175,000
SSWRF	133,000	38,980,000	153,410	286,410	0	473,880	473,880
Total	506,600	148,464,900	1,160,010	1,666,610	1,175,000	473,880	1,648,880

With the Planned Improvements:

- The total energy demand is reduced by 123,400 MMBTU, a 6.9% reduction.
- The renewable gas energy increased by 963,480 MMBTU, a 141% increase.
- The total renewable gas available cannot be directly compared to the total energy demand to see if we can achieve 100% renewable energy because there are inefficiencies due to electricity generation when combusting the renewable gas. Therefore, to generate the required 506,600 MMBTU/yr of renewable electricity, more renewable gas is needed because 1 MMBTU of renewable gas is does not result in 1 MMBTU of renewable electricity.

Section 3 Energy Baseline Demand with Energy Reduction Improvements After Energy Improvements

3.1 Introduction

This section incorporates and summarizes energy reduction improvements from TM-2 – 4. The energy baseline demand is updated to include both planned and recommended energy reduction improvements.

The costs presented in this report are the Engineer's Opinion of Probable Construction Cost (OPCC) and are AACE Class 5 estimates.

3.2 Recommended Improvements

Table 3-1, **Table 3-2**, and **Table 3-3 s**ummarize the recommended improvements by location, consumer, and energy reduction.

Table 3-4 summarizes the impacts to the energy baseline demand and energy production after recommended improvements are included.

Additional energy monitoring, including down to the individual Motor Control Center (MCC) level is recommended to validate and verify energy reduction assumptions and estimates in this project. This plan defers to project M030112 regarding MMSD's SCADA and monitoring.

Table 3-1: Conveyance System Energy Reduction Recommended Improvements

Improvement	Consumer	Description	Impact		OPCC
			kWh/year	MMBTU/year	
Install Higher Efficiency Lift Station Motors and Pumps	Pumps	Recommend installing higher efficiency motors and pumps at the eight pump stations throughout the Conveyance System	-76,784	-262	$8,000,000[1]

1. The total cost amount has been updated from the cost presented in TM-2.

Table 3-2: JIWRF Recommended Improvements

Improvement	Consumer	Description	Impact		OPCC
			kWh/year	MMBTU/year	
Process Modifications	Aeration and Blowers	Recommend improving and modifying the aeration tanks for biological nutrient removal to decrease overall energy usage and remove nutrients.	-3,136,000	-10,700	$20,700,000
Blower Improvements	Aeration and Blowers	Recommend replacing all blowers with new high efficiency turbo blowers that can produce an energy savings of 13% and 22% over Siemens High Efficiency blower (PAC 1) and Allis Chalmers blower (PAC 2, 3 & 4) respectively.	-2,189,000	-7,500	$11,300,000
Diffusers and Aeration Control	Aeration and Blowers	Recommend replacing the existing diffusers with new disc diffuser to reduce energy consumption and installing a new control system to automatically monitor and control the dissolved oxygen concentrations in the aeration tanks.	-3,956,000	-13,500	$36,900,000
Lighting	Lighting	MMSD completed lighting improvements in 2021 at JIWRF. The energy reduction due to these improvements were not included in the 2018-2020 data used and is estimated here for inclusion in this study.	-4,540,000	-15,500	$0[1]
High Efficiency Motors	Process Pumps, D&D Dust System and HVAC	Recommends installing high efficiency motors for the following: RAS Pumps, WAS Pumps, IPS Pumps, Influent Pumps, Effluent Pumps, Primary Sludge Pumps, D&D Dust System Fans, and D&D HVAC Fans.	-1,026,000	-3,500	$7,900,000

1. Lighting improvements at JIWRF were completed in 2021.

Table 3-3: SSWRF Recommended Improvements

Improvement	Consumer	Description	Impact		OPCC
			kWh/year	MMBTU/year	
Ammonia Sidestream Treatment	Aeration	Recommends installation of a new sidestream treatment to remove ammonia prior to recycling the flow back to the secondary process.	-293,070	-1,000	$12,339,000[1]
Blower Improvements	Aeration	Recommend replacing all blowers with new high efficiency turbo blowers that can produce an energy savings of 17% over the existing blowers.	-2,914,000	-9,950	$7,525,000
Lighting	Lighting	MMSD completed lighting improvements in 2021 at SSWRF. The energy reduction due to these improvements were not included in the 2018-2020 data used and is estimated here for inclusion in this study.	-2,425,000	-8,275	$0[2]
High Efficiency Motors	RAS, Effluent Pumps, IPS, RAS/WAS Transfer Pumps, WAS, Primary Sludge Pumps	Recommends installing high efficiency motors for the following: RAS Pumps, WAS Pumps, RAS/WAS Transfer Pumps, IPS Pumps, Effluent Pumps, and Primary Sludge Pumps.	-316,500	-1,080	$3,281,000
Anaerobic Digester Mixing	Other (HVAC, Misc. Process)	Recommend upgrading the existing 100 HP pumps for Digester No. 12 to new linear motion mixers.	-1,103,000	-3,764	$1,700,000

1. The total cost amount has been updated from the cost presented in TM-4.

2. Lighting improvements at SSWRF were completed in 2021.

3.3 Baseline Demand with Planned and Recommended Improvements

Table 3-4 below summarizes MMSD's baseline energy demands and gas availability after planned and recommended improvements. The volume of DG is dependent on the alternatives that are discussed in **Section 4**.

Table 3-4: Energy Baseline Demand after Planned and Recommended Improvements and Renewable Gas Available

Facility	Energy Demand				Renewable Gas Available		
	Electricity		Gas	Total	LFG	DG	Total
	MMBTU	kWh	MMBTU	MMBTU	MMBTU	MMBTU	MMBTU
Conveyance	9,160	2,684,500	2,100	11,260	0	0	0
Administration	8,200	2,400,000	25,300	33,500	0	0	0
JIWRF	305,400	89,500,000	979,200	1,284,600	1,175,000	0	1,175,000
SSWRF	108,800	31,890,000	153,410	262,210	0	473,880	473,880
Total	431,560	126,474,500	1,160,010	1,591,570	1,175,000	473,880	1,648,880

With the Planned and Recommended Improvements:

- The total energy demand is reduced by 198,400 MMBTU, an 11.1% reduction.
- The renewable gas energy increased by 963,480 MMBTU, a 141% increase.
- The total renewable gas available cannot be directly compared to the total energy demand to see if we can achieve 100% renewable energy because there are inefficiencies due to electricity generation when combusting the renewable gas.
- Therefore, to generate the required 431,560 MMBTU/yr of renewable electricity, more renewable gas is needed because 1 MMBTU of renewable gas is does not result in 1 MMBTU of renewable electricity.

Section 4 Alternatives Evaluation

4.1 Introduction

This section assumes energy reductions summarized in the previous section have been completed and details alternatives in which MMSD can achieve the 2035 Vision goals. Each alternative differs in how energy is consumed and generated to meet the 2035 Vision.

- Alternative 1 prioritizes landfill and digester gas generation.
- Alternative 2 prioritizes photovoltaic and wind electricity generation.
- Alternative 3 includes a new Milorganite® drying facility at SSWRF per the recommendation for the Biosolids Advanced Facility Plan (BAFP) (by others) and prioritizes the production and utilization of digester gas and utilization of landfill gas.

Alternatives 1, 2, and 3 incorporate a gas pipeline connecting JIWRF and SSWRF. Alternative 3 shows DG is not needed at JIWRF after the dryer load shift; however, it is still recommended to be incorporated to provide redundancy and flexibility.

Photovoltaic Assumptions

The photovoltaic (PV) electricity generation estimates were developed using PVWatts, a calculator from the National Renewable Energy Laboratory. The results include the estimated values for annual electricity generation per area and installed panel capacity per electricity generation below.

- Annual electricity generation per area: 199.3 kWh/m^2
- Installed generation capacity per electricity generation: 7.5W/kWh

PV capital costs include a cost of $2.1/W for commercially sized PV systems (10 kW – 2MW). This includes complete project costs including hardware, labor, interconnect, and soft costs. Costs include a small battery storage installation meant for buffering of energy demand vs supply, and not large storage. O&M costs are estimated to cost $20/kW-year based on installed capacity.

PV locations shown in the alternatives are examples. PV locations may be adjusted if MMSD determines a location is not feasible or there is more suitable location available. The available area and generation capacity of the PV systems will have to be matched.

PV was prioritized for this analysis due to the anticipated ease of installation, regulatory approval, and social impact on neighbors near MMSD facilities or properties. Locations close to facility electricity consumers are prioritized to minimize electrical distribution costs and for ease of local municipality approval.

Good Energy Practices and Energy Management

The recommendations in these alternatives address overall energy generation and sourcing, impactful energy reduction projects, and provides a roadmap to meet the 2035 Vision. General good energy practices such as building- and MCC-level energy monitoring are recommended to assist energy monitoring and project planning. Additional improvements such as building envelope and HVAC equipment improvements are recommended when buildings and equipment are due for replacement. Additionally, an MMSD energy program manager is recommended to keep track of this plan's implementation, progress, and vision. This plan is written to allow for design and incorporation flexibility where an energy program manager can evaluate specific project priorities and constraints when considering design decisions and how the energy plan goals are incorporated, or project goals adapted to facilitate decision making. One example is projects with design decisions of whether to change from natural gas to electric equipment at site. A project's constraints in electrical service and installation and operation and maintenance costs must be considered along with the alternative chosen in this plan. Alternative paths for getting to the 2035 Goals allow for some renewable gas purchasing from the utility and renewable gas consumption from digester gas cleaning at the WRFs, if it makes sense to keep a natural gas fueled unit.

We recommend that an energy program manager would be designated and utilized in the following MMSD processes and tasks to weave the energy plan priorities in with MMSD's other priorities for capital improvements:

- Project planning
- Project prioritization for the CIP into the capital budget
- Attending the energy team meetings
- Attending the water team asset management review meetings

Net Metering or Wheeling Power Assumptions

All alternatives exclude potential, negotiated arrangements for power transfer agreements with We Energies such as net metering or wheeling. Net metering is a billing mechanism that credits utility customers who generate electricity that is added to the grid. The customer can then account the energy they generate against energy they pull from the grid at another time. Customers are then only billed for their net energy use. Wheeling is the transmission of electric energy from within an electrical grid to an electrical load outside the grid boundaries.

If wheeling power is possible, PV or wind installations can be consolidated, energy storage can be reduced, and renewable energy purchasing can be reduced.

In Wisconsin, there are other large renewable energy projects that have been proposed and are moving forward, including a solar and battery project in Kenosha County and the Koshkonong Solar Energy Project in Dane County. A partnership with We Energies is highly encouraged for a continued power connection and backup power.

Engineers Opinion of Probable Construction Cost

The OPCCs in this section are in accordance with AACE Class 5 estimates. This level is appropriate as these are primarily concept screening analyses and recommendations with more detailed design required in the future. The expected accuracy range of a class 5 estimate is -20%-50% low and +30%-100% high. The project team acknowledges that some estimates may be low and others high to offset towards the listed estimate, however this range typically provides a 90% confidence that the actual cost will fall within the bounds. OPCCs are included for each recommendation of each alternative. Capital costs for the recommendations are presented first in the tables. Additional costs, such as structural improvements and electrical improvements, are shown next, with a description of how the cost was estimated provided in parentheses. A capital cost subtotal was calculated and then overhead and profit (20%), contingency (40%), and design and engineering services (15%) were applied to the subtotal to generate a total capital cost. An annual operation and maintenance (O&M) cost is included at the end of the table.

Present worth (PW) costs utilize a 3.375% discount rate, consistent with the BAFP.

Landfill Gas and High Strength Waste Availability

Alternatives 1 and 3 show a significant volume of gas from a new LFG pipeline connection to the Waste Management Metro Landfill as part of project P02004. If this project does not happen, additional digester gas generation, equipment electrification, and other initiatives described in Alternative 2 will have to be incorporated.

The 700,000 MMBTU of LFG from the Waste Management Metro Landfill project is equivalent to 250,000 lbs/day of food waste for HSW DG generation.

If significant volumes of renewable gas are unavailable, MMSD may have to consider electrifying assets and acquiring additional renewable electricity. The 700,000 MMBTU of gas is equivalent to 205,150,000 kWh of electricity. 11,080,000 SF of PV, equivalent to a 153,850 kW installation, would be needed to generate the equivalent volume of gas unavailable.

4.2 Alternative 1 – Prioritize Landfill and Digester Gas Generation

Alternative 1 is a business-as-usual operating alternative that prioritizes the use of renewable gas, both LFG and DG, with renewable electricity minimized.

4.2.1 Energy Profile

The recommended renewable energy generation and consumption energy profile for Alternative 1 is shown for JIWRF and SSWRF in **Figure 4-1**, **Figure 4-2**, **Figure 4-3**, and **Figure 4-4** below. The recommendation shows no anticipated energy consumption at the WRFs from We Energies, however we are not recommending islanding the facilities. Coordination with We Energies to be a backup power source is required.

The conveyance system and administration facilities electricity demand will be met by the recommended PV locations and renewable purchased renewable energy from We Energies, as summarized in **Sections 4.2.4** and **4.2.5**. These facilities' renewable NG consumption and associated emissions is included in the GHG emissions calculation in **Section 4.2.6**.

- Alternative 1 prioritizes landfill and digester gas generation.
  - JIWRF
    - Install two new Solar Turbines
    - Install 158,400 SF or 2,200 kW of PV panels
    - Convert one more dryer to LFG fueled
  - SSWRF
    - Install new engine generators
    - Install 1,315,400 SF or 18,300 kW of PV panels
    - Build a 16 tons per day high strength waste receiving station and anaerobic digesters to increase digester gas generation
    - Install a 1,800 SFM gas cleaning system
    - Install 5,640,000 CF of gas storage serving JIWRF and SSWRF
    - Build a digester gas pipeline connecting JIWRF and SSWRF
  - Conveyance System
    - Install 4,600 kW of PV panels
    - Purchase the remaining renewable electricity and natural gas from We Energies
  - Administration Facilities
    - Installing 36,400 SF or 500 kW of PV panels
    - Purchasing the remaining renewable electricity and renewable natural gas from We Energies

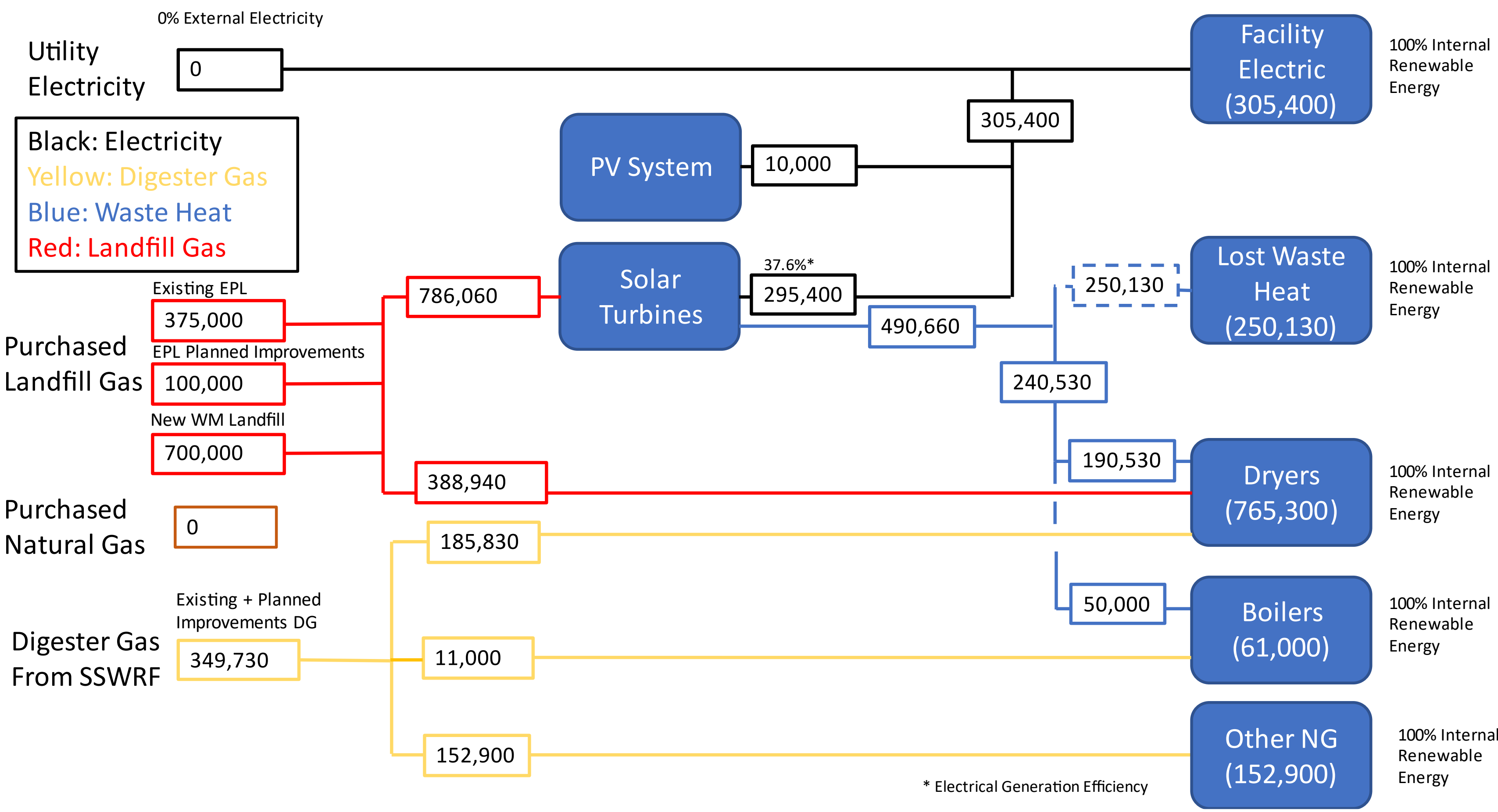

Figure 4-1: Alt 1 - JIWRF Energy Profile (MMBTU/Year)

Figure 4-2: Alt 1 – JIWRF Energy Profile Site Plan (MMBTU/Year)

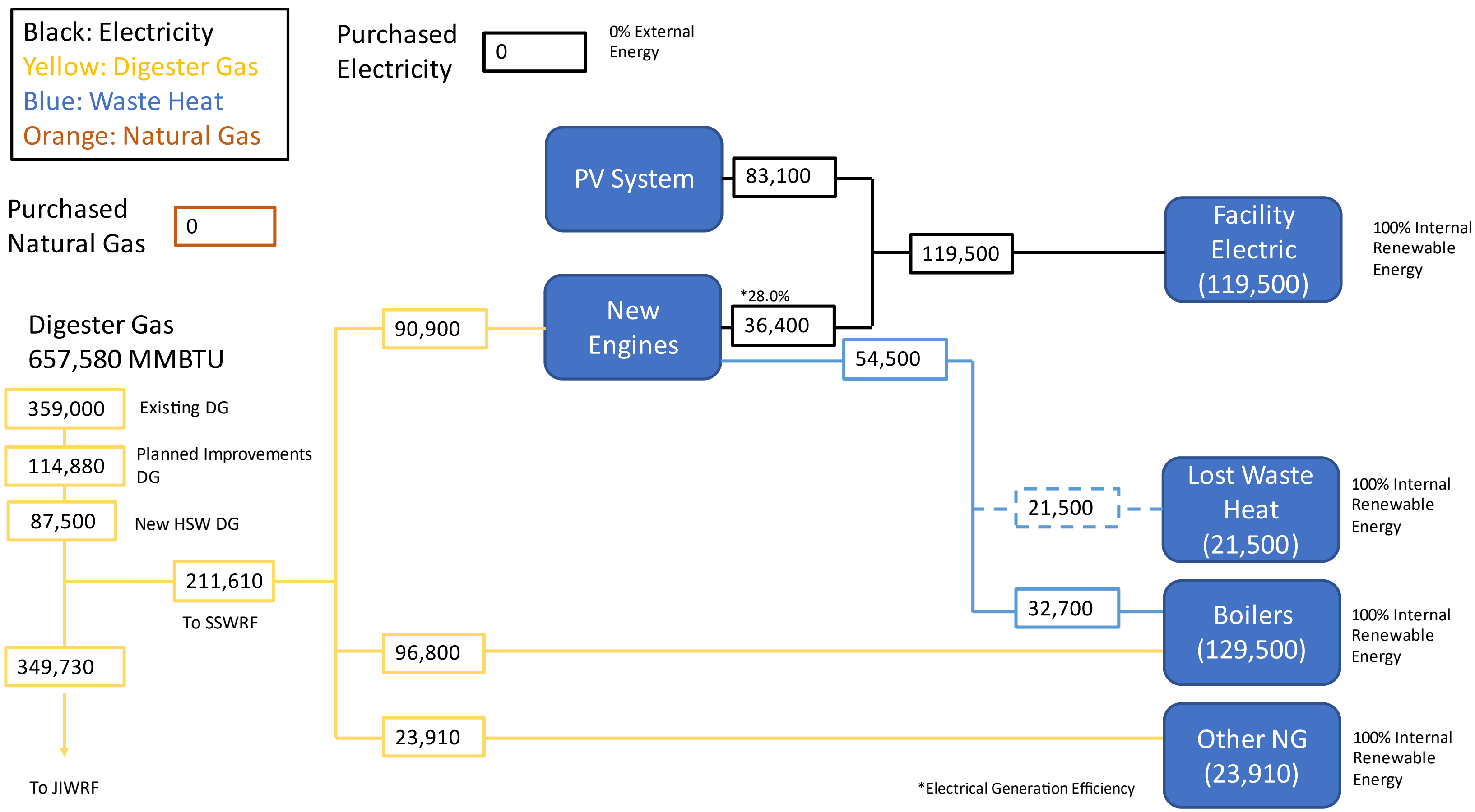

Figure 4-3: Alt 1 - SSWRF Energy Profile (MMBTU/Year)

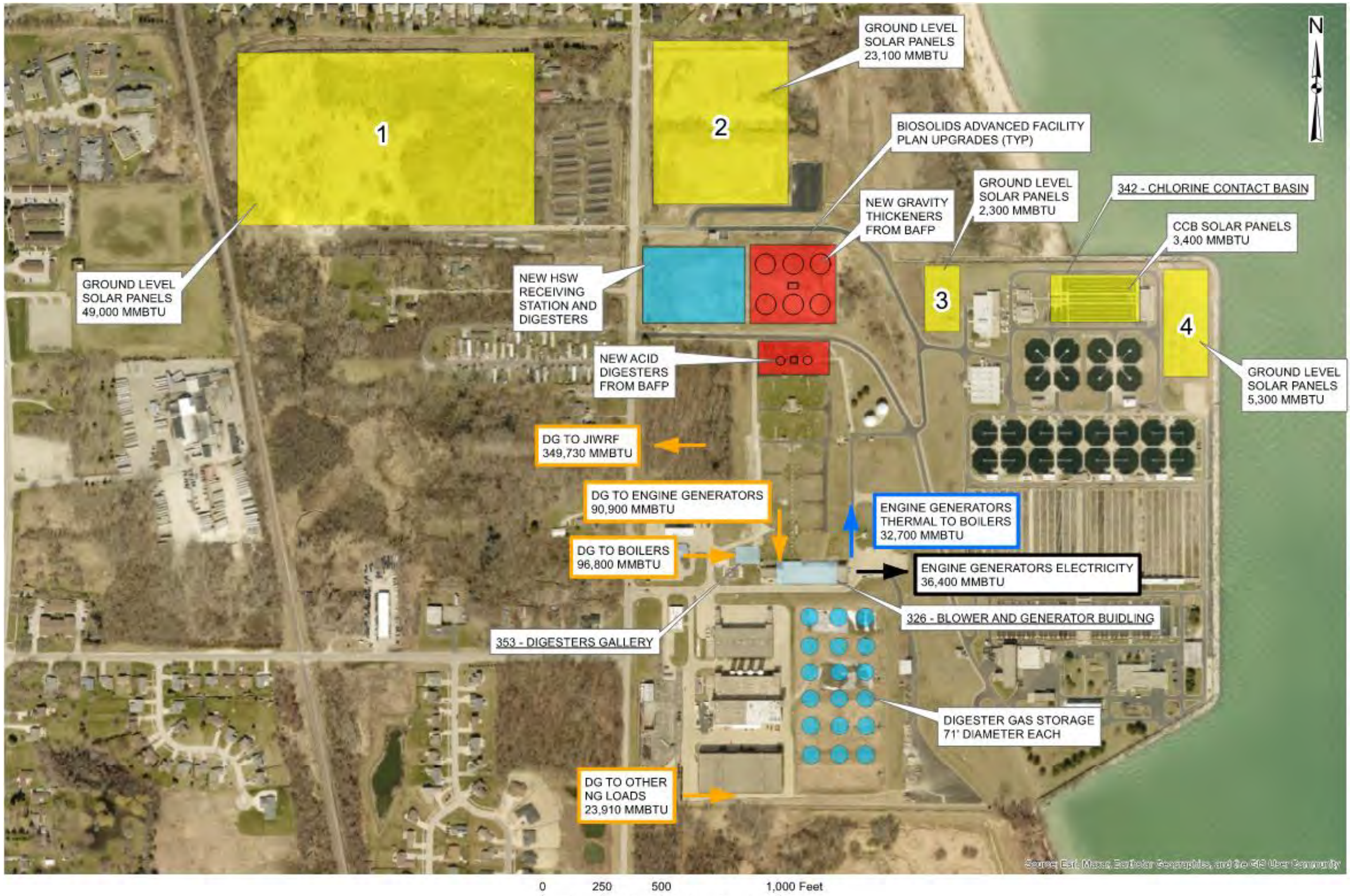

Figure 4-4: Alt 1 - SSWRF Energy Profile Site Plan (MMBTU/Year)

4.2.2 JIWRF

Renewable Electricity Generation

JIWRF Turbine Generation
The JIWRF electricity generation calculation determined that approximately two solar turbines are required to generate the facility's consumed electricity, minus the new PV generation. The calculation assumed electrical and thermal efficiencies of 37.6% and 30.6% and an electrical output of 4,800 kW for each turbine. The fuel input required is approximately 786,000 MMBTU/year. LFG was used as the primary fuel for energy generation as shown in **Figure 4-1**.

JIWRF Turbine Asset Management

Solar Turbines
The three Solar turbines were installed in 2012 and are 11 years old. Each turbine is rated for 4.8 MW of electrical power generation. MMSD has a maintenance contract with Solar Turbines Incorporated and pays $22,031,208 for 10 years, or $2,203,120 per year. This equates to an average of $734,374 per turbine per year.

It is recommended to increase the total installed generation capacity to 24 MW by installing two additional Solar turbines and skids and retire the GE turbines. Currently, GE turbine #1 is active and available, while GE turbine #2 is decommissioned and no longer used. The average wet weather demand is 17.2 MW, therefore to maintain redundancy, four Solar turbines can meet wet weather demand. The 4 turbines are N and 5th would be +1 to maintain N+1 operation during average wet weather conditions. The turbine room and system were designed for a total of five Solar turbines and five gas conditioning skids.

At 90°F, the turbines are derated to ~3.9 MW each. Four turbines operating results in only 15.6 MW of generation capacity, not achieving the N+1 redundancy. 90°F is the ASHRAE 90.1 0.4% cooling design condition and is not considered a typical operating condition. Additionally, wet weather demand typically occurs with or directly after rainstorms that drop the ambient temperature. At 75°F, the turbines are derated to ~4.3 MW each, resulting in four turbines generating 17.2 MW of capacity, which meets the wet weather demand while maintaining N+1 redundancy.

Additionally, a common gas header connecting compressors should be considered to incorporate additional redundancy and flexibility to reduce equipment downtime.

Project cost data from the EPA catalog of CHP technologies for combustion turbine generators, which include total project costs including design, equipment, labor, financing, fees, etc. The two 4,800 kW turbine generators are estimated to cost $4,240/kW[2]. This includes an inflation factor of 1.3 to account for the costs changes since the data was presented[3]. The current O&M costs per turbine are assumed to be maintained, with the addition of an inflation factor of 1.3 to account for costs increases since 2012. The estimated O&M costs is $969,375 per turbine or $1,938,750 for two turbines.

Table 4-1 summarizes the new turbine generator cost.

Table 4-1: Alt 1 – JIWRF New Turbine Generator Cost Estimate

Description	Cost
Turbine Generator Capital Cost	$40,704,000
Subtotal	$40,704,000
Overhead and Profit (20% of Subtotal)	$8,141,000
Contingency (40% of Subtotal)	$16,282,000
Design and Engineering Services (15% of Subtotal)	$6,106,000
Total Capital Cost	**$71,233,000**
AACE: -50%	$35,617,000
AACE: +100%	$142,466,000
Total Annual O&M Cost	**$1,939,000**

GE Turbines

The 2 GE turbines were installed in 1972 and are 51 years old. The controls were upgraded in 1994 and the turbines were rebuilt in 1996. The post rebuild age is 27 years old. Each unit is rated for 16 MW of electrical power generation. MMSD is responsible for maintenance and longevity of the turbines. The average maintenance cost over the past 14 years is $238,000 per year. Currently, GE turbine #1 is active and available, while GE turbine #2 is decommissioned and no longer used.

It is recommended to retire the GE turbines due to:

- Their inability to operate using renewable fuels and costly retrofit that would be required.
- Lower electrical efficiency relative to the newer Solar turbines.

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[2] https://www.epa.gov/sites/default/files/2015-07/documents/catalog_of_chp_technologies_section_3._technology_characterization_-_combustion_turbines.pdf
[3] https://www.bls.gov/data/inflation_calculator.htm

JIWRF Photovoltaic Power Generation

TM-3 evaluated potential areas at JIWRF for PV electricity generation. This section summarizes the locations, generation potential, and cost of the recommended installations at JIWRF for Alternative 1. The recommended areas focus on open parking lots, rooftops, and above the Chlorine Contact Basins. These areas would have minimal impact on plant operations. **Table 4-2** shows the recommended PV locations and generation potential.

Table 4-2: Alt 1 – JIWRF PV Recommended Locations

Location	Area (m^2)	Area (SF)	kWh/year	kW	MMBTU/year
280 - Maintenance Building	2,650	28,500	528,000	396	1,802
258 - D&D Facility	2,160	23,300	430,000	323	1,467
Parking NE of 280	2,100	22,600	419,000	315	1,430
242 - Chlorine Contact Basins	6,800	73,200	1,355,000	1,017	4,623
261 - New Milorganite Packaging Facility	1,000	10,800	199,000	150	679
Total	14,710	158,400	2,931,000	2,201	10,001

The capital cost includes a cost escalation factor of two to account for the potential structural improvements to roofs and additional support structures over tanks and parking spaces.

Table 4-3: Alt 1 – JIWRF PV Cost Summary

Description	Cost
Capital Cost for PV Panels	$4,623,000
Structural Improvements (100% of PV Panel Cost)	$4,623,000
Electrical Improvements (20% of PV Panel Cost)	$925,000
Subtotal	$10,171,000
Overhead and Profit (20% of Subtotal)	$2,035,000
Contingency (40% of Subtotal)	$4,069,000
Design and Engineering Services (15% of Subtotal)	$1,526,000
Total Capital Cost	**$17,801,000**
AACE: -50%	$8,901,000
AACE: +100%	$35,602,000
Total Annual O&M Cost ($20/kW)	**$45,000**

Renewable Gas

JIWRF receives LFG from the Emerald Park Landfill. The current contract for LFG expires in 2030 and there is uncertainty in pricing and availability moving forward. An adaptive management plan addressing LFG availability is required. Aspects of Alternative 2's analysis may be incorporated in the LFG adaptive management plan to mitigate the decrease in LFG supply.

Gas Storage Analysis

Gas storage is needed for MMSD to maximize renewable gas consumption and eliminate non-renewable gas and electricity purchased from the utility. This section summarizes how much storage is available and how long it will last under normal and wet weather conditions. If net metering is feasible, less storage is required.

Existing gas supply and demand data were used to evaluate storage capacity for LFG and DG from SSWRF. Current scenarios of LFG supply and demand at JIWRF result in no storage capacity needed because consumption always exceeds supply. The future scenario with additional LFG supply after planned improvements does not require LFG storage as LFG is prioritized in the turbines and dryers. DG storage based on projected JIWRF gas demands is summarized with the assumptions below. All gasholders are located at SSWRF.

- Three years of existing LFG and DG supply and thermal demand data was used to find the mean, standard deviation (SD), and SD/mean ratio for the supply and thermal demand at each JIWRF and SSWRF.
- The projected LFG and DG supply and projected thermal demands were determined using the Energy Profile summarized in **Section 4.2.1**.
- The projected low and high supply and demands were determined by multiplying the existing SD/mean ratio with the projected average supply and thermal demands to find the projected SD. The highs and lows were determined by adding and subtracting 2 times the SD from the projected average.
- The SCFMs are converted from MMBTU/Day which incorporates the energy content of the gas and are 100% methane after gas cleaning. All gas stored in this analysis is cleaned.

Table 4-4 shows the projected low and high supply and demand for gas, as well as the associated maximum surplus and deficits.

Table 4-4: Alt 1 – LFG + DG Storage Analysis – JIWRF Demands

Supply		Demand		Surplus		Deficit	
Low	High	Low	High	Max		Max	
MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	SCFM	MMBTU/Day	SCFM
2,000	4,500	3,100	5,300	1,400	970	-3,300	-2,290

This results in maximum deficit volume of 3,300 MMBTU/day or 2,290 SCFM of DG.

For this evaluation, dual membrane gasholding tanks on concrete pads were used. A 70' diameter, 3/4 sphere dual membrane gasholder can hold 282,000 CF of gas at 9.5 in w.c. **Figure 4-4** shows the area required for 20 gasholders. 20 gasholders equate to approximately 5,640,000 CF or 1.19 days of storage capacity at the maximum deficit. Each gasholder costs approximately $800,000 each.

Table 4-5: Alt 1 – Gas Storage Cost Summary

Description	Cost
Gasholder Capital Cost	$16,000,000
Civil / Site Improvements (50% of Gasholder Cost)	$8,000,000
Installation and Labor (50% of Gasholder Cost)	$8,000,000
Subtotal	$32,000,000
Overhead and Profit (20% of Subtotal)	$6,400,000
Contingency (40% of Subtotal)	$12,800,000
Design and Engineering Services (15% of Subtotal)	$4,800,000
Total Capital Cost	**$56,000,000**
AACE: -50%	$28,000,000
AACE: +100%	$112,000,000
Total Annual O&M Cost (2% of Capital Cost)	**$1,120,000**

The dryers are rated for a maximum 25 MMBTU/hr each but operate at 12.5 MMBTU/hr each, and the turbines are rated for a maximum of 43 MMBTU/hr each. These equate to 415 and 715 CFM respectively. An operating scenario where 8 dryers operating at 12.5 MMBTU/hr and 2 turbines are in operation, they would consume 3,090 CFM of gas. Assuming the low supply rate, the resulting gas drain would be 1,090 CFM (3,090 CFM – 2,000 CFM). This operating scenario would take approximately 3.6 days for the storage capacity to be drained. This scenario conservatively assumes no waste heat from the turbines are offsetting dryer gas consumption.

It is recommended to maintain N+1 capacity to burn the gas available. Alternative 1 dryer LFG demand is 390,000 MMBTU/yr or ~44.5 MMBTU/hr. This necessitates 4 dryers as N and the 5th dryer would be +1. There are 4 existing LFG dryers, therefore converting at least 1 more dryer to LFG is recommended. LFG cleaning at JIWRF is not needed because all available LFG is utilized by the dryers and turbines which do not require full LFG cleaning. Alternative 1's Other NG demands are satisfied by clean DG from SSWRF.

Maintaining the 3 LFG turbines is recommended for sustaining operation of 2 Solar Turbines as N and the 3rd as +1 for N+1. As previously discussed, installing 2 additional Solar Turbines allows for additional redundancy to limit facility electric utility demand charges in case any turbines are down for maintenance, or a large wet weather event occurs where additional electrical generation capacity is required.

4.2.3 SSWRF

SSWRF Engine Generator Electricity Generation

The SSWRF electricity generation calculation assumes approximately two CAT engine generators are in operation with electrical and thermal efficiencies of 28.0% and 36.0% and each generator has electrical output of 760.5 kW. This information is based on historical data as presented in TM-4. The fuel input required is approximately 129,900 MMBTU/year.

New SSWRF Engine Generators

If new, more electrically efficient engine generators were installed at SSWRF, they would generate the same electricity and thermal heat using just 90,900 MMBTU/year. That is a savings of 39,000 MMBTU/year of DG (129,900 – 90,900 MMBTU). The value for gas offset is summarized for different values of fuel costs below, calculated based on the 39,000 MMBTU/year of DG savings.

- $2.11/MMBTU equates to $82,000/year
- $5/MMBTU equates to $195,000/year
- $10/MMBTU equates to $390,000 /year

SSWRF Engine Asset Management

CAT Engine Generators

The four CAT engine generators were installed in 2009, placed into operation in 2010 and are 14 years old. Each unit is rated for 925 kW when operating on DG and 770 kW on NG. The CAT engines require DG to be at approximately 5 psig. MMSD is responsible for maintenance of the engine generators. The average annual maintenance cost over the past 10 years is $367,934 per engine generators as per MMSD maintenance records.

The 2018-2020 SSWRF average wet weather energy demand was 6.2 MW. It is recommended that MMSD have N+1 the engine generation capacity to meet this wet weather demand. The calculations for this report were based off Jenbacher engine generators, however other biogas rated engine generator equivalents may be used. Using the recommended average engine generation 36,400 MMBTU/yr or 10,668,000 kWh/yr results in an average demand of 1,217 kW. A J420 engine generator generates 1,429 kW. Six J420 engine generators results in a total installed capacity of 8,574 kW or firm capacity (largest unit out of service) of 7,145 kW. The J420 engine generators operate with a fuel pressure under 5 psig. This installation also allows for a duty engine generator capable of meeting the average demand of 1,217 kW.

Using project cost data from the EPA catalog of CHP technologies for reciprocating internal combustion engines, which include total project costs including design, equipment, labor, financing, fees, etc., the new engine generators are estimated to cost $3,080/kW[4]. This includes an expected assumed inflation factor of 1.3 to account for the costs changes since the data was presented[5]. The O&M costs are estimated similarly, resulting in $0.025/kWh. Assuming an expected 80% of the installed capacity is operational for the year for O&M purposes, the resulting yearly O&M cost is $1,591,000/year or about $398,000/year per engine. This is similar, but slightly higher than the existing engines yearly maintenance costs per year per engine due to the recommended engine's larger capacities.

Table 4-6 summarizes the new engine generators cost.

Table 4-6: Alt 1 – SSWRF New Engine Generator Cost Estimate

Description	Cost
Engine Generator Capital Cost	$26,408,000
Subtotal	$26,408,000
Overhead and Profit (20% of Subtotal)	$5,282,000
Contingency (40% of Subtotal)	$10,564,000
Design and Engineering Services (15% of Subtotal)	$3,962,000
Total Capital Cost	**$46,216,000**
AACE: -50%	$23,108,000
AACE: +100%	$92,432,000
Total Annual O&M Cost	**$1,591,000**

White Superior Engine

The White Superior (WS) engine was placed into operation in 2000 and is 23 years old. It is rated for 1,500 kW when operating on either DG or NG. The WS engine requires DG to be compressed to

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4 https://www.epa.gov/sites/default/files/2015-07/documents/catalog_of_chp_technologies_section_2._technology_characterization_-_reciprocating_internal_combustion_engines.pdf
5 https://www.bls.gov/data/inflation_calculator.htm

approximately 45 psig. MMSD is responsible for maintenance and longevity of the engine. The average annual maintenance cost over the past 10 years is $133,000.

The White Superior engine currently provides redundancy and additional capacity to the CAT engines, allowing MMSD to minimize their electric utility demand charges by generating electricity internally. The engine is however reaching the end of its expected useful life as it is almost 25 years old and operates on DG at times. It also requires higher gas compression than the CAT or Jenbacher engines, requiring additional compressors. It is recommended for this engine to be decommissioned once new Jenbacher or equivalent engine generation capacity is installed.

SSWRF PV Generation

TM-4 evaluated potential areas at SSWRF for PV electricity generation. This section summarizes the locations, generation potential, and cost of the recommended installations at SSWRF for Alternative 1. The recommended areas focus on open areas and above the Chlorine Contact Basins. These areas would have minimal impact on plant operations.

Table 4-7 shows the recommended PV locations and generation potential. Generation potential was determined based on system size, tilt, and direction. A 20-degree tilt was assumed. System losses were estimated to be 14.08%.

Table 4-7: Alt 1 – SSWRF PV Recommended Locations

Location	Area (m^2)	Area (SF)	kWh/year	kW	MMBTU/year
1 - Open Area	72,000	775,000	14,349,600	10,761	48,963
2 - Open Area	34,000	366,000	6,776,200	5,081	23,121
3 - Open Area	3,400	36,600	677,620	508	2,312
4 - Open Area	7,800	84,000	1,554,540	1,166	5,304
Chlorine Contact Basin	5,000	53,800	996,500	747	3,400
Total	122,200	1,315,400	24,354,460	18,263	83,100

Cost Table

The capital cost also includes a cost escalation factor of 2 to account for the additional support structures and complexity of installing the PV panels above process tanks. **Table 4-8** summarizes SSWRF's recommended PV installation costs.

Gas storage is recommended at both JIWRF and SSWRF. The gas storage is intended to satisfy demands during periods where direct PV is unavailable and the generators can produce the required demand. Additional battery and energy storage requirements will be confirmed as the implementation of the plan progresses. A more detailed design and study of the PV system will occur during the PV project design phase.

Table 4-8: Alt 1 – SSWRF PV Cost Summary

Description	Cost
Capital Cost for PV Panels	$38,353,000
Structural Improvements (100% of PV Panel Cost)	$38,353,000
Electrical Improvements (20% of PV Panel Cost)	$7,671,000
Subtotal	$84,377,000
Overhead and Profit (20% of Subtotal)	$16,876,000
Contingency (40% of Subtotal)	$33,751,000
Design and Engineering Services (15% of Subtotal)	$12,657,000
Total Capital Cost	**$147,661,000**
AACE: -50%	$73,831,000
AACE: +100%	$295,322,000
Total Annual O&M Cost ($20/kW)	**$366,000**

Renewable Gas

SSWRF HSW

Additional DG will be required to provide energy to JIWRF and SSWRF. A high strength waste (HSW) food waste program was evaluated and summarized as part of TM-4. This report uses the same assumptions and analysis previously discussed.

- Additional 87,500 MMBTU/year of DG gas is needed after planned improvements.
    - Less gas is needed if new engine generators are installed as previously discussed in the engine generator asset management section.
- This is equal to approximately 277 SCFM of DG @ 60% Methane.

As shown in **Table 4-9**, approximately 15.7 tons per day of food waste will be needed to produce the 277 SCFM of DG. This quantity was determined assuming a specific biogas production rate of 16 ft^3/lb VSR and a 0.94 volatile solids to total solids ratio. Complete calculations are included in **Appendix J**.

Table 4-9: Alt 1 – HSW Food Waste Calculations

DG Parameters		
DG Needed After Planned Improvements	MMBTU/year	87,500
	dth/year	87,479
	CF/year	87,480,000
	SCFM	166
	SCFM of DG	277
Biogas Production Potential		
Biogas Production Needed	SCFD	400,000
Volatiles Destroyed	Lbs/Day	25,000
VS Loading Capacity	Lbs/Day	29,500
Loading Rate	Lbs/Day	31,400
	Tons/Day	15.7
Additional Biosolids for Disposal	Lbs/Day	6,400

The calculated loading rate of 15.7 tons per day was used to determine the digester quantity and size needed to accept this quantity of HSW. This was done under three different conditions: first, using the existing digester conditions with planned improvements, second, using the expected 2045 digester capacity based on proposed changes from the BAFP but keeping the current loading rates, and third, using both the 2045 capacity and projected 2045 loading rates. The digester volume needed is calculated based on the remaining capacity of the existing digesters. It was assumed that no more than 20% of the remaining digester capacity would be available to accept HSW. Only mesophilic digester space was considered due to unknowns surrounding food waste in thermophilic digesters. The remaining HSW will be sent to new digesters. A minimum of two digesters was assumed for redundancy purposes. The quantity and size of these new digesters are presented in **Table 4-10**.

Table 4-10: Alt 1 – Digester Capacity Evaluation

	Unit	Existing Conditions	2045 Capacity with Current Loading Rates	2045 Capacity and Loading Rates
DG Needed After Planned Improvements	MMBTU/year	87,500		
	SCFM of DG	277		
Quantity of Food Waste Needed	Tons/Day	15.7		
Digester Volume Needed	CF	246,000		

	Unit	Existing Conditions	2045 Capacity with Current Loading Rates	2045 Capacity and Loading Rates
Digester Volume to Existing Digesters	CF	126,000	76,000	0
Digester Volume to New Digesters	CF	120,000	170,000	246,000
New Digester Size	MG	0.50	0.75	1.25
Quantity of New Digesters Needed		2	2	2
Digester Diameter	Ft	58	71	92
Digester Sidewater Depth	Ft	25.0	25.0	25.0

The new digesters and additional loading will require additional energy to heat the sludge. The new HSW facility will also have equipment and building energy demands. The projected digester heating and building energy requirements are summarized below for Alternative 1's HSW improvements.

- Digester Heating: 15,000 MMBTU/yr
- Building Energy: 1,500 MMBTU/yr
- Equipment Energy: 3,500 MMBTU/yr

Table 4-11 includes the cost for a new high strength waste system, including digesters, a high strength waste receiving station, and high strength waste processing equipment like receiving tanks, slurry tanks, slurry pumps, macerators and grinders, paddle finishers, conveyance equipment, odor control equipment, and instrumentation. There is a planning study in the District's budget for 2024 to look at not only the capital improvements which are needed, but also what is available for a steady pipeline of additional high strength waste and where those resources could be found and what costs and impacts may be associated with those sources.

Table 4-11: Alt 1 – SSWRF HSW System Cost Summary

Description	Cost
Anaerobic Digester Capital Cost	$21,946,000
HSW Building Capital Cost	$7,500,000
Subtotal 1	$29,446,000
Anaerobic Digester and HSW Equipment (100% of Subtotal 1)	$29,446,000
Site Work (20% of Subtotal 1)	$5,890,000
Additional Electricity (20% of Subtotal 1)	$5,890,000
Installation and Labor (50% of Building, Equipment, Site Costs)	$32,391,000
Subtotal 2	$103,063,000
Overhead and Profit (20% of Subtotal 2)	$20,613,000
Contingency (40% of Subtotal 2)	$41,226,000
Design and Engineering Services (15% of Subtotal 2)	$15,460,000
Total Capital Cost	**$180,362,000**
AACE: -50%	$90,181,000
AACE: +100%	$360,724,000
Total Annual O&M Cost (2% of Capital Cost)	**$3,608,000**

Gas Cleaning Analysis

It is recommended to clean all generated DG to allow for consumption flexibility and equipment longevity. The cleaned DG can be connected to the facilities' NG lines to allow for renewable gas consumption by the other NG consumers. SSWRF's total DG production for Alternative 1 is 561,380 MMBTU/year as shown in **Section 4.2.1**. This equates to 1,800 SCFM of DG @60% Methane.

An additional 1,538,600 kWh/year or 5,250 MMBTU/year is required to generate the additional electricity required to power the gas cleaning system. This value is included in SSWRF's electricity demand in **Section 4.2.1**. This equates to the following:

- 13,200 MMBTU/year of DG for engine electricity generation
- 81,600 SF or 7,720 m^2 of PV panels

Table 4-12 summarizes the electricity requirements and costs of a 1,800 SCFM gas cleaning system to RNG quality at SSWRF.

Table 4-12: Alt 1 – SSWRF DG Cleaning Summary

SCFM	Cost		Electricity			Footprint
	Capital	Yearly O&M	Demand	Consumption		SF
			kW	kWh/year	MMBTU/year	
1,800	$22,745,000	$375,000	176	1,537,380	5,250	4,000

Table 4-13 breaks down the DG cleaning system cost.

Table 4-13: Alt 1 – DG Cleaning Cost Summary

Description	Cost
Equipment Capital Cost	$6,840,000
Structural Improvements (20% of Equipment Cost)	$1,368,000
Electrical Improvements (20% of Equipment Cost)	$1,368,000
Labor (50% of Equipment Cost)	$3,420,000
Subtotal	$12,996,000
Overhead and Profit (20% of Subtotal)	$2,600,000
Contingency (40% of Subtotal)	$5,199,000
Design and Engineering Services (15% of Subtotal)	$1,950,000
Total Capital Cost	$22,745,000
AACE: -50%	$11,373,000
AACE: +100%	$45,490,000
Total Annual O&M Cost (2% of Capital Cost)	**$375,000**

Gas Storage Analysis

Similar to JIWRF, a gas supply and demand analysis was completed for SSWRF. In this case, the gas supply and thermal demands were analyzed and projected for DG production and SSWRF's thermal demands using existing data. The high and low supply and demands were calculated similar to the analysis above. **Table 4-14** summarizes the gas surplus and deficits based on SSWRF's high and low supply and demands.

Table 4-14: Alt 1 – DG Storage Analysis – SSWRF Demands

Supply		Demand		Surplus		Deficit	
Low	High	Low	High	Max		Max	
MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	SCFM	MMBTU/Day	SCFM
900	2,200	1,000	2,100	1,200	830	-1,200	-830

This results in maximum deficit volume of 1,200 MMBTU/day or 830 SCFM. The max surplus volume is 1,200 MMBTU/day or 830 SCFM. The resulting time to fill 20 gasholders is approximately 4.7 days.

The largest boilers are rated for a maximum of 16.7 MMBTU/hr each or 280 SCFM @ 100% methane. The recommended engine generation demand is 10.4 MMBTU/hr or 170 SCFM @ 100% methane. JIWRF is estimated to consume 349,730 MMBTU/year or an average of 670 SCFM of gas.

An operating scenario when 1 engine and 1 boiler are operating at SSWRF with 670 SCFM going to JIWRF results in a total demand of 1,120 SCFM of DG. Assuming the low supply rate, the resulting DG drain would be 220 CFM (1,120-900). This operating scenario would take approximately 17.8 days for the storage capacity to be drained. This scenario conservatively assumes no waste heat from the engines are offsetting boiler gas consumption.

If new engine generators were to generate all the electricity during wet weather demand of 6.2 MW, 52.8 MMBTU/hr of fuel is needed. This equates to 850 SCFM of DG @ 100% methane. This plus 1 boiler operating and JIWRF's average DG demand results in a total of 1,800 SCFM and would take approximately 4.3 days to drain the 20 gasholder storage capacity assuming the low supply rate.

If JIWRF were also operating at its wet weather demand average of 17.2 MW, 157 MMBTU/hr or 2,520 SCFM of gas is needed. LFG averages 90 MMBTU/hr or 1,450 SCFM. Therefore, an additional 1,070 CFM of DG is needed at JIWRF. This results in a total wet weather DG demand of 2,870 SCFM (1,800 + 1,070) and would take approximately 2 days to drain the storage capacity.

See **Table 4-5** for the costs associated with installing 20 gasholders at SSWRF.

4.2.3.1 SSWRF to JIWRF Gas Pipeline

A gas pipeline connecting JIWRF to SSWRF to fully utilize DG is included as part of Alternative 1. The pipeline is approximately 12 miles long and follows the same path as the Interplant Sludge Pipeline and the LFG pipeline (starting at College Ave) to JIWRF. **Figure 4-5** shows the proposed pipeline and path.

Figure 4-5: SSWRF to JIWRF DG Pipeline

Two sizes of pipeline were evaluated. Both sizes were evaluated at 40 psig. The State of Wisconsin limits gas pipelines to 60 psig unless the number of services from these mains are limited and have series regulators or other pressure limiting devices[6]. The pipeline pressure was limited to 40 psig for this study. High density polyethylene pipe is recommended. The pipeline would not require booster compressors along the route but would require three 60 HP compressors at SSWRF.

- An 8-inch pipeline could convey up to 1,600 SCFM of DG at 40 psig.

[6] Wisconsin Administration Code 49 CFR 192.621 and PSC 135.621

- A 10-inch pipeline could convey up to 3,000 SCFM at 40 psig.

Table 4-15 breaks down the cost of this SSWRF to JIWRF gas pipeline. Cost assumptions are listed below:

- Compressors cost $174,000 each and are in containerized skids or will be installed in an existing building.
- A 10" pipeline is recommended and costs $2,067,170/mi.
  - Includes trenching, backfill, valves, appurtenances, and restoration.
  - Includes HDPE pipe only and no additional casing.
  - Assumes the existing easement has enough space for additional 10" pipe.

Table 4-15: SSWRF to JIWRF Gas Pipeline Cost Summary

Description	Cost
Pipeline Capital Cost	$24,807,000
Compressors Capital Cost	$522,000
Compressor Electrical Improvements (20% of Equipment Cost)	$105,000
Compressor Installation and Labor (50% of Capital Cost)	$261,000
Subtotal	$25,695,000
Overhead and Profit (20% of Subtotal)	$5,139,000
Contingency (40% of Subtotal)	$10,278,000
Design and Engineering Services (15% of Subtotal)	$3,855,000
Total Capital Cost	**$44,967,000**
AACE: -50%	$22,484,000
AACE: +100%	$89,934,000
Total Annual O&M Cost (2% of Capital Cost)	**$900,000**

4.2.4 Conveyance System

There are opportunities for generating renewable energy at MMSD's Conveyance System. **Table 4-16** shows the top ten Conveyance System locations with the highest annual energy consumption from 2018-2020. The top ten Conveyance System energy users account for 70% of the total Conveyance System energy usage.

Each of these locations was considered for PV panels instead of wind due to the locations having relatively small footprints and typically being located in urban areas where wind power could be challenging to install due to the impact to neighbors. The locations were evaluated to determine if the PV panels at the site were feasible.

Out of the ten locations, five were determined to be feasible for PV panels. Reasoning for the elimination of the other locations is provided in the "Notes" column of **Table 4-16** and typically was due to insufficient available area. Of the five locations, PV panels can be used to supplement the available energy at the top three locations, but electrical generation will not be sufficient to meet the full energy consumption at those locations. The other two feasible locations have ample room for the installation of both rooftop and ground PV panels. These two locations each have energy consumption percentages much larger than 100%, meaning that more energy can be generated than is needed to meet the average annual energy consumption of that location.

A former high energy using location was a construction trailer located at 162 N 44th St in Milwaukee. This trailer no longer exists and there is no facility present and was not included in the evaluation. The land is still owned by MMSD and could be used for PV panels.

Table 4-16: Conveyance System Renewable Energy Potential Summary

Facility	Address	Average Annual Energy Consumption 2018-2020 (MMBTU/year)	Energy Source	Feasible for PV Panels (Y/N)?	PV Panels Capacity (kW)	PV Panels Generation (kWh/year)	PV Panels Generation (MMBTU/year)	% Energy Consumption Covered by Solar Panels	Notes
Port Washington Road PS	5022 N Port Washington Rd - Glendale	2,269	Electric	Yes	15	18,000	61	2.7%	Potential for rooftop PV panels.
32nd and Hampton - Large Bypass PS: BS0502	4830 N 32nd St - Milwaukee	1,908	Both	Yes	143	193,700	661	34.6%	Potential for rooftop PV panels.
Underwood Creek PS	12308 W Underwood Pkwy - Wauwatosa	1,663	Electric	No	--	--	--	--	Insufficient rooftop space for PV panels. Land not owned by MMSD.
CT1 Drop Shaft	8950 W Watertown Plank Rd - Milwaukee	690	Electric	No	--	--	--	--	Facility located in ROW
Greentree Road PS	1300 W Green Tree Rd - River Hills	639	Both	Yes	36	39,700	135	21.2%	Potential for rooftop and ground PV panels.
59th and State - Large Bypass PS: BS0405	5901 W State St - Milwaukee	459	Electric	Yes	2,750	3,663,900	12,501	2,723.6%	Potential for rooftop and ground PV panels.
Greenfield Park PS	1500 S 124th St - West Allis	391	Electric	No	--	--	--	--	Insufficient rooftop space for PV panels. Land not owned by MMSD.
Beach Road PS	7509 N Beach Dr – Fox Point	301	Both	No	--	--	--	--	Insufficient rooftop space for PV panels. Ground PV panels would require significant tree removal.
CT7 Drop Shaft	1610 W Canal St - Milwaukee	143	Electric	No	--	--	--	--	Facility located in ROW
CT34 Drop Shaft	4298 W Monarch Pl - Milwaukee	131	Electric	Yes	1,680	2,236,200	7,630	5,824.4%	Potential for rooftop and ground PV panels.
	TOTAL:	8,594	--	--	4,624	6,151,500	20,988.9	244.2%	

Powering the Conveyance System facilities with 100% renewable energy while not wheeling energy or net metering is feasible, but capital and operational costs will increase. There are two sub-alternatives considered for achieving this: purchasing renewable electricity and gas from We Energies, or building a sufficient renewable energy distribution system for the Conveyance System facilities.

Conveyance System Renewable Electricity

Conveyance System Recommended Energy Generation

The recommended energy generation procedure at the Conveyance System is a combination of the PV installation and purchasing renewable energy from We Energies. Of the five feasible Conveyance System locations presented in **Table 4-16,** three locations are located directly on top of buildings and can supply electricity directly to those buildings. The other two locations are open areas in which PV panels can be installed and then electricity can be distributed elsewhere. At these locations, it is an easier and more cost-effective choice to buy renewable energy and NG from We Energies. **Table 4-17** shows the cost of PV panels at Port Washington Road PS, 32nd and Hampton - Large Bypass PS, and Greentree Road PS.

Table 4-17: Conveyance System Recommended PV Cost

Description	Cost
PV Panel Capital Cost	$408,000
Structural Improvements (100% of PV Panel Cost)	$408,000
Electrical Improvements (20% of PV Panel Cost)	$82,000
Subtotal	$898,000
Overhead and Profit (20% of Capital Cost)	$180,000
Contingency (40% of Capital Cost)	$360,000
Design and Engineering Services (15% of Capital Cost)	$135,000
Total Capital Cost	**$1,573,000**
-50%	$787,000
+100%	$3,146,000
PV Panel Annual O&M Cost ($20/kW)	**$4,000**
Renewable Electricity Purchased from We Energies, Annual Cost	$328,000
Renewable NG Purchased from We Energies, Annual Cost	$22,000
Purchased We Energies Annual O&M Cost (2% of We Energies Costs)	$7,000
Total Annual O&M Cost	**$361,000**

Purchase Renewable Electricity and Gas from We Energies

The first option for consideration is to purchase renewable electricity and renewable NG from We Energies. The quantity and annual cost of electricity and NG needed for all conveyance accounts is shown in **Table 4-18**, determined from MMSD Energy Data from 2018-2021. Electricity and gas values were summed across that period and then converted to an annual value. Rates are estimated based on existing rates for electricity and NG. A 20% increase to that existing rate was used to estimate a renewable electricity and NG rate.

Table 4-18: Conveyance Renewable Electricity and Natural Gas Needed

Description	Quantity	Rate	Unit	Cost ($/year)
WE Electrical Conveyance Accounts (kWh/year)	2,433,470	$0.15	$/kWh	$366,000
WE Gas Conveyance Accounts (dth/year)	2,100	$10	$/dth	$22,000
			Subtotal	**$388,000**
Increase on Rate to Purchase Renewable Energy (20%)				$78,000
			Total	**$466,000**
			-50%	$233,000
			+100%	$932,000

Build Renewable Energy Facilities and Distribution System to Conveyance System Sites

If net metering and power wheeling with We Energies cannot be done, then a distribution system to convey electricity to all Conveyance System sites would be required.

Conveyance System PV Panels

If net metering and power wheeling are not allowed, PV panel generation would be recommended at every available and feasible conveyance facility. These facilities, and the costs associated with installing PV panels there, are presented in **Table 4-19**.

Table 4-19: Large PV System Capital Cost

Description	Quantity (kWh/year)	Quantity (W)	Rate	Unit	Cost
Port Washington Road PS	18,000	21,000	$2.10	$/W	$45,000
32nd and Hampton - Large Bypass PS	193,700	222,000	$2.10	$/W	$467,000
Greentree Road PS	39,700	46,000	$2.10	$/W	$97,000
59th and State - Large Bypass PS	3,663,900	4,183,000	$2.10	$/W	$8,785,000
CT34 Drop Shaft	2,236,200	2,553,000	$2.10	$/W	$5,362,000
				Subtotal	**$14,756,000**
Overhead and Profit (20% of Subtotal)					$2,952,000
Contingency (40% of Subtotal)					$5,903,000
Design and Engineering Services (15% of Subtotal)					$2,214,000
				Total Capital Cost	**$25,825,000**
				-50%	$12,913,000
				+100%	$51,650,000
				Total Annual O&M Cost	**$141,000**

Conveyance System Electrification

If net metering and power wheeling are not allowed, it would be recommended to electrify the Conveyance System so that only renewable electricity would need to be distributed. All conveyance NG systems will need to be converted to electricity systems. The estimated cost for this is $500,000 for the largest site, $300,000 for any other sites larger than 1,000 therms, and $25,000 for any other sites smaller than 1,000 therms. **Table 4-20** below shows this cost for all NG conveyance systems.

Table 4-20: Conveyance System Electrification Costs

Description	Variable #	Total Usage (therms)	Electrification Cost
2702 S 6th St, Milwaukee	90512	39	$25,000
510 W Green Tree Rd, Glendale	90513	135	$25,000
9409 N Lake Dr, Bayside	90514	203	$25,000
2211 S Bay St, Milwaukee	90515	45	$25,000
8000 W Wisconsin Ave, Wauwatosa	90516	554	$25,000
7509 N Beach Dr, Fox Point	90517	2,255	$300,000
3070 S 6th St, Milwaukee	90518	105	$25,000
162 N 44th St, Milwaukee	90519	8,464	$300,000
5101 W Hampton Ave, Milwaukee	90520	384	$25,000
7007 N River Rd, River Hills	90521	8,614	$300,000
4830 N 32nd St Unit A, Milwaukee	90522	3,413	$300,000
4830 N 32nd St, Milwaukee	90523	48,470	$500,000
5800 S Howell Ave, Milwaukee	90524	425	$25,000
3620 S Clement Ave Side, Milwaukee	90525	51	$25,000
1701 N Lincoln Memorial Dr, Milwaukee	90526	2	$25,000
	Subtotal	73,159	$1,950,000
Overhead and Profit (20% of Subtotal)			$390,000
Contingency (40% of Subtotal)			$780,000
Design and Engineering Services (15% of Subtotal)			$293,000
	Total Capital Cost		$3,413,000
AACE: -50%			$1,707,000
AACE: +100%			$6,826,000

Conveyance System Power Transmission

An effective distribution system needs to be built in order to transmit generated power to conveyance and administration facilities. This analysis assumes 69 KV overhead Aluminum is used to transmit power. An estimated distribution cost of $550,000 per mile was used, and a distribution system length of 100 miles was assumed. Thus, a $55 million cost is needed to create this power transmission system. This calculation is shown in **Table 4-21** below.

Table 4-21: Power Transmission Calculations

Description	Cost / Quantity
Electrical Distribution Length (miles)	100
Distribution Cost per Mile	$550,000
Electrical Distribution Cost (Subtotal)	**$55,000,000**
Overhead and Profit (20% of Subtotal)	$11,000,000
Contingency (40% of Subtotal)	$22,000,000
Design and Engineering Services (15% of Subtotal)	$8,250,000
Total Capital Cost	**$96,250,000**
AACE: -50%	$48,125,000
AACE: +100%	$192,500,000
Total Annual O&M Cost (2% of Capital Cost)	**$1,925,000**

Conveyance System Battery Storage

If net metering and power wheeling with We Energies cannot be done, then battery storage would be required to handle peak loads throughout the Conveyance System.

Table 4-22 and **Table 4-23** summarize the Conveyance System's battery storage. Utility scale storage is estimated to cost $446/kWh[7]. This is total project costs including material, labor, electrical interconnection, etc.

Table 4-22: Conveyance System Battery Storage Summary

Electricity Consumption		Average Demand	Estimated Wet Weather Demand[1]	1 Day of Electricity Storage	Number of Battery Containers[2]	Area Required for Batteries[3]
MMBTU/year	kWh/year	kW	kW	kWh	QTY	SF
9,160	2,684,521	310	1,550	37,200	9	3,000

1. Assumes Peaking Factor of 5
2. 4 MWh per Battery Storage Container
3. Each Container is 40 ft long with a footprint of 30 m^2 or 323 ft^2

[7] https://www.nrel.gov/docs/fy22osti/83586.pdf

Table 4-23: Conveyance System Battery Storage Cost Estimate

Description	Cost
Battery Storage Capital Cost[1]	$16,592,000
Subtotal	$16,592,000
Overhead and Profit (20% of Subtotal)	$3,319,000
Contingency (40% of Subtotal)	$6,637,000
Design and Engineering Services (15% of Subtotal)	$2,489,000
Total Capital Cost	**$29,037,000**
AACE: -50%	$14,519,000
AACE: +100%	$58,074,000
Total Annual O&M Cost (2% of Capital Cost)	**$581,000**

1. Assumes Peaking Factor of 5

Conveyance System Recommendation

The recommendation is to install PV at the three locations identified and fill in the remaining energy required with purchased renewable electricity and gas from We Energies.

Refer to **Table 4-17** for PV costs. The cost of renewable energy from We Energies is:

- $327,500 per year for renewable electricity
- $21,000 per year for renewable NG

4.2.5 Administration Facilities

This section summarizes the renewable electricity potential at the MMSD Administration Facilities, including the headquarters and lab. There is space to build PV panels over portions of the parking lot that will cover approximately 30% of the total Administration Facility. The central lab roof was not considered for PV panels because there is currently a HVAC project replacing equipment on the roof and there is a large number of vents throughout the entire roof.

To get the Administration Facility to be 100% renewable without net metering or power wheeling, MMSD could purchase renewable energy from We Energies or distribute electricity from off-site renewable energy generation facility. This could be from JIWRF, SSWRF, a Conveyance System site, or another property owned by MMSD.

Similar to the analysis done for the Conveyance System in **Section 4.2.4**, it is recommended to purchase renewable energy from We Energies.

Administration Facilities Recommended Energy Generation

This section summarizes the locations, generation potential, and cost of the recommended installation at the Administration Facilities. **Table 4-24** shows the recommended PV locations and generation potential.

Table 4-24: Administration Facilities PV Recommended Locations

Location	Area (m^2)	Area (SF)	kWh/year	kW	MMBTU/year
Covered Parking	3,378	36,400	673,235	505	2,300
Total	3,378	36,400	673,235	505	2,300

Figure 4-6 shows the recommended location and sizes for the PV installation in the Administration Building parking lot.

Figure 4-6: Administration Facilities Recommended PV Locations

The capital cost also includes a cost escalation factor of 2 to account for the support structures over the car ports.

Table 4-25: Administration Building PV Cost Summary

Description	Cost
PV Panel Capital Cost	$1,061,000
Structural Improvements (100% of PV Panel Cost)	$1,061,000
Electrical Improvements (20% of PV Panel Cost)	$213,000
Subtotal	$2,335,000
Overhead and Profit (20% of Subtotal)	$467,000
Contingency (40% of Subtotal)	$934,000
Design and Engineering Services (15% of Subtotal)	$351,000
Total Capital Cost	**$4,087,000**
AACE: -50%	$2,044,000
AACE: +100%	$8,174,000
PV Panel Annual O&M Cost	$11,000
Renewable Electricity Purchased from We Energies, Annual Cost	$135,000
Renewable NG Purchased from We Energies, Annual Cost	$237,000
Purchased We Energies Annual O&M Cost (2% of We Energies Costs)	$8,000
Total O&M Cost	**$391,000**

Administration Facilities Recommendation

The recommendation is to install PV at the available locations presented in **Figure 4-6** and fill in the remaining energy required with purchased renewable electricity and gas from We Energies.

Refer to **Table 4-25** for PV costs. The cost of renewable energy from We Energies is:

- $134,500 per year for renewable electricity
- $236,000 per year for renewable NG

4.2.6 Greenhouse Gas Emissions

Table 4-26 summarizes the new GHG emissions associated with the energy profile analyzed in **Section 4.2**.

Table 4-26: Alt 1 - GHG Emissions Calculation with Planned and Recommended Improvements

	Conveyance		Administration		JIWRF		SSWRF		Total	
	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile
Purchased Non-Renewable Natural Gas Emissions (metric tons CO2e)	112	0	1,392	0	86,311	0	6,098	0	93,912	0
Purchased Renewable Natural Gas Emissions (metric tons CO2e)	0	1	0	6	0	0	0	0	0	7
Landfill Gas Emissions (metric tons CO2e)	0	0	0	0	84	301	0	0	84	301
Digester Gas Emissions (metric tons CO2e)	0	0	0	0	0	90	98	54	98	144
Purchased Electricity Emissions (metric tons CO2e)	1,564	0	1,414	0	11,479	0	11,496	0	25,953	0
Purchased Renewable Electricity Emissions (metric tons CO2e)	0	0	0	0	0	0	0	0	0	0
Purchased Oil Emissions (metric tons CO2e)	0	0	0	0	4	0	0	0	4	0
Total Emissions (metric tons CO2e)	1,675	1	2,806	6	97,878	391	17,691	54	**120,051**	**452**
GHG Difference								metric tons CO2e		**-119,599**
								%		**-99.6%**

4.2.7 Alternative 1 Summary

Table 4-27 presents all proposed projects for Alternative 1 and their associated costs.

Table 4-27: Alternative 1 OPCC Summary Table

Project Number	Project	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost
1	Energy Reduction Recommended Improvements Total	$109,645,000	$0	$0	$109,645,000
2	JIWRF New Turbine Generators	$71,233,000	$1,939,000	$27,872,000	$99,105,000
3	JIWRF PV Panel Installation	$17,801,000	$45,000	$647,000	$18,448,000
	JIWRF Subtotal	**$89,034,000**	**$1,984,000**	**$28,519,000**	**$117,553,000**
4	SSWRF New Engine Generators	$48,938,000	$1,591,000	$22,870,000	$71,808,000
5	SSWRF PV Panel Installation	$147,661,000	$366,000	$5,261,000	$152,922,000
6	SSWRF High Strength Waste	$180,362,000	$3,608,000	$51,863,000	$232,225,000
7	SSWRF Digester Gas Cleaning	$22,745,000	$375,000	$5,390,000	$28,135,000
8	SSWRF Digester Gas Storage	$56,000,000	$1,120,000	$16,099,000	$72,099,000
9	SSWRF to JIWRF Gas Pipeline	$44,967,000	$900,000	$12,937,000	$57,904,000
	SSWRF Subtotal	**$500,673,000**	**$7,960,000**	**$114,420,000**	**$615,093,000**
10	Conveyance System Renewable Energy	$1,573,000	$361,000	$5,189,000	$6,762,000
11	Administration Facilities Renewable Energy	$4,087,000	$391,000	$5,620,000	$9,707,000
	Conveyance and Admin Facilities Subtotal	**$5,660,000**	**$752,000**	**$10,810,000**	**$16,470,000**
	TOTAL	**$705,012,000**	**$10,696,000**	**$153,748,000**	**$858,760,000**
	Alternative 1 Total GHG Emissions	452	Metric Tons CO2e		
	Percent Reduction from 2005 Baseline	99.7%			

Table 4-28: Alternative 1 Energy Summary Table (MMBTU)

	Conveyance		Administration		JIWRF		SSWRF		Total	
	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile
Purchased Non-Renewable Natural Gas (MMBTU)	2,100	0	26,200	0	1,625,000	0	114,800	0	1,768,100	0
Purchased Renewable Natural Gas (MMBTU)	0	2,100	0	23,600	0	0	0	0	0	25,700
Landfill Gas (MMBTU)	0	0	0	0	326,600	1,175,000	0	0	326,600	1,175,000
Digester Gas (MMBTU)	0	0	0	0	0	349,730	381,700	211,610	381,700	561,340
Purchased Electricity (MMBTU)	9,400	0	8,500	0	69,000	0	69,100	0	156,000	0
Purchased Renewable Electricity (MMBTU)	0	8,303	0	5,350	0	0	0	0	0	13,653
Purchased Oil (MMBTU)	0	0	0	0	400	0	0	0	400	0
Total	11,500	10,403	34,700	28,950	2,021,000	1,524,730	565,600	211,610	**2,632,800**	**1,775,693**
Energy Consumption Difference									MMBTU	**-857,107**
									%	**-32.6%**

4.3 Alternative 2 – Prioritize Photovoltaic and Wind Renewable Energy

This alternative prioritizes photovoltaic and wind renewable electricity for generation. Existing thermal demands will be met through renewable gas combustion. This alternative minimizes GHG emissions required with a focus on photovoltaic and wind generation.

4.3.1 Energy Profile

The recommended renewable energy generation and consumption energy profile for Alternative 2 is shown for JIWRF and SSWRF in **Figure 4-7**, **Figure 4-8**, **Figure 4-9**, and **Figure 4-10** below. The recommendation shows no anticipated energy consumption at the WRFs from We Energies, however we are not recommending islanding the facilities. Coordination with We Energies to be a backup power source is required.

The Conveyance System and Administration facilities electricity consumption will be met by the recommended PV locations and renewable purchased renewable energy from We Energies, as summarized in **Sections 4.2.4** and **4.2.5**. These facilities' NG consumption and associated emissions is included in the GHG emissions calculation in **Section 4.2.6**.

- Alternative 2 prioritizes photovoltaic and wind electricity generation.
  - JIWRF
    - Install 1,165,200 SF 16,200 kW of PV panels
    - Install 412,800 kWh (3,120 m2 or 33,600 SF) of battery storage for JIWRF at SSWRF
    - Convert three more dryers to LFG fueled
  - SSWRF
    - Install 1,800,800 SF or 25,000 kW of PV panels
    - Install three wind turbines
    - Build five additional wind turbines or an additional 2,351,000 SF or 32,700 kW of PV off-site at other MMSD owned properties if power wheeling is possible
    - Install a 1,500 SFM gas cleaning system
    - Install 846,000 CF of gas storage serving SSWRF
    - Build an electrical ductbank connecting JIWRF and SSWRF electrically
    - Install 148,800 kWh (1,140 m2 or 12,270 SF) of battery storage for SSWRF
    - Build a digester gas pipeline connecting JIWRF and SSWRF

- Conveyance System
    - Install 4,600 kW of PV panels
    - Purchasing the remaining renewable electricity and natural gas from We Energies
- Administration Facilities
    - Install 36,400 SF or 500 kW of PV panels
    - Purchase the remaining renewable electricity and renewable natural gas from We Energies

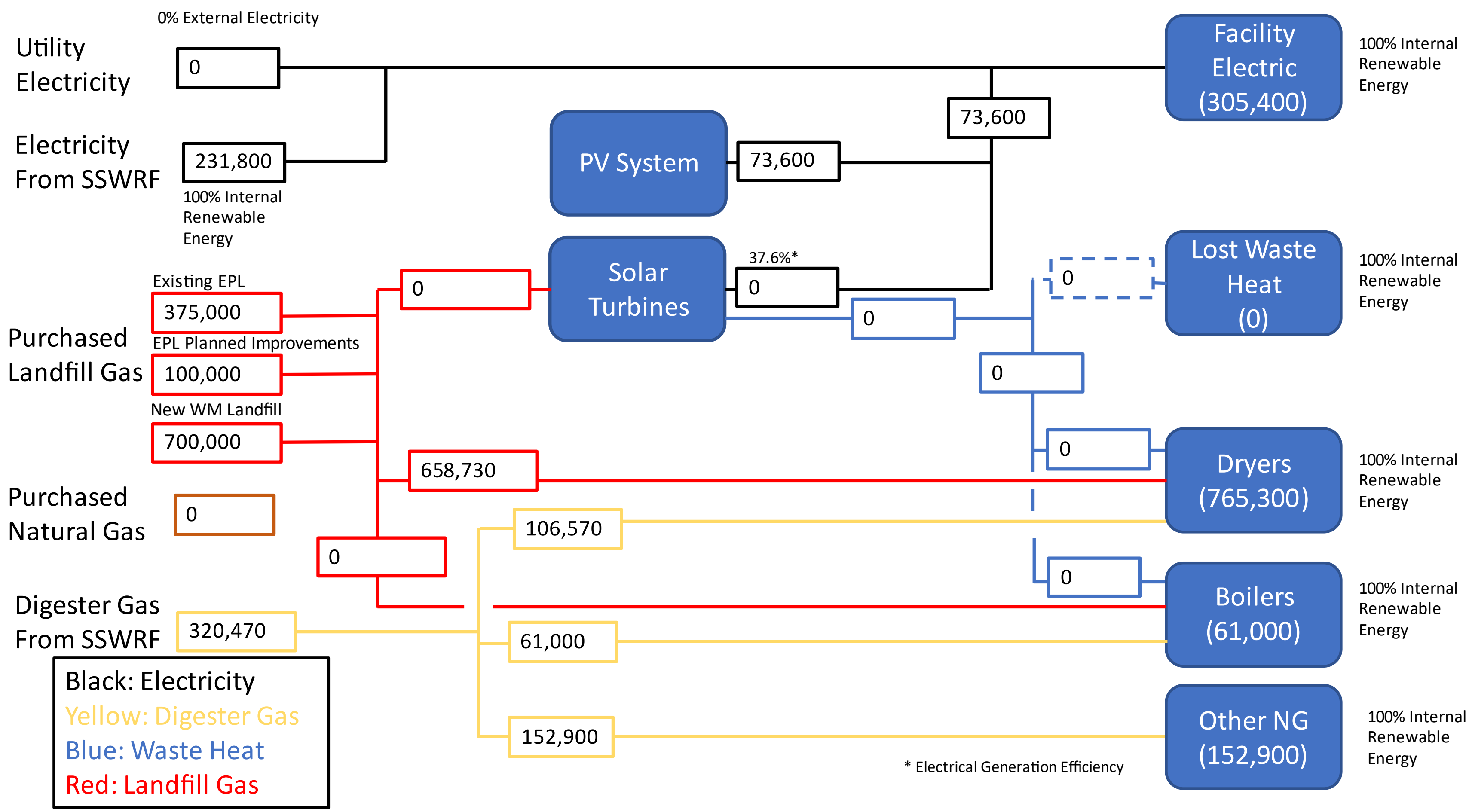

Figure 4-7: Alt 2 - JIWRF Energy Profile (MMBTU/Year)

Figure 4-8: Alt 2 - JIWRF Energy Profile Site Plan (MMBTU/Year)

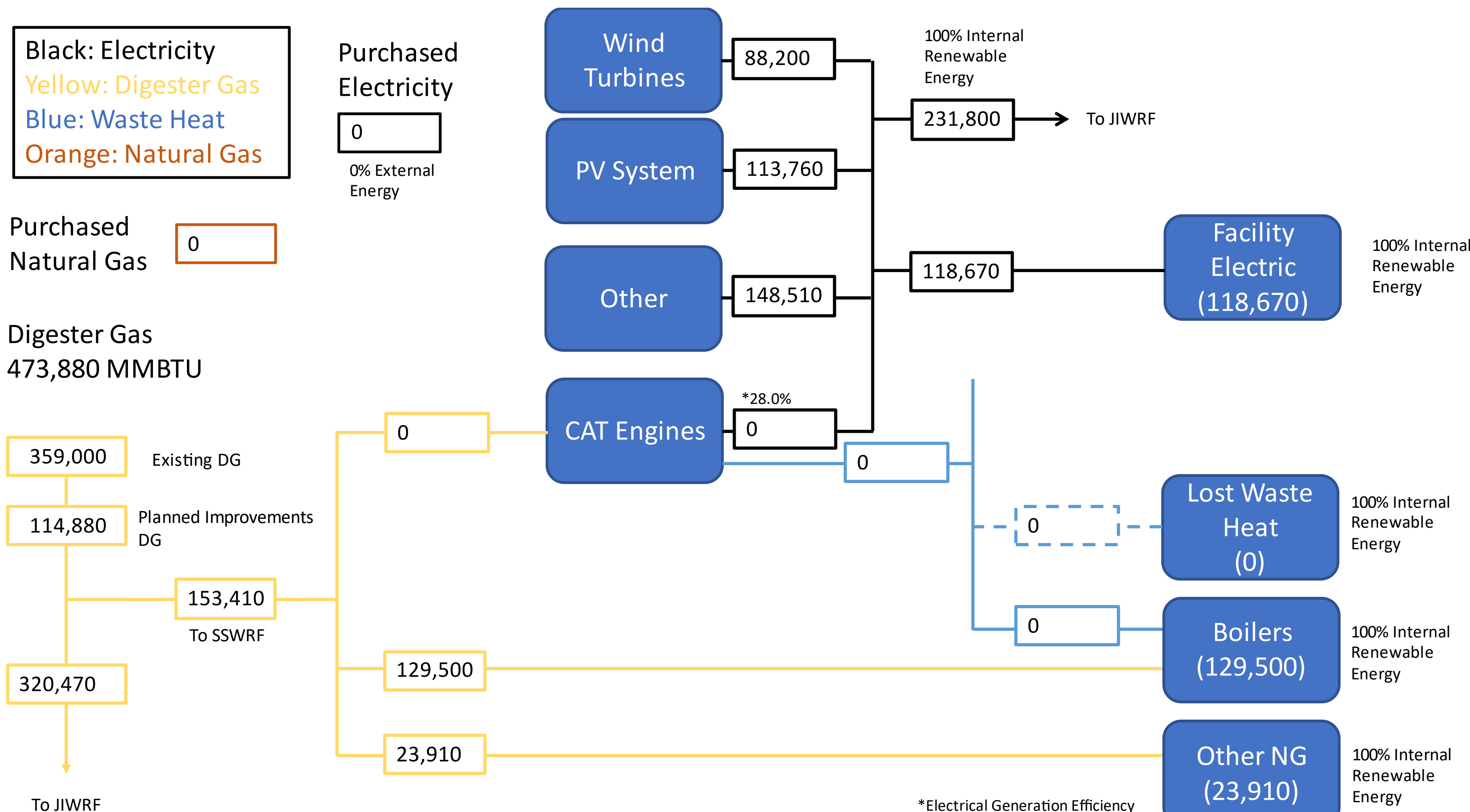

Figure 4-9: Alt 2 - SSWRF Energy Profile (MMBTU/Year)

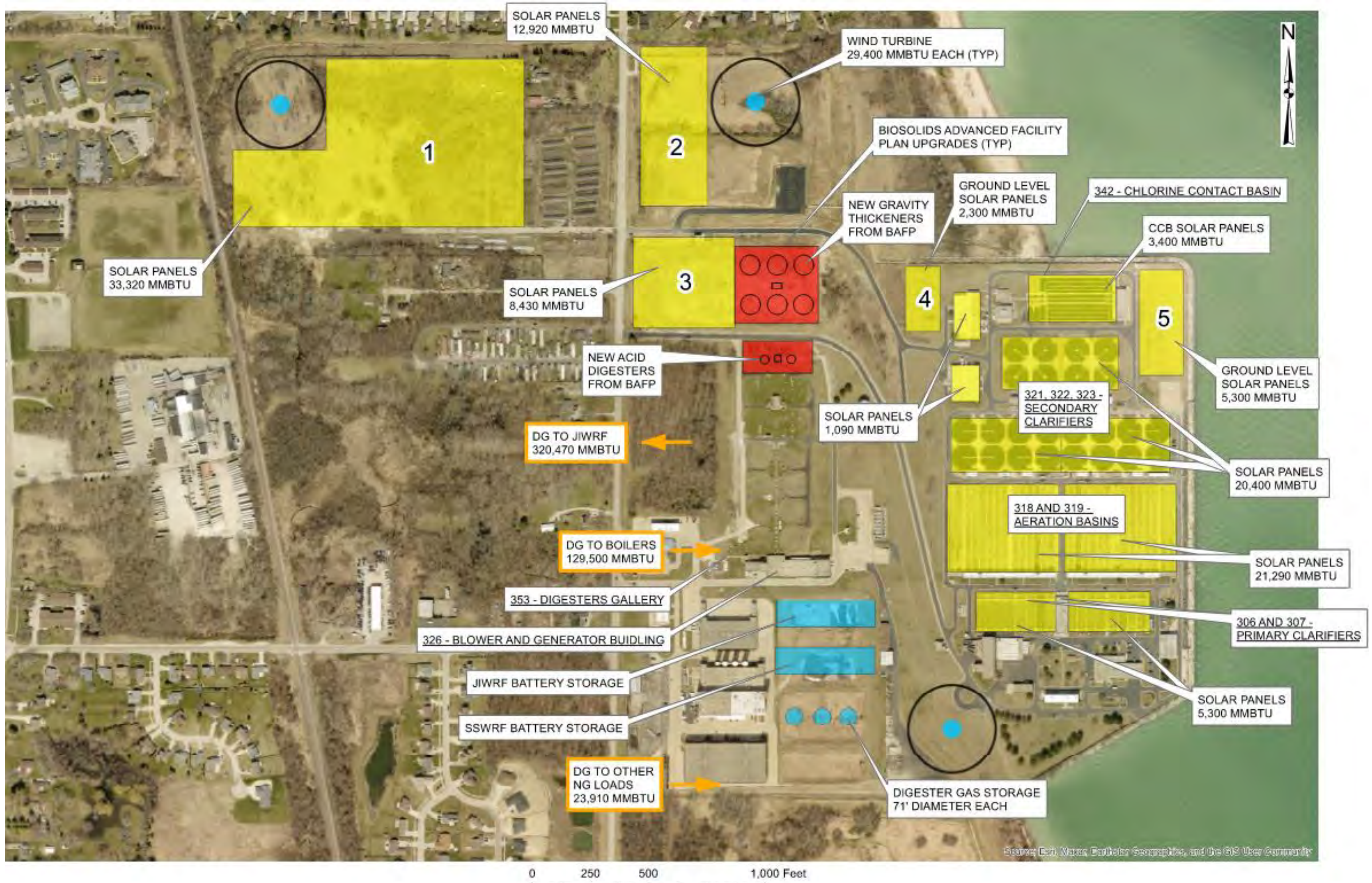

Figure 4-10: Alt 2 - SSWRF Energy Profile Site Plan (MMBTU/Year)

4.3.2 JIWRF

Renewable Electricity Generation

JIWRF Turbine Generators

The turbine generators are not used in this alternative as renewable electricity from PV and wind is prioritized. The dryer, boiler, and other NG loads are fueled from direct LFG and DG combustion.

JIWRF Photovoltaic Power Generation

TM-3 evaluated all potential areas at JIWRF for PV electricity generation. This section summarizes the locations, generation potential, and cost of the recommended installations at JIWRF for Alternative 2. **Table 4-29** shows the recommended PV locations and generation potential.

Table 4-29: Alt 2 – JIWRF PV Recommended Locations

Location	Area (m^2)	Area (SF)	kWh/year	kW	MMBTU/year
280 - Maintenance Building	2,650	28,500	528,000	396	1,800
258 - D&D Facility	2,160	23,300	430,000	323	1,470
Parking NE of 280	2,100	22,600	419,000	315	1,430
206 - Primary Clarifiers	18,000	193,800	3,587,000	2,690	12,240
222 - East Secondary Clarifiers	13,100	141,000	2,611,000	1,958	8,910
223 - West Secondary Clarifiers	18,000	193,800	3,587,000	2,690	12,240
218 & 219 - Aeration Basins	44,425	478,200	8,854,000	6,640	30,210
242 - Chlorine Contact Basins	6,800	73,200	1,355,000	1,017	4,620
261 - New Milorganite Packaging Facility	1,000	10,800	199,000	150	680
Total	108,235	1,165,200	21,570,000	16,179	73,600

The capital cost also includes a cost escalation factor of 2 to account for the potential structural improvements to roofs and additional support structures over tanks and parking spaces. **Table 4-30** summarizes the costs associated with installing PV at the locations identified for JIWRF.

Table 4-30: Alt 2 – JIWRF PV Cost Summary

Description	Cost
Capital Cost for PV Panels	$33,976,000
Structural Improvements (100% of PV Panel Cost)	$33,976,000
Electrical Improvements (20% of PV Panel Cost)	$6,796,000
Subtotal	$74,748,000
Overhead and Profit (20% of Subtotal)	$14,950,000
Contingency (40% of Subtotal)	$29,900,000
Design and Engineering Services (15% of Subtotal)	$11,213,000
Total Capital Cost	**$130,811,000**
-50%	$65,406,000
+100%	$261,622,000
Total Annual O&M Cost ($20/kW)	**$324,000**

Gas Storage Analysis

This alternative results in more renewable gas being available than what is needed for consumption. DG is prioritized as MMSD will be generating it anyways. LFG is purchased, so this analysis assumes MMSD can purchase only what they need for use. Gas would be stored at SSWRF.

The same assumptions from the previous gas storage analysis apply, in addition to the assumption below.

- The projected LFG and DG supply and projected thermal demands were determined using the Energy Profile summarized in **Section 4.3.1**.

Table 4-31 shows the projected low and high supply and demand for gas, as well as the associated maximum surplus and deficits.

Table 4-31: Alt 2 – DG Storage Analysis – JIWRF Demands

Supply		Demand		Surplus		Deficit	
Low	High	Low	High	Max		Max	
MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	SCFM	MMBTU/Day	SCFM
2,000	4,500	2,000	3,400	2,500	1,740	-1,400	-970

This results in maximum deficit volume of 1,400 MMBTU/day or 970 SCFM of DG.

For this evaluation, dual membrane gasholding tanks on concrete pads were used. A 70' diameter, 3/4 sphere dual membrane gasholder can hold 282,000 CF of gas. **Figure 4-10** shows the area required for 3 gasholders. 3 gasholders equate to approximately 846,000 or 0.6 days of storage capacity at the maximum deficit for this Alternative. Each gasholder costs approximately $800,000 each. **Table 4-32** summarizes the estimated cost for 3 gasholders.

Table 4-32: Alt 2 – JIWRF Gas Storage Cost Summary

Description	Cost
Gasholder Capital Cost	$2,400,000
Civil / Site Improvements (50% of Gasholder Cost)	$1,200,000
Installation and Labor (50% of Gasholder Cost)	$1,200,000
Subtotal	$4,800,000
Overhead and Profit (20% of Subtotal)	$960,000
Contingency (40% of Subtotal)	$1,920,000
Design and Engineering Services (15% of Subtotal)	$720,000
Total Capital Cost	**$8,400,000**
-50%	$4,200,000
+100%	$16,800,000
Total Annual O&M Cost	**$168,000**

The dryers are rated for a maximum 25 MMBTU/hr but operate at 12.5 MMBTU/hr each, or 207.5 SCFM. An operating scenario where 8 dryers are in operation would consume 1,660 CFM of gas. Assuming the low supply rate shows there is a net positive of gas available, showing that JIWRF can purchase only the volume of LFG it needs, after prioritizing and consuming available DG.

It is recommended to maintain an N+1 capacity in the dryers to burn the gas available. Alternative 2 dryer LFG demand is 660,000 MMBTU/yr or ~44.5 MMBTU/hr. This necessitates 6 dryers as N and the 7^{th} dryer would be +1. There are 4 existing LFG dryers, therefore converting at least 3 more dryer to LFG is recommended.

4.3.2.1 JIWRF Battery Storage

This section calculates the battery capacity needed to store electricity for JIWRF during the average wet weather demand of 17.2 MW for a duration of 1 day. This results in 412,800 kWh of battery storage required. Utility scale battery storage has a container size of 4 MWh per 40-foot container with an area of

323 square feet. This results in 104 storage containers or a minimum of 33,600 ft^2 area required to meet the wet weather demand for 1 day. **Figure 4-10** shows the area required for JIWRF's battery storage.

Utility scale storage is estimated to cost $446/kWh[8]. This is total project costs including material, labor, electrical interconnection, etc. **Table 4-33** summarizes the costs associated with installing battery storage for JIWRF.

Table 4-33: Alt 2 –JIWRF Battery Storage Cost Summary

Description	Cost
Capital Cost for Battery Storage	$184,109,000
Subtotal	$184,109,000
Overhead and Profit (20% of Subtotal)	$36,822,000
Contingency (40% of Subtotal)	$73,644,000
Design and Engineering Services (15% of Subtotal)	$27,617,000
Total Capital Cost	**$322,192,000**
-50%	$161,096,000
+100%	$644,384,000
Total Annual O&M Cost (2% of Capital Cost)	**$6,444,000**

4.3.3 SSWRF

Renewable Electricity Generation

TM-4 and this section details the renewable electricity generation potential at SSWRF. **Figure 4-9** shows an additional 231,800 MMBTU/year of electricity is needed to be generated at SSWRF for JIWRF consumption, as well as 118,670 MMBTU/year is needed for SSWRF consumption. There is not enough land area available for PV and wind electricity generation to cover the electrical demands (350,470 MMBTU/year at both facilities) at SSWRF alone, so using other MMSD-owned land areas for PV and wind electricity generation will be required. Wind has a better payback than PV systems and maximizing wind generation is recommended. The Energy Profile in **Section 4.3.1** shows 88,200 MMBTU/year from wind and 113,760 for PV at SSWRF. The additional 148,510 MMBTU/year is recommended to be generated by wind turbines off-site, however MMSD can substitute this with equivalent PV generation off-site if wind is not feasible due to local regulatory hurdles. The PV area required to generate the total 350,470 MMBTU/year and additional 148,510 MMBTU is shown below.

- 350,470 MMBTU/year requires 5,446,000 SF of PV

[8] https://www.nrel.gov/docs/fy22osti/83586.pdf

- 148,510 MMBTU/year requires 2,308,000 SF of PV

SSWRF Engine Generator Generation

The engine generators are not used in this alternative as renewable electricity from PV and wind is prioritized. The boiler and other NG loads are fueled from direct DG combustion.

SSWRF PV Electricity Generation

TM-4 evaluated all potential areas at SSWRF for PV electricity generation. This section summarizes the locations, generation potential, and cost of the recommended installations at SSWRF for Alternative 2. **Table 4-34** shows the recommended PV locations and generation potential.

Table 4-34: Alt 2 – SSWRF PV Recommended Locations

Location	Area (m^2)	Area (SF)	kWh/year	kW	MMBTU/year
1 - Open Area	49,000	527,400	9,765,700	7,323	33,320
2 - Open Area	19,000	204,500	3,786,700	2,840	12,920
3 - Open Area	12,400	133,500	2,471,320	1,853	8,430
4 - Open Area	3,400	36,600	677,620	508	2,310
5 - Open Area	7,800	84,000	1,554,540	1,166	5,300
358 - Sludge Thickener Building New	700	7,500	139,510	105	480
357 - Sludge Thickener Building	900	9,700	179,370	135	610
342 - Chlorine Contact Basin	5,000	53,800	996,500	747	3,400
306 & 307 - Primary Clarifiers	7,800	84,000	1,554,540	1,166	5,300
321, 322, & 323 - Secondary Clarifiers	30,000	322,900	5,979,000	4,484	20,400
318 & 319 - Aeration Basins	31,300	336,900	6,238,090	4,678	21,290
Total	167,300	1,800,800	33,342,890	25,005	113,760

The capital cost also includes a cost escalation factor of 2 to account for the potential structural improvements to roofs and additional support structures over tanks and parking spaces. **Table 4-35** summarizes the costs associated with installing PV panels at the locations identified for SSWRF.

Table 4-35: Alt 2 – SSWRF PV Cost Summary

Description	Cost
Capital Cost for PV Panels	$52,509,000
Structural Improvements (100% of PV Panel Cost)	$52,509,000
Electrical Improvements (20% of PV Panel Cost)	$10,502,000
Subtotal	$115,520,000
Overhead and Profit (20% of Subtotal)	$23,104,000
Contingency (40% of Subtotal)	$46,208,000
Design and Engineering Services (15% of Subtotal)	$17,328,000
Total Capital Cost	**$202,160,000**
-50%	$101,080,000
+100%	$404,320,000
Total Annual O&M Cost ($20/kW)	**$501,000**

SSWRF Wind Electricity Generation

Figure 4-10 shows the wind energy generation potential at SSWRF. There is space for 3 wind turbines to be installed, each capable of generating 29,412 MMBTU/year of electricity. This results in a total generation capacity of 88,200 MMBTU/year. **Table 4-36** summarizes the costs associated with installing wind turbines at the locations identified for SSWRF.

Table 4-36: Alt 2 – SSWRF Wind Cost Summary

Description	Cost
Wind Turbine Capital Cost	$10,584,000
Structural Improvements (100% of Wind Turbine Cost)	$10,584,000
Electrical Improvements (20% of Wind Turbine Cost)	$2,117,000
Subtotal	$23,285,000
Overhead and Profit (20% of Subtotal)	$4,657,000
Contingency (40% of Subtotal)	$9,314,000
Design and Engineering Services (15% of Subtotal)	$3,493,000
Total Capital Cost	**$40,749,000**
-50%	$20,375,000
+100%	$81,498,000
Total Annual O&M Cost (2% of Capital Cost)	**$815,000**

Additional Renewable Electricity

SSWRF can generate 201,960 MMBTU/year of the required 350,470 MMBTU/year for SSWRF and JIWRF electricity demands. Therefore, an additional 148,510 MMBTU/year is required to be generated and conveyed to SSWRF and JIWRF.

This 148,510 MMBTU/year can be generated by five 2.4 MW wind turbines as analyzed in TM-4. These turbines are an estimated 380 feet in diameter. Looking at all properties that are feasible for renewable energy, wind turbines can be placed on potentially up to three of the Fee Simple properties and all of the feasible Greenseams properties. Possible configurations are shown in **Appendix I**. The remaining properties are either not large enough or are shaped in a way that is not conducive to installing a wind turbine. At each of the three properties available, consideration was given for the inclusion of multiple turbines. However, an estimated 1,500 feet is needed in between turbines, and there is not enough space present at any of the properties to achieve this. So, some of the remaining electricity can be generated by wind turbines at Fee Simple properties, but additional considerations will be needed to generate all of the remaining electricity.

Alternatively, the 148,510 MMBTU/year can be generated by 218,390 m^2 or 2,351,000 SF of PV panels. Several Greenseams, Fee Simple, and Conveyance properties have potential for PV panels. Based on the area of available space at each of these properties, the required square footage can be achieved. Possible configurations are shown in **Appendix I**. Additionally, it may be possible to include both PV panels and wind turbines at the same location. This is something to consider at the 4926 W Green Tree Rd and 4343 S 6th St locations, and potentially some of the Greenseams locations. There is a chance that more electricity can be generated from this hybrid approach than considering only PV panels or only wind turbines at these locations. Possible configurations for this approach are shown in **Appendix I**.

A complete table of all feasible properties and their available area for renewable energy is presented in **Table 4-43** in **Section 4.3.6**. If net metering or power wheeling are not feasible, then electrical distribution and battery storage would be required. The cost for these would be similar to the costs presented in **Section 4.2.4**.

Gas Cleaning Analysis

It is recommended to clean all generated DG to allow for consumption flexibility and equipment longevity. The cleaned DG can be connected to the facilities' NG lines to allow for renewable gas consumption by the other NG consumers. SSWRF's total DG production for Alternative 2 is 473,880 MMBTU/year as shown in **Section 4.3.1**. This equates to 1,500 SCFM of DG @60% Methane.

An additional 1,281,150 kWh/year or 4370 MMBTU/year is required to generate the additional electricity required to power the gas cleaning system. This equates to the following:

- 69,200 SF or 6,430 m^2 of PV panels

Table 4-14 summarizes the electricity requirements and costs of a 1,500 SCFM gas cleaning system at SSWRF.

Table 4-37: Alt 2 – SSWRF DG Cleaning Summary

SCFM	Cost		Electricity			Footprint
	Capital	Yearly O&M	Demand	Consumption		SF
			kW	kWh/year	MMBTU/year	
1,500	$18,953,000	$312,000	146	1,281,150	4,370	4,000

Table 4-38 breaks down the DG cleaning system cost.

Table 4-38: Alt 2 – DG Cleaning Cost Summary

Description	Cost
Equipment Capital Cost	$5,700,000
Structural Improvements (20% of Equipment Cost)	$1,140,000
Electrical Improvements (20% of Equipment Cost)	$1,140,000
Labor (50% of Equipment Cost)	$2,850,000
Subtotal	$10,830,000
Overhead and Profit (20% of Subtotal)	$2,166,000
Contingency (40% of Subtotal)	$4,332,000
Design and Engineering Services (15% of Subtotal)	$1,625,000
Total Capital Cost	**$18,953,000**
-50%	$9,477,000
+100%	$37,906,000
Total Annual O&M Cost (2% of Capital Cost)	**$312,000**

Gas Storage Analysis

The same gas supply and demand analysis that was performed for JIWRF for this alternative is also performed and summarized for SSWRF below. In this case, the gas supply and thermal demands were analyzed and projected for DG production and SSWRF's thermal demands using existing data. The high and low supply and demands were calculated similar to the analysis above. **Table 4-39** summarizes the gas surplus and deficits based on SSWRF's high and low supply and demands.

Table 4-39: Alt 2 – DG Storage Analysis – SSWRF Demands

Supply		Demand		Surplus		Deficit	
Low	High	Low	High	Max		Max	
MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	SCFM	MMBTU/Day	SCFM
800	1,900	900	1,700	1,000	695	-900	-625

This results in maximum deficit volume of 900 MMBTU/day or 625 SCFM.

The max surplus volume is 1,000 MMBTU/day or 695 SCFM. The resulting time to fill 3 gasholders is approximately 0.85 days.

The largest boilers are rated for a maximum of 16.7 MMBTU/hr or 280 SCFM each. JIWRF is estimated to consume 320,470 MMBTU/year or an average of 610 SCFM of gas.

An operating scenario when one boiler is operating at SSWRF with 610 SCFM going to JIWRF results in a total demand of 890 SCFM. Assuming the low supply rate, the resulting DG drain would be 90 SCFM (890-800). This operating scenario would take approximately 6.5 days for the storage capacity to be drained.

4.3.3.1 SSWRF to JIWRF Electrical Connection

Alternative 2 requires an electrical connection (ductbank) to share power between JIWRF and SSWRF, as SSWRF has more renewable electricity generation capacity due to the land area available. This power cord would follow the same path as the existing 12-mile Interplant Sludge Pipeline connection between JIWRF and SSWRF. **Table 4-40** below shows the estimated costs for 24.9 KV and 69 KV connections for aluminum and copper cables. This analysis assumes there is sufficient space for a new electrical ductbank in the existing easement. This assumption would have to be verified during detailed design if pursued.

Table 4-40: Power Cord Connection Cost Alternatives

Connection Option	December 2022 Estimated Material Cost ($/mi)	December 2022 Estimated Labor Cost ($/mi)	December 2022 Total Cost ($/mi)
24.9KV Underground Aluminum	$658,000	$622,000	$1,280,000
24.9KV Underground Copper	$736,000	$622,000	$1,357,000
69KV Underground Aluminum	$1,562,000	$1,111,000	$2,673,000
69KV Underground Copper	$929,000	$622,000	$1,550,000
24.9KV Overhead Aluminum	$180,000	$185,000	$364,000
69KV Overhead Aluminum	$300,000	$221,000	$520,000

To minimize transmission losses, 69KV underground copper is recommended. **Table 4-41** summarizes the estimated cost.

Table 4-41: JIWRF to SSWRF Power Cord Cost

Description	Cost
Power Cord Material Cost	$11,148,000
Power Cord Labor Cost	$7,464,000
Electrical Improvements at JIWRF and SSWRF (50% of Total Power Cord Cost)	$9,306,000
Subtotal	$27,918,000
Overhead and Profit (20% of Subtotal)	$5,584,000
Contingency (40% of Subtotal)	$11,168,000
Design and Engineering Services (15% of Subtotal)	$4,188,000
Total Capital Cost	**$48,858,000**
-50%	$24,429,000
+100%	$97,716,000
Total Annual O&M Cost (2% of Capital Cost)	**$978,000**

4.3.3.2 SSWRF Battery Storage

Similar to **Section 4.3.2.1**, this section calculates the battery capacity needed to store electricity for SSWRF during the average wet weather demand of 6.2 MW for a duration of 1 day. This results in 148,800 kWh of battery storage required. Utility scale battery storage has a container size of 4 MWh per 40-ft container with an area of 323 square feet. This results in 38 storage containers or a minimum of 1,140 m^2 area required to meet the wet weather demand for 1 day. **Figure 4-10** shows the area required for SSWRF's battery storage.

Utility scale storage is estimated to cost $446/kWh[9]. This is total project costs including material, labor, electrical interconnection, etc. **Table 4-42** summarizes the costs associated with installing battery storage for JIWRF.

Table 4-42: Alt 2 – SSWRF Battery Storage Cost Summary

Description	Cost
Capital Cost for Battery Storage	$66,365,000
Subtotal	$66,365,000
Overhead and Profit (20% of Subtotal)	$13,273,000
Contingency (40% of Subtotal)	$26,546,000
Design and Engineering Services (15% of Subtotal)	$9,955,000
Total Capital Cost	**$116,139,000**
-50%	$58,070,000
+100%	$232,278,000
Total Annual O&M Cost (2% of Capital Cost)	**$2,323,000**

4.3.3.3 SSWRF to JIWRF Gas Pipeline

A connection to convey DG from SSWRF to JIWRF is required for this alternative and would be similar to Alternative 1. Refer to **Section 4.2.3.1** for the gas pipeline connection summary.

9 https://www.nrel.gov/docs/fy22osti/83586.pdf

4.3.4 Conveyance System

Refer to **Section 4.2.4**. The Alternative 2 analysis is the same as Alternative 1 for the Conveyance System.

4.3.5 Administration Facilities

Refer to **Section 4.2.5**. The Alternative 2 analysis is the same as Alternative 1 for the Administration Facilities.

4.3.6 Offsite Renewable Electricity Potential

If net metering and/or wheeling power is feasible, MMSD has properties that can be utilized for renewable electricity generation. These can be used instead of installation over tanks or wind at SSWRF if MMSD prefers other PV locations. **Table 4-43** summarizes the available locations for renewable energy generation at Greenseams® properties, fee simple sites, and conveyance sites. All MMSD owned properties at Greenseams® sites and conveyance sites were evaluated for their renewable energy potential and if they would be feasible for use. These are summarized in **Appendix G** and **Appendix H**.

Table 4-43: Offsite Renewable Electricity Potential

GREENSEAMS								
Property Name	**Municipality**	**County**	**Area (Acres)**	**Non-Hydric Area (Acres)**	**Wind Feasible?**	**PV Feasible?**	**PV Area (ft^2)**	**PV Area (acres)**
Joerres	Kewaskum	Washington	117.4	39.4	Yes	Yes	1,643,000	37.7
Kaiser	Milwaukee	Milwaukee	85.0	27.7	Yes	Yes	373,000	8.6
Ernst	Germantown	Washington	34.5	21.5	Yes	Yes	528,000	12.1
Kohlwey	Mequon	Ozaukee	32.5	20.9	Yes	Yes	779,000	17.9
New Testament Church	Milwaukee	Milwaukee	35.9	11.9	Yes	Yes	302,000	6.9
Grall	Oak Creek	Milwaukee	22.1	9.3	Yes	Yes	373,000	8.6

FEE SIMPLE							
FID	**Property #**	**Property Address**	**Area (Acres)**	**Wind Feasible?**	**PV Feasible?**	**PV Area (ft^2)**	**PV Area (acres)**
53	722	4926 W Green Tree Rd	45.1	Yes	Yes	1,265,000	29.0
397	1152	4343 S 6th St	15.2	Yes	Yes	622,000	14.3
408	3468	1436 E Forest Hill Ave	11.8	No	Yes	175,000	4.0
378-381, 383	3137-3140, 3142	4250-4350 N 35th St	9.5	Yes	Yes	289,000	6.6
63	72	4900 W State St	3.5	No	Yes	51,000	1.2
284	70	1016 N Hawley Rd	3.3	No	Yes	27,000	0.6
42	3092	900 N 43rd St	2.4	No	Yes	65,000	1.5
214	76	4200 W Monarch Pl	1.1	No	Yes	28,000	0.6

CONVEYANCE AND ADMINISTRATION						
Facility	**Property Address**	**Area (Acres)**	**Wind Feasible?**	**PV Feasible?**	**PV Area (ft^2)**	**PV Area (acres)**
59th and State - Large Bypass PS: BS0405	5901 W State St - Milwaukee	20.0	No	Yes	127,000	2.9
Construction Trailer (No Longer Exists)	162 N 44th St - Milwaukee	10.3	No	Yes	166,000	3.8

4.3.7 Greenhouse Gas Emissions

Table 4-44 summarizes the new GHG emissions associated with the energy profile analyzed in **Section 4.3**.

Table 4-44: Alt 2 - GHG Emissions Calculation with Planned and Recommended Improvements

	Conveyance		Administration		JIWRF		SSWRF		Total	
	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile
Purchased Non-Renewable Natural Gas Emissions (metric tons CO2e)	112	0	1,392	0	86,311	0	6,098	0	93,912	0
Purchased Renewable Natural Gas Emissions (metric tons CO2e)	0	1	0	6	0	0	0	0	0	7
Landfill Gas Emissions (metric tons CO2e)	0	0	0	0	84	169	0	0	84	169
Digester Gas Emissions (metric tons CO2e)	0	0	0	0	0	82	98	39	98	122
Purchased Electricity Emissions (metric tons CO2e)	1,564	0	1,414	0	11,479	0	11,496	0	25,953	0
Purchased Renewable Electricity Emissions (metric tons CO2e)	0	0	0	0	0	0	0	0	0	0
Purchased Oil Emissions (metric tons CO2e)	0	0	0	0	4	0	0	0	4	0
Total Emissions (metric tons CO2e)	1,675	1	2,806	6	97,878	251	17,691	39	**120,051**	**297**
GHG Difference									metric tons CO2e	**-119,754**
									%	**-99.8%**

4.3.8 Alternative 2 Summary

Table 4-45 presents all proposed projects for Alternative 2 and their associated costs.

Table 4-45: Alternative 2 OPCC Summary Table

Project Number	Project	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost
1	Energy Reduction Recommended Improvements Total	$109,645,000	$0	$0	$109,645,000
2	JIWRF PV Panels	$130,811,000	$324,000	$4,657,000	$135,468,000
3	JIWRF Battery Storage	$322,192,000	$6,444,000	$92,629,000	$414,821,000
	JIWRF Subtotal	**$453,003,000**	**$6,768,000**	**$97,286,000**	**$550,289,000**
4	SSWRF PV Panels	$202,160,000	$501,000	$7,202,000	$209,362,000
5	SSWRF Wind Turbines	$40,749,000	$815,000	$11,715,000	$52,464,000
6	SSWRF DG Cleaning	$18,953,000	$312,000	$4,485,000	$23,438,000
7	SSWRF DG Storage	$8,400,000	$168,000	$2,415,000	$10,815,000
8	JIWRF to SSWRF Electrical Duct Bank Connection	$48,858,000	$978,000	$14,058,000	$62,916,000
9	SSWRF Battery Storage	$116,139,000	$2,323,000	$33,392,000	$149,531,000
10	SSWRF to JIWRF Gas Pipeline	$44,967,000	$900,000	$12,937,000	$57,904,000
	SSWRF Subtotal	**$480,226,000**	**$5,997,000**	**$86,204,000**	**$566,430,000**
11	Conveyance System Renewable Energy	$1,573,000	$361,000	$5,189,000	$6,762,000
12	Administration Facilities Renewable Energy	$4,087,000	$391,000	$5,620,000	$9,707,000
	Conveyance and Admin Facilities Subtotal	**$5,660,000**	**$752,000**	**$10,810,000**	**$16,470,000**
	TOTAL	**$1,048,534,000**	**$13,517,000**	**$194,299,000**	**$1,242,833,000**
	Alternative 2 Total GHG Emissions	297	Metric Tons CO2e		
	Percent Reduction from 2005 Baseline	99.8%			

Table 4-46: Alternative 2 Energy Summary Table (MMBTU)

	Conveyance		Administration		JIWRF		SSWRF		Total	
	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile
Purchased Non-Renewable Natural Gas (MMBTU)	2,100	0	26,200	0	1,625,000	0	114,800	0	1,768,100	0
Purchased Renewable Natural Gas (MMBTU)	0	2,100	0	23,600	0	0	0	0	0	25,700
Landfill Gas (MMBTU)	0	0	0	0	326,600	658,730	0	0	326,600	658,730
Digester Gas (MMBTU)	0	0	0	0	0	320,470	381,700	153,410	381,700	473,880
Purchased Electricity (MMBTU)	9,400	0	8,500	0	69,000	0	69,100	0	156,000	0
Purchased Renewable Electricity (MMBTU)	0	8,303	0	5,350	0	0	0	0	0	13,653
Purchased Oil (MMBTU)	0	0	0	0	400	0	0	0	400	0
Total	11,500	10,403	34,700	28,950	2,021,000	979,200	565,600	153,410	**2,632,800**	**1,171,963**
Energy Consumption Difference									MMBTU	**-1,460,837**
									%	**-55.5%**

4.4 Alternative 3 – Drying at both JIWRF and SSWRF

Alternative 3 is similar to Alternative 1, however half the drying energy demand is shifted from JIWRF to SSWRF, consistent with a new sludge dewatering and drying Milorganite® facility at SSWRF as discussed in the BAFP. The following energy shift is included as part of this alternative:

- Thermal demand for drying at JIWRF decreases from 861,000 MMBTU/year to 430,500 MMBTU/year.
- Electricity demand for the D&D Facility at JIWRF decreases from 32,800 MMBTU/year to 16,400 MMBTU/year.
    - Total JIWRF electricity demand is now 289,000 MMBTU/year.

This alternative includes installing a new thermal hydrolysis process (THP) to improve sludge dewaterability for the new facility at SSWRF. **Section 4.4.3** summarizes the thermal energy reductions associated with THP. The following energy changes at SSWRF are included as part of this alternative:

- Thermal demand for dewatering and drying at SSWRF is 288,435 MMBTU/year
- Electricity demand for dewatering drying at JIWRF is 16,400 MMBTU/year
    - Total SSWRF electricity demand is now 125,200 MMBTU/year

4.4.1 Energy Profile

The recommended renewable energy generation and consumption energy profile for Alternative 3 is shown for JIWRF and SSWRF in **Figure 4-11**, **Figure 4-12**, **Figure 4-13**, and **Figure 4-14** below. The recommendation shows no anticipated energy consumption at the WRFs from We Energies, however we are not recommending islanding the facilities. Coordination with We Energies to be a backup power source is required.

The conveyance system and administration facilities electricity consumption will be met by the recommended PV locations and renewable purchased renewable energy from We Energies, as summarized in **Section 4.2.4**. These facilities' NG consumption and associated emissions is included in the GHG emissions calculation in **Section 4.4.6**.

- Alternative 3 includes a new Milorganite® drying facility at SSWRF per the recommendation from the Biosolids Advanced Facility Plan (BAFP), completed by others
    - JIWRF
        - Install two new Solar Turbines

    - Install 158,400 SF or 2,200 kW of PV panels
    - Install a 520 SCFM gas cleaning system
- SSWRF
    - Install new engine generators
    - Install 1,315,400 SF or 18,300 kW of PV panels
    - Install a new thermal hydrolysis process (THP)
    - Build an 11.5 tons per day high strength waste receiving station and anaerobic digesters to increase digester gas generation
    - Install a 1,600 SCFM gas cleaning system
    - Install 2,538,000 CF of gas storage serving JIWRF and SSWRF
    - Build a digester gas pipeline connecting JIWRF and SSWRF
- Conveyance System
    - Install 4,600 kW of PV panels
    - Purchase the remaining renewable electricity and natural gas from We Energies
- Administration Facilities
    - Install 36,400 SF or 500 kW of PV panels
    - Purchase the remaining renewable electricity and renewable natural gas from We Energies

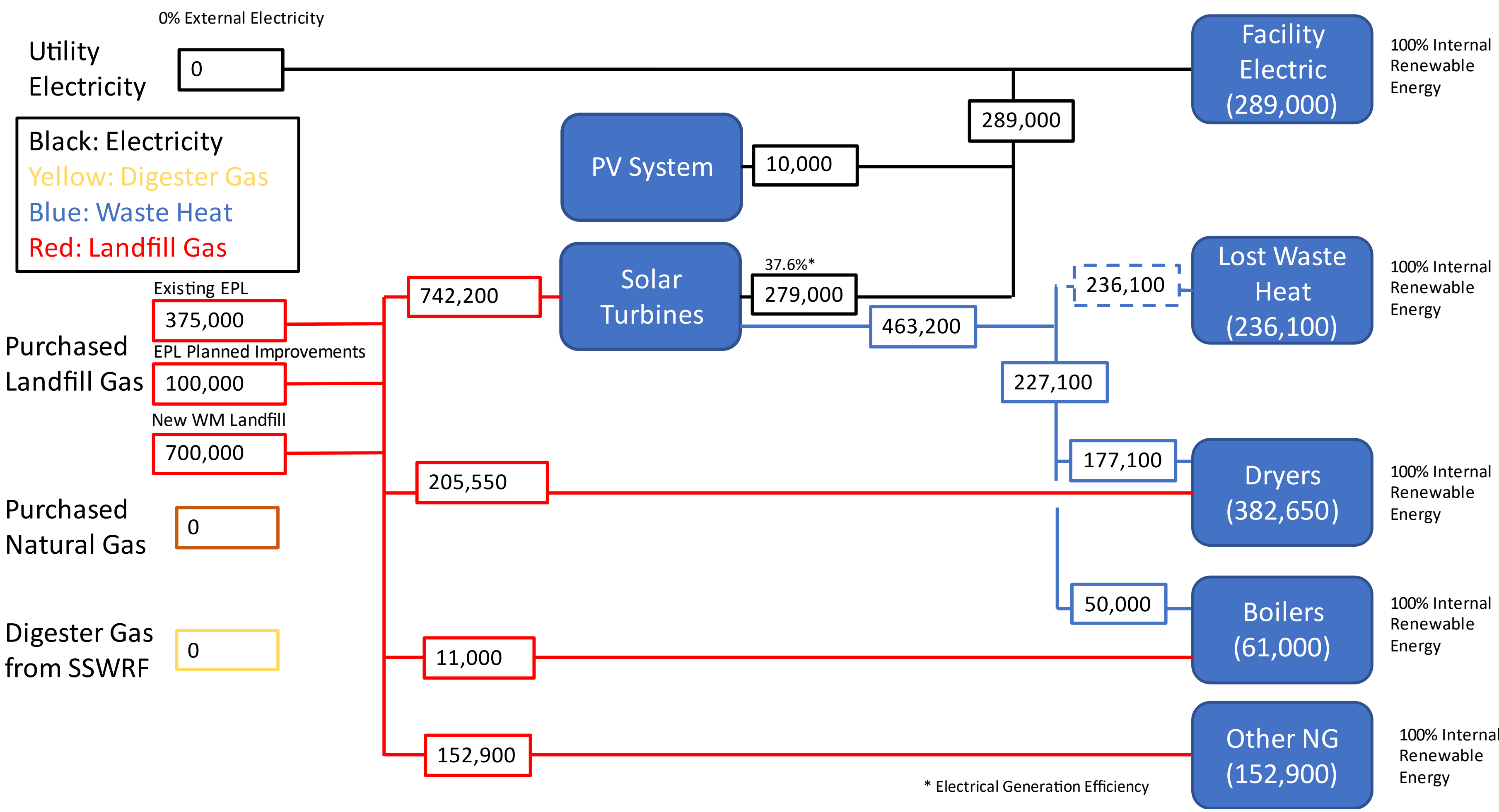

Figure 4-11: Alt 3 - JIWRF Energy Profile (MMBTU/Year)

Figure 4-12: Alt 3 - JIWRF Energy Profile Site Plan (MMBTU/Year)

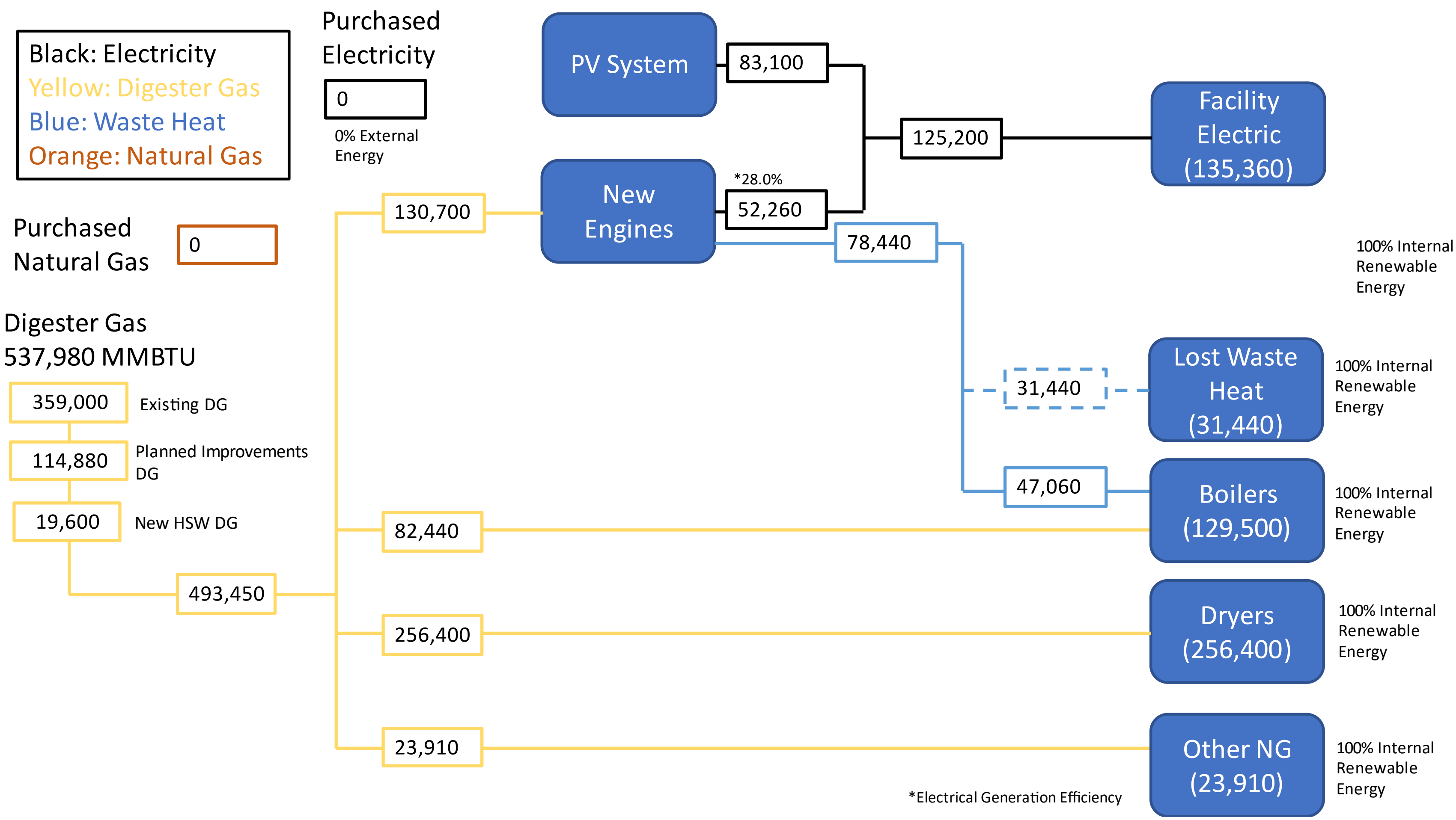

Figure 4-13: Alt 3 - SSWRF Energy Profile (MMBTU/Year)

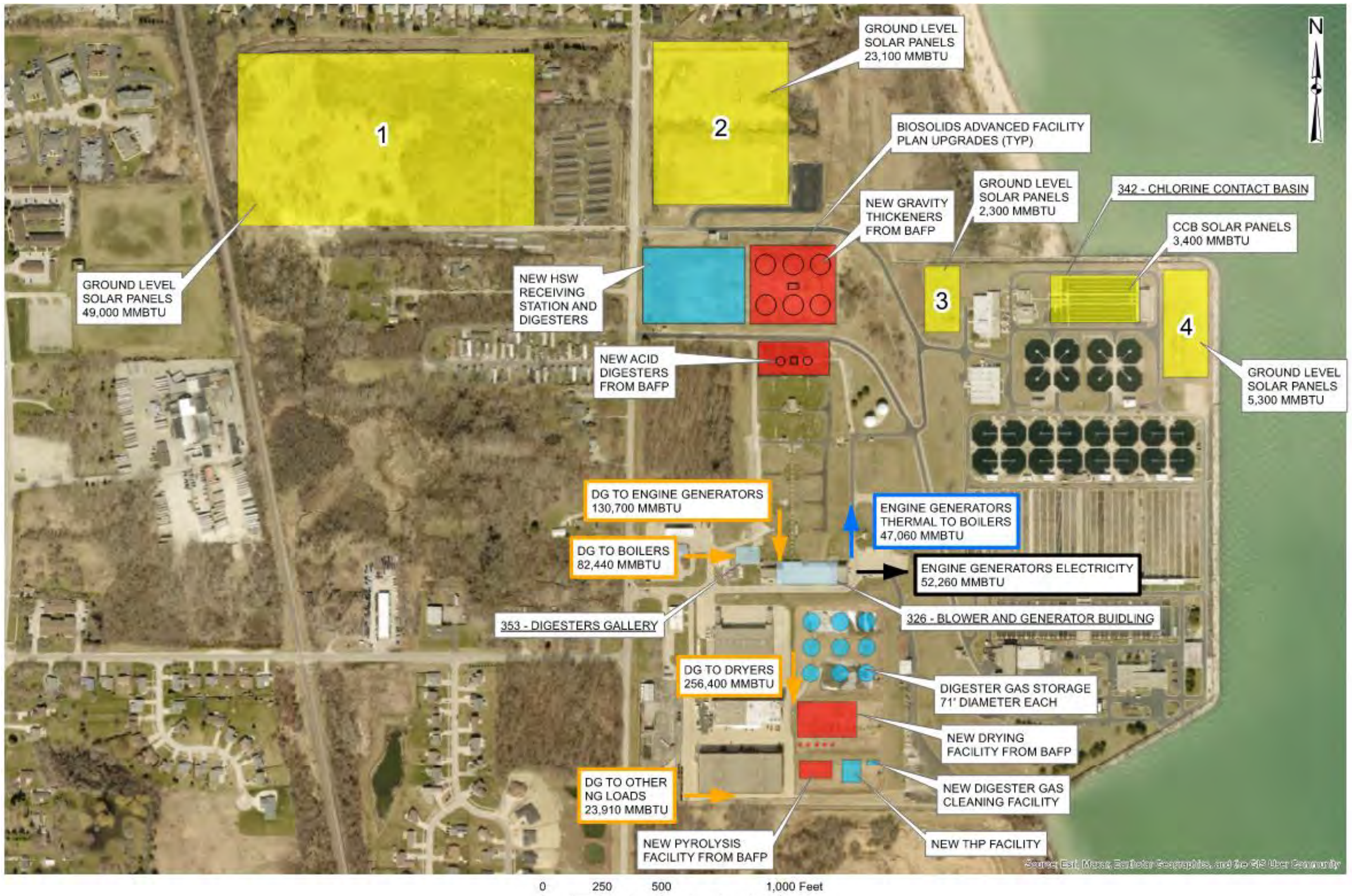

Figure 4-14: Alt 3 - SSWRF Energy Profile Site Plan (MMBTU/Year)

4.4.2 JIWRF

Alternative 3 has the same recommendations to Alternative 1 in terms of electricity generation through the turbines and PV panels. See **Section 4.2.2**. This section details the changes to renewable gas usage at JIWRF due to reduced drying demand.

<u>JIWRF Turbine Generation</u>

The JIWRF electricity generation calculation determined that approximately two Solar turbines are required to generate the facility's consumed electricity minus the new PV generation at average conditions. The calculation assumed electrical and thermal efficiencies of 37.6% and 30.6% and an electrical output of 4,800 kW for each turbine. The fuel input required is approximately 742,200 MMBTU/year. LFG was used as the primary fuel for energy generation as shown in **Figure 4-11**.

<u>Gas Cleaning Analysis</u>

It is recommended to clean LFG for consumption in the boilers and other NG loads at JIWRF to allow for consumption flexibility and equipment longevity. The cleaned LFG can be connected to the facilities NG lines to allow for renewable gas consumption by the other NG consumers. JIWRF's LFG consumption in the Boilers and other NG loads for Alternative 3 is 163,900 MMBTU/year. This equates to 620 SCFM of gas @51% Methane.

An additional 529,500 kWh/year or 1,810 MMBTU/year is required to generate the additional electricity required to power the gas cleaning system. This equates to the following:

- 4,525 MMBTU/year of LFG for electricity generation
- 28,150 SF or 2,700 m^2 of PV panels

Table 4-47 summarizes the electricity requirements and costs of a 620 SCFM gas cleaning system at JIWRF.

Table 4-47: Alt – 3 JIWRF LFG Cleaning Summary

SCFM	Cost		Electricity			Footprint
	Capital	Yearly O&M	Demand	Consumption		SF
			kW	kWh/year	MMBTU/year	
JIWRF	$7,848,000	$129,000	60	529,500	1,810	2,000

Table 4-48 breaks down the LFG cleaning system cost.

Table 4-48: Alt – 3 JIWRF LFG Cleaning Cost Summary

Description	Cost
Equipment Capital Cost	$2,360,000
Structural Improvements (20% of Equipment Cost)	$472,000
Electrical Improvements (20% of Equipment Cost)	$472,000
Labor (50% of Equipment Cost)	$1,180,000
Subtotal	$4,484,000
Overhead and Profit (20% of Subtotal)	$897,000
Contingency (40% of Subtotal)	$1,794,000
Design and Engineering Services (15% of Subtotal)	$673,000
Total Capital Cost	$7,848,000
-50%	$3,924,000
+100%	$15,696,000
Total Annual O&M Cost (2% of Capital Cost)	**$129,000**

4.4.3 SSWRF

Alternative 3 has the same recommendations to Alternative 1 in terms of electricity generation through the engine generators and PV panels. See **Section 4.2.3**. This section details the changes to renewable gas usage at SSWRF due to the new drying facility.

SSWRF Engine Generator Electricity Generation

The SSWRF electricity generation calculation assumes the equivalent of approximately two CAT engine generators are in operation with electrical and thermal efficiencies of 28.0% and 36.0% and each generator has electrical output of 760.5 kW. The fuel input required is approximately 187,600 MMBTU/year.

New SSWRF Engine Generators

If new, more electrically efficient engine generators were installed at SSWRF, they would generate the same electricity and thermal heat using just 130,700 MMBTU/year. That is a savings of 56,900 MMBTU/year of DG (187,600 – 130,700 MMBTU). The value for gas offset is summarized for different values of fuel costs below, calculated based on the 56,900 MMBTU/year of DG savings.

- $2.11/MMBTU equates to $120,000/year
- $5/MMBTU equates to $284,500/year

- $10/MMBTU equates to $569,000/year

SSWRF Engine Asset Management

CAT Engine Generators
The four CAT engine generators were installed in 2009, placed into operation in 2010 and are 14 years old. Each unit is rated for 938 kW when operating on DG and 770 kW on NG. The CAT engines require DG to be at approximately 5 psig. MMSD is responsible for maintenance of the engine generators. The average annual maintenance cost over the past 10 years is $367,934 per engine generators as per MMSD maintenance records.

The 2018-2020 SSWRF average wet weather energy demand was 6.2 MW. It is recommended that MMSD have N+1 the engine generation capacity to meet this wet weather demand. The calculations for this report were based off Jenbacher engine generators, however other biogas rated engine generator equivalents may be used. Using the recommended average engine generation 52,260 MMBTU/yr or 15,316,000 kWh/yr results in an average demand of 1,749 kW. Alternative 3 assumes a new dewatering and drying facility at SSWRF and therefore requires a higher electricity demand. Adding increased electricity consumption to the demand results in a projected wet weather demand of 6.8 MW. A J420 engine generator generates 1,429 kW. The J420 engine generators operate with a fuel pressure under 5 psig. Six J420 engine generators results in a total installed capacity of 8,574 kW or firm capacity (largest unit out of service) of 7,145 kW. This firm capacity meets the 6.8 MW wet weather demand. This installation two engine generators operating to meeting the average demand of 1,749 kW.

Thermal Hydrolysis for Sludge Drying
THP was evaluated to be incorporated at SSWRF with the new biosolids dewatering and drying facility. THP would be used post-digestion to improve dewaterability of the solids prior to drying. THP would improve dewaterability of the digested solids from 18% to 23-24%, approximately a 33% increase. This was evaluated by CAMBI, one of the leaders in THP worldwide.

CAMBI reviewed the drying process and provided the dewaterability numbers and resulting energy estimates based on CAMBI proprietary software. The existing D&D building at JIWRF consumes 861,000 MMBTU/year of thermal energy for drying. Half that energy, 430,500 MMBTU/year will be shifted to SSWRF. With a new THP facility, there is approximately a 33% decrease in energy required for dewatering and drying. The new thermal energy demand at SSWRF for drying is 288,435 MMBTU/year (430,500 x 0.67 = 288,435).

The anticipated cost based on information provided by CAMBI of introducing a THP system is shown below in **Table 4-49**.

Table 4-49: THP Cost Summary

Description	Cost
CAMBI Equipment Capital Cost	$11,000,000
Civil Site Improvements (100% of CAMBI Cost)	$11,000,000
Yard Piping Improvements (100% of CAMBI Cost)	$11,000,000
Electrical Improvements (30% of CAMBI Cost)	$3,300,000
Controls Improvements (10% of CAMBI Cost)	$1,100,000
Installation and Labor (50% of All Above Costs)	$18,700,000
Subtotal	$56,100,000
Overhead and Profit (20% of Subtotal)	$11,220,000
Contingency (40% of Subtotal)	$22,440,000
Design and Engineering Services (15% of Subtotal)	$8,415,000
Total Capital Cost	**$98,175,000**
-50%	$49,088,000
+100%	$196,350,000
Total Annual O&M Cost (from CAMBI)	**$450,000**

It is recommended to incorporate THP at SSWRF to reduce energy. A pilot test is recommended to verify its effect on the Milorganite® product and how it fits in with the BAFP.

SSWRF HSW

Similar to Alternatives 1 and 2, additional DG is required to provide energy to JIWRF and SSWRF. An HSW program will be required to increase DG generation.

- Additional 19,600 MMBTU/year of DG gas is needed after planned improvements.
  - Less gas is needed if new engine generators are installed as previously discussed in the engine generator asset management section.
- This is equal to approximately 62 SCFM of DG @ 60% Methane.

Food waste is anticipated to be more readily available than FOG and was used to calculate DG generation. As shown in **Table 4-50**, approximately 3.7 tons per day of food waste will be needed to produce the 62 SCFM of DG.

Table 4-50: Alt 3 – HSW Food Waste Calculations

DG Parameters		
DG Needed After Planned Improvements	MMBTU/year	19,600
	dth/year	19,595
	CF/year	19,596,000
	SCFM of NG	37
	SCFM of DG	62
Biogas Production Potential		
Biogas Production Needed	SCFD	90,000
Volatiles Destroyed	Lbs/Day	5,700
VS Loading Capacity	Lbs/Day	6,800
Loading Rate	Lbs/Day	7,300
	Tons/Day	3.7
Additional Biosolids for Disposal	Lbs/Day	1,600

The calculated loading rate of 3.7 tons per day was used to determine the digester quantity and size needed to accept this quantity of HSW. This was done under the same three different conditions as Alternative 1, presented in **Section 4.2.3**. The same assumptions were used as well. The quantity and size of these new digesters are presented in **Table 4-51**.

Table 4-51: Alt 3 – Digester Capacity Evaluation

	Unit	Existing Conditions	2045 Capacity with Current Loading Rates	2045 Capacity and Loading Rates
DG Needed After Planned Improvements	MMBTU/year	19,600		
	SCFM of DG	62		
Quantity of Food Waste Needed	Tons/Day	3.7		
Digester Volume Needed	Ft^3	57,000		
Digester Volume to Existing Digesters	Ft^3	57,000	57,000	0
Digester Volume to New Digesters	Ft^3	0	0	57,000
New Digester Size	MG	N/A	N/A	0.50
Quantity of New Digesters Needed		N/A	N/A	2
Digester Diameter	Ft	N/A	N/A	58
Digester Sidewater Depth	Ft	N/A	N/A	25.0

The new digesters and additional loading will require additional energy to heat the sludge. The new HSW facility will also have equipment and building energy demands. The projected digester heating and building energy requirements are summarized below for Alternative 3's HSW improvements.

- Digester Heating: 10,000 MMBTU/yr
- Building Energy: 1,500 MMBTU/yr
- Equipment Energy: 3,500 MMBTU/yr

The cost of introducing HSW at SSWRF is presented in **Table 4-52**. The anaerobic digester capital cost is estimated based on digester costs presented in the BAFP. The HSW building cost is estimated based on a footprint of 20,000 square feet. This is smaller than the footprint presented in Alternative 1 since there is significantly less HSW that needs to be processed.

Table 4-52: Alt 3 – SSWRF HSW Cost Summary

Description	Cost
Anaerobic Digester Capital Cost	$18,586,000
HSW Building Capital Cost	$5,000,000
Subtotal 1	$23,586,000
Anaerobic Digester & HSW Equipment (100% of Subtotal 1)	$23,586,000
Site Work (20% of Subtotal 1)	$4,718,000
Installation and Labor (50% of Subtotal 1, Equipment & Site Work Costs)	$25,945,000
Subtotal 2	$77,835,000
Overhead and Profit (20% of Subtotal 2)	$15,567,000
Contingency (40% of Subtotal 2)	$31,134,000
Design and Engineering Services (15% of Subtotal 2)	$11,676,000
Total Capital Cost	**$136,212,000**
AACE: -50%	$68,106,000
AACE: +100%	$272,424,000
Total Annual O&M Cost (2% of Capital Cost)	**$2,725,000**

Gas Cleaning Analysis

It is recommended to clean all generated DG to allow for consumption flexibility and equipment longevity. The cleaned DG can be connected to the facilities NG lines to allow for renewable gas consumption by the other NG consumers. SSWRF's total DG production for Alternative 3 is 493,480 MMBTU/year. This equates to 1,600 SCFM of DG @60% Methane.

An additional 1,366,000 kWh/year or 4,660 MMBTU/year is required to generate the additional electricity required to power the gas cleaning system. This value is included in SSWRF's electricity demand in **Section 4.4.1**. This equates to the following:

- 11,650 MMBTU/year of DG for engine electricity generation
- 72,500 SF or 6,850 m^2 of PV panels

Table 4-53 summarizes the electricity requirements and costs of a 1,600 SCFM gas cleaning system at SSWRF.

Table 4-53: Alt 3 – SSWRF DG Cleaning Summary

SCFM	Cost		Electricity			Footprint
	Capital	Yearly O&M	Demand	Consumption		SF
			kW	kWh/year	MMBTU/year	
1,600	$20,217,000	$333,000	156	1,366,600	4,660	4,000

Table 4-54 breaks down the DG cleaning system cost.

Table 4-54: Alt 3 – SSWRF DG Cleaning Cost Summary

Description	Cost
Equipment Capital Cost	$6,080,000
Structural Improvements (20% of Equipment Cost)	$1,216,000
Electrical Improvements (20% of Equipment Cost)	$1,216,000
Labor (50% of Equipment Cost)	$3,040,000
Subtotal	$11,552,000
Overhead and Profit (20% of Subtotal)	$2,311,000
Contingency (40% of Subtotal)	$4,621,000
Design and Engineering Services (15% of Subtotal)	$1,733,000
Total Capital Cost	$20,217,000
-50%	$10,109,000
+100%	$40,434,000
Total Annual O&M Cost (2% of Capital Cost)	**$ 333,000**

Gas Storage Analysis

The same gas supply and demand analysis that was performed for the previous alternatives was performed and summarized for Alternative 3 at SSWRF below. **Figure 4-14** shows space for 9 gasholders, resulting in a total storage volume of 2,538,000 SCF of DG.

The high and low supply and demands were calculated similar to the analysis previously. **Table 4-55** summarizes the gas surplus and deficits based on SSWRF's high and low supply and demands.

Table 4-55: Alt 3 – DG Storage Analysis – SSWRF Demands

Supply		Demand		Surplus		Deficit	
Low	High	Low	High	Max		Max	
MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	MMBTU/Day	SCFM	MMBTU/Day	SCFM
800	1,900	900	1,800	1,000	695	-1,000	-695

This results in maximum deficit volume of 1,000 MMBTU/day or 695 SCFM. The max surplus volume is 1,000 MMBTU/day or 695 SCFM. The resulting time to fill or drain 9 gasholders is approximately 2.5 days.

The largest boilers are rated for a maximum of 16.7 MMBTU/hr each or 280 SCFM @ 100% methane. The recommended engine generation demand is 14.92 MMBTU/hr or 240 SCFM @ 100% methane. The average dryer demand at SSWRF is 29.3 MMBTU/hr or 490 SCFM @ 100% methane/ JIWRF does not consume and DG under dry conditions in the alternative.

An operating scenario when the recommended engine generation demand, 1 boiler, and average dryer demands are operating at SSWRF results in a total demand of 1,040 SCFM of DG (280+240+490). Assuming the low supply rate, the resulting DG drain would be 240 SCFM (1,040-800). This operating scenario would take approximately 7.3 days for the storage capacity to be drained. This scenario conservatively assumes no waste heat from the engines are offsetting boiler gas consumption.

If new engine generators were to generate all the electricity during wet weather demand of 6.2 MW, 52.8 MMBTU/hr of fuel is needed. This equates to 850 SCFM of DG. This plus 1 boiler and the dryers operating results in a total of 1,620 SCFM and would take approximately 2.1 days to drain the 9 gasholder storage capacity assuming the low supply rate.

If JIWRF were also operating at its wet weather demand average of 17.2 MW, 157 MMBTU/hr or 2,520 SCFM of gas is needed. LFG averages 90 MMBTU/hr or 1,450 SCFM. Therefore, an additional 1,070 CFM of DG is needed at JIWRF. This results in a total wet weather DG demand of 2,690 SCFM (1,620 + 1,070) and would take approximately 0.9 days to drain the storage capacity assuming the low supply rate.

Table 4-55 summarizes the costs associated with Alternative 3’s gas storage.

Table 4-56: Alt 3 – Gas Storage Cost Summary

Description		Cost
Capital Cost	$	7,200,000
Installation and Labor (50% of Capital Cost)	$	3,600,000
Subtotal	$	10,800,000
Overhead and Profit (20% of Subtotal)	$	2,160,000
Contingency (40% of Subtotal)	$	4,320,000
Design and Engineering Services (15% of Subtotal)	$	1,620,000
Total Capital Cost	**$**	**18,900,000**
-50%	$	9,450,000
+100%	$	37,800,000
Total Annual O&M Cost (2% of Capital Cost)	**$**	**378,000**

4.4.3.1 SSWRF to JIWRF Gas Pipeline

To provide flexibility and redundancy between JIWRF and SSWRF, it is recommended to install a DG pipeline between the facilities. It is intended to supply JIWRF with cleaned DG to support wet weather demand power generation. Refer to **Section 4.2.3.1** for the gas pipeline connection summary.

4.4.4 Conveyance System

Refer to **Section 4.2.4**. The Alternative 3 analysis is the same as Alternative 1 for the Conveyance System.

4.4.5 Administration Facilities

Refer to **Section 4.2.5**. The Alternative 3 analysis is the same as Alternative 1 for the Administration Facilities.

4.4.6 Greenhouse Gas Emissions

Table 4-57 summarizes the new GHG emissions associated with the energy profile analyzed in **Section 4.4**.

Table 4-57: Alt 3 - GHG Emissions Calculation with Planned and Recommended Improvements

	Conveyance		Administration		JIWRF		SSWRF		Total	
	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile
Purchased Non-Renewable Natural Gas Emissions (metric tons CO2e)	112	0	1,392	0	86,311	0	6,098	0	93,912	0
Purchased Renewable Natural Gas Emissions (metric tons CO2e)	0	1	0	6	0	0	0	0	0	7
Landfill Gas Emissions (metric tons CO2e)	0	0	0	0	84	285	0	0	84	285
Digester Gas Emissions (metric tons CO2e)	0	0	0	0	0	0	98	127	98	127
Purchased Electricity Emissions (metric tons CO2e)	1,564	0	1,414	0	11,479	0	11,496	0	25,953	0
Purchased Renewable Electricity Emissions (metric tons CO2e)	0	0	0	0	0	0	0	0	0	0
Purchased Oil Emissions (metric tons CO2e)	0	0	0	0	4	0	0	0	4	0
Total Emissions (metric tons CO2e)	1,675	1	2,806	6	97,878	285	17,691	127	**120,051**	**418**
GHG Difference								metric tons CO2e		**-119,633**
								%		**-99.7%**

4.4.7 Alternative 3 Summary

Table 4-58 and **Table 4-59** presents all proposed projects for Alternative 3 and their associated costs. **Table 4-60** summarizes Alternative 3's energy compared to the 2018-2020 baseline.

Table 4-58: Alternative 3 OPCC Summary Table

Project Number	Project	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost
1	Energy Reduction Recommended Improvements Total	$109,645,000	$0	$0	$109,645,000
2	JIWRF New Turbine Generators	$71,233,000	$1,939,000	$27,872,000	$99,105,000
3	JIWRF PV Panel Installation	$17,801,000	$45,000	$647,000	$18,448,000
4	JIWRF Landfill Gas Cleaning	$7,848,000	$129,000	$1,854,000	$9,702,000
	JIWRF Subtotal	**$96,882,000**	**$2,113,000**	**$30,373,000**	**$127,255,000**
4	SSWRF New Engine Generators	$48,938,000	$1,591,000	$22,870,000	$71,808,000
5	SSWRF PV Panel Installation	$147,661,000	$366,000	$5,261,000	$152,922,000
6	THP at SSWRF	$98,175,000	$450,000	$6,469,000	$104,644,000
7	SSWRF High Strength Waste	$136,212,000	$2,725,000	$39,171,000	$175,383,000
8	SSWRF DG Cleaning	$20,217,000	$405,000	$5,822,000	$26,039,000
9	SSWRF DG Storage	$18,900,000	$378,000	$5,434,000	$24,334,000
10	SSWRF to JIWRF Gas Pipeline	$44,967,000	$900,000	$12,937,000	$57,904,000
	SSWRF Subtotal	**$515,070,000**	**$6,815,000**	**$97,964,000**	**$613,034,000**
11	Conveyance System Renewable Energy	$1,573,000	$361,000	$5,189,000	$6,762,000
12	Administration Facilities Renewable Energy	$4,087,000	$391,000	$5,620,000	$9,707,000
	Conveyance and Admin Facilities Subtotal	**$5,660,000**	**$752,000**	**$10,810,000**	**$16,470,000**
	TOTAL	**$727,257,000**	**$9,608,000**	**$138,111,000**	**$865,368,000**
	Alternative 3 Total GHG Emissions	418	Metric Tons CO2e		
	Percent Reduction from 2005 Baseline	99.7%			

Table 4-59: Alternative 3 Energy Summary by Category

Project Category	OPCC	Total 20 Yr PW Cost
Efficiency Improvements	$109,645,000	$109,645,000
PV Generation	$165,462,000	$171,370,000
LFG Generation Improvements	$79,081,000	$108,807,000
HSW Generation	$136,212,000	$175,383,000
DG Generation Improvements	$186,230,000	$225,790,000
Renewable Energy Purchasing	$5,660,000	$16,469,000
JIWRF to SSWRF Pipeline	$44,967,000	$57,904,000
Total	$727,257,000	$865,368,000

Table 4-60: Alternative 3 Energy Summary Table (MMBTU)

	Conveyance		Administration		JIWRF		SSWRF		Total	
	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile	2018-2020 Average	After Recommended Energy Profile
Purchased Non-Renewable Natural Gas (MMBTU)	2,100	0	26,200	0	1,625,000	0	114,800	0	1,768,100	0
Purchased Renewable Natural Gas (MMBTU)	0	2,100	0	23,600	0	0	0	0	0	25,700
Landfill Gas (MMBTU)	0	0	0	0	326,600	1,111,650	0	0	326,600	1,111,650
Digester Gas (MMBTU)	0	0	0	0	0	0	381,700	493,450	381,700	493,450
Purchased Electricity (MMBTU)	9,400	0	8,500	0	69,000	0	69,100	0	156,000	0
Purchased Renewable Electricity (MMBTU)	0	8,303	0	5,350	0	0	0	0	0	13,653
Purchased Oil (MMBTU)	0	0	0	0	400	0	0	0	400	0
Total	11,500	10,403	34,700	28,950	2,021,000	1,111,650	565,600	493,450	**2,632,800**	**1,644,453**
Energy Consumption Difference									MMBTU	**-988,347**
									%	**-37.5%**

Section 5 Recommendations

5.1 Introduction

This section summarizes the alternatives evaluation presented in **Section 4** and provides a recommendation for the most preferred alternative MMSD can use to plan projects to meet the 2035 Vision and make progress toward the Carbon Neutrality Goals. A triple bottom line approach of evaluating the alternatives sustainability through their ability to meet the goals of the 2035 Vision, provide operational flexibility benefiting MMSD and the people they serve, and the economics through the OPCC and PW analyses.

5.2 Recommendation

All three alternatives will meet the goals of MMSD's 2035 Vision. MMSD will need to implement carbon sequestration as described in **Section 2.2** for the remaining metric tons $CO2_e$ to become carbon neutral.

The three alternatives were evaluated using OPCC, 20-year present worth cost, GHG emissions, and total energy consumption. **Table 5-1** summarizes the three alternatives and **Table 5-2** summarizes the alternative's achievement with respect to the 2035 Vision goals.

Table 5-1: Alternative Evaluation Summary

Alternative	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost	Total GHG Emissions (Metric Tons CO2e)	% Reduction from 2005 Baseline	Total Energy Consumption (MMBTU/year)
Alternative 1	$705,012,000	$10,696,000	$153,748,000	$858,760,000	452	99.7%	1,775,693
Alternative 2	$1,048,534,000	$13,517,000	$194,299,000	$1,242,833,000	297	99.8%	1,171,963
Alternative 3	$727,257,000	$9,608,000	$138,111,000	$865,368,000	418	99.7%	1,644,453

Table 5-2: Alternative 2035 Vision Goal Evaluation Summary

Alternative	% Net Energy From Renewable Sources	% Internal, Renewable Energy	% Reduction from 2005 Baseline	Meets All 2035 Vision Goals
Alternative 1	100%	97.8%	99.7%	Yes
Alternative 2	100%	96.6%	99.8%	Yes
Alternative 3	100%	97.6%	99.7%	Yes

Table 5-3 compares alternatives on their evaluation criteria including meeting the 2035 Vision Goals, operational flexibility, and costs and presents them in rankings.

Table 5-3: Evaluation Criteria Alternative Summary

	Meets 2035 Vision Goals	Operational Flexibility	Costs
Alternative 1	Yes	Preferred	Preferred
Alternative 2	Yes	Least Preferred	Least Preferred
Alternative 3	Yes	Most Preferred	Most Preferred

It is recommended that MMSD implement Alternative 3 as the path to achieve the 2035 Vision Goals. Alternative 3 provides MMSD with the most operational flexibility, mitigates community impacts, and has the most preferred costs resulting in the largest return on investment. The single largest energy user for MMSD is the biosolids drying process for Milorganite® production. Shifting half of this energy load to SSWRF, where DG is generated, puts the largest energy load at the same location as the largest energy producer, the anaerobic digesters. This is why Alternative 3 is considered the most preferred operational flexibility. This and connecting the facilities with a gas pipeline allows for greater redundancy and renewable gas consumption, assisting with minimizing DG flaring.

MMSD is experienced using renewable gases (LFG and DG) and will continue to rely on renewable gas to generate electricity for both JIWRF and SSWRF and the biosolids drying process. Renewable electricity generation through solar PV will fill in the electricity gaps at both WRFs. Community impacts are mitigated through not needing large wind turbines at WRF, Greenseams, or conveyance facilities like Alternative 2 requires. The recommendation shows no anticipated energy consumption at the WRFs from We Energies, however we are not recommending islanding the facilities. Coordination with We Energies to be a backup power source is required.

The Conveyance System and Administration Facilities will generate renewable electricity using solar PV and fill in the remaining energy gap at these facilities by purchasing renewable energy through We Energies to meet MMSD's goal of using 100% renewable energy.

Given the high degree of unknowns and uncertainties, MMSD should be consistently monitoring the likelihood of recommended projects. An MMSD energy program manager is recommended to keep track of this plan's implementation, progress, and vision. This plan is written to allow for design and incorporation flexibility where an energy program manager can evaluate specific project priorities and constraints when considering design decisions and how the energy plan goals are incorporated, or project goals adapted to facilitate decision making. An example of where an energy program manager may have to amend the plan's implementation is LFG or HSW availability. If LFG or HSW is unavailable, portions of Alternative 2 may have to be incorporated. Projects that should be considered regardless of LFG and HSW availability are the PV projects, LFG and DG cleaning, engine upgrades at SSWRF, and THP for increased dewaterability at SSWRF in anticipation of a new dewatering facility.

Section 6 Capital Improvement Plan

6.1 Introduction

This section provides a summary of the selected Alternative 3 projects and provides a conceptual roadmap for MMSD to follow and implement up to meet the 2035 Vision by 2035.

Listed below are key questions, alternatives, and issues that should be investigated prior to starting the next phase of the project. After the evaluations below are completed, the downstream impacts of the technologies investigated on treatment processes, energy impact, and greenhouse gas emissions should be reviewed and the projects should be reprioritized as needed.

- Coordination with We Energies on the potential for power wheeling and net metering.
- Evaluate sources for high strength waste and pilot test digestion of sourced food waste in existing or new anaerobic digesters.
- Evaluate and pilot test ammonia sidestream removal at both plants.
- Evaluate and pilot test THP, impacts to energy savings impacts, and impacts to the drying process.
- Evaluate generator type at both SSWRF and JIWRF.
- Incorporate power meters installed to monitor energy usage and generation as new improvements are made.
- Continue to improve building efficiencies, including windows, insulation, and automation and efficiency improvements of building lighting and HVAC.

6.2 Engineer's Opinion of Probable Construction Cost

Table 6-1 summarizes Alternative 3's OPCC for projects.

Table 6-1: Alternative 3 OPCC Summary

Project Number	Project	Capital OPCC	Annual O&M Cost	Total PW O&M Cost over 20 Years	Total PW Cost
1	Energy Reduction Recommended Improvements Total	$109,645,000	$0	$0	$109,645,000
2	JIWRF New Turbine Generators	$71,233,000	$1,939,000	$27,872,000	$99,105,000
3	JIWRF PV Panel Installation	$17,801,000	$45,000	$647,000	$18,448,000
4	JIWRF Landfill Gas Cleaning	$7,848,000	$129,000	$1,854,000	$9,702,000
	JIWRF Subtotal	**$96,882,000**	**$2,113,000**	**$30,373,000**	**$127,255,000**
4	SSWRF New Engine Generators	$48,938,000	$1,591,000	$22,870,000	$71,808,000
5	SSWRF PV Panel Installation	$147,661,000	$366,000	$5,261,000	$152,922,000
6	THP at SSWRF	$98,175,000	$450,000	$6,469,000	$104,644,000
7	SSWRF High Strength Waste	$136,212,000	$2,725,000	$39,171,000	$175,383,000
8	SSWRF DG Cleaning	$20,217,000	$405,000	$5,822,000	$26,039,000
9	SSWRF DG Storage	$18,900,000	$378,000	$5,434,000	$24,334,000
10	SSWRF to JIWRF Gas Pipeline	$44,967,000	$900,000	$12,937,000	$57,904,000
	SSWRF Subtotal	**$515,070,000**	**$6,815,000**	**$97,964,000**	**$613,034,000**
11	Conveyance System Renewable Energy	$1,573,000	$361,000	$5,189,000	$6,762,000
12	Administration Facilities Renewable Energy	$4,087,000	$391,000	$5,620,000	$9,707,000
	Conveyance and Admin Facilities Subtotal	**$5,660,000**	**$752,000**	**$10,810,000**	**$16,470,000**
	TOTAL	**$727,257,000**	**$9,608,000**	**$138,111,000**	**$865,368,000**
	Alternative 3 Total GHG Emissions	418	Metric Tons CO2e		
	Percent Reduction from 2005 Baseline	99.7%			

6.3 Updated Blended Energy Rates

MMSD purchases electricity from We Energies with different rate structures for different facilities. Both JIWRF and SSWRF generate electricity using landfill gas, natural gas, and digester gas, so the actual cost of electricity at these facilities is a blend of purchased utility electricity, purchased gas costs for electricity generation, and energy generation equipment O&M costs. The current blended rates for JIWRF and SSWRF are listed below.

- JIWRF: $0.042/kWh
- SSWRF: $0.052/kWh

To better project future energy costs, the blended rates are calculated for the Alternative 3 energy profile for JIWRF and SSWRF. Blended rates are also calculated using the same method for the 2018-2020 average energy profile for comparison. Assumptions for this calculation are listed below.

- Utility electricity cost: $0.1038/kWh
  - 2023 actual JIWRF and SSWRF cost
- Utility natural gas cost: $5/MMBTU
- Landfill gas cost: $2.11/MMBTU
- Digester gas cost: $2.11/MMBTU
  - O&M cost of digester gas per the EPAs project economics and financing for gas conditioning [10]
- Existing O&M costs of generators included in calculation
  - JIWRF Turbines: $969,375
    - Contract per turbine
  - SSWRF Engines: $367,934
    - 2010 – 2021 AVG yearly O&M cost per engine
- The Alternative 3 blended rate assumes MMSD will pay the electric utility a supply connection fee similar to the current total electricity charges. The alternative blended rate utilizes the baseline utility purchased electricity cost for its calculation.

[10] https://www.epa.gov/system/files/documents/2021-07/pdh_chapter4.pdf

Table 6-2: Blended Rate Calculation

Facility	Alternative	Energy Consumption								Costs		
		Purchased Electricity		NG	LFG	DG	Generated Electricity		Total Electricity	Generator Yearly O&M	Utility Electricity	Blended Rate
		MMBTU/yr	kWh/yr	MMBTU/yr	MMBTU/yr	MMBTU/yr	MMBTU/yr	kWh/yr	kWh/yr	$/yr	$/yr	$/kWh
JIWRF	Baseline	69,000	20,222,000	753,000	323,000	0	290,000	84,990,300	105,212,000	$1,939,000	$2,099,000	$0.081
	Alt 3	0	0	0	742,200	0	0	0	84,697,000	$3,878,000	$2,099,000	$0.089
SSWRF	Baseline	69,100	20,251,000	77,500	0	224,000	86,000	25,204,020	45,455,000	$1,472,000	$2,102,000	$0.098
	Alt 3	0	0	0	0	130,700	0	0	39,670,000	$1,591,000	$2,102,000	$0.100

Table 6-2 shows the baseline and alternative 3 calculated blended electricity rates. This calculation only includes electricity, or energy used to generate electricity.

6.4 Schedule

Table 6-3 summarizes Alternative 3's schedule to complete the recommended projects by 2035 to meet the 2035 Vision. This is a potential timeline that incorporates BAFP projects and aligns recommended projects with start and completion dates.

Projects that can be independently completed at any time:

- 1, 12, 6, 3, 11, 2, 4, 13

Projects that must be completed in sequence:

- 5, 8, 7, 9, 10

Engineer's Opinion of Probable Construction Capital Costs and 20-year PW are organized by MMSD O&M and good practice improvements that likely will happen regardless of the Energy Plan, MMSD improvements that should happen for redundancy and in concert with the new dewatering and drying facility at SSWRF, regardless of energy plan implementation, and Energy Plan specific recommendations. This allows for a 20-year PW comparison for projects.

Table 6-3: Alternative 3 Schedule

#	Project	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	OPCC	Total 20 Yr PW Cost
MMSD Planned Improvement Projects															
	SSWRF Drying Facility														
	WM - LFG Pipeline														
Alternative 3 Projects															
1	Energy Reduction Recommended Improvements Total													$109,645,000	$109,645,000
12	Conveyance System Renewable Energy													$1,573,000	$6,762,000
6	SSWRF PV Panel Installation													$147,661,000	$152,922,000
3	JIWRF PV Panel Installation													$17,801,000	$18,448,000
11	SSWRF to JIWRF Gas Pipeline													$44,967,000	$57,904,000
2	JIWRF New Turbine Generators													$71,233,000	$99,105,000
5	SSWRF New Engine Generators													$48,938,000	$71,808,000
8	SSWRF High Strength Waste													$136,212,000	$175,383,000
7	THP at SSWRF													$98,175,000	$104,644,000
4	JIWRF Landfill Gas Cleaning													$7,848,000	$9,702,000
9	SSWRF Digester Gas Cleaning													$20,217,000	$25,004,000
10	SSWRF Digester Gas Storage													$18,900,000	$24,334,000
13	Administration Facilities Renewable Energy													$4,087,000	$9,707,000
													Total	**$727,257,000**	**$865,368,000**
	Yearly Cost	$103,549,583	$54,104,083	$80,370,083	$292,462,083	$9,137,083	$9,137,083	$45,993,583	$9,137,083	$95,955,083	$9,137,083	$9,137,083	$9,137,083		
	Cumulative Cash Flow	$103,549,583	$157,653,667	$238,023,750	$530,485,833	$539,622,917	$548,760,000	$594,753,583	$603,890,667	$699,845,750	$708,982,833	$718,119,917	$727,257,000		

O&M and Process Improvements that are good practice	$109,645,000	$109,645,000
MMSD Implements Outside of Energy	$165,138,000	$228,817,000
Energy Plan Specific Improvements	$452,474,000	$526,906,000

6.5 Future Flow Projections Energy Effects

This section summarizes the impacts on energy consumption and gas generation due to projected flows. This report assumes that energy consumption and DG generation will change proportionally to the future flows. Average flows and energy consumption for 2018-2020 are used to determine the baseline side of the proportion. These calculations assume that there are no additional energy efficiency improvements other than those listed in **Section 2** and **3**. The 2050 Facilities Plan is used for projected flows and loadings.

Existing Flow

Existing flow data was analyzed and summarized below for 2018-2020.

- JIWRF: 109 MGD
- SSWRF: 100 MGD
- Conveyance: 209 MGD

Future Flow

The 2050 Facilities Plan projected future conditions and flows for population change for the conveyance system and WRFs. The future average flows from the 2050 Facilities Plan are listed below.

- JIWRF: 101 MGD
- SSWRF: 120 MGD
- Conveyance: 221 MGD

JIWRF

JIWRF is projected to decrease flows by 7.3%. Therefore, future energy demand is also projected to decrease by 7.3%. summarizes JIWRF's energy consumption and decrease.

Table 6-4: JIWRF Future Energy Consumption (MMBTU/yr)

Source	Alt 3 Consumption	After 7.3% Decrease
LFG	1,111,650	1,030,450
DG	0	0
PV Electricity	10,000	9,300
Total	1,121,650	1,039,750

SSWRF

SSWRF is projected to increase flows by 20%. Therefore, future energy demand at SSWRF is expected to increase by 20%. Total flow is expected to increase by 5.7%, therefore total gas production is also projected to increase by 5.7%. **Table 6-5** and **Table 6-6** summarize SSWRF's energy consumption and gas generation increase.

Table 6-5: SSWRF Future Energy Consumption (MMBTU/yr)

Source	Alt 3 Consumption	After 20% Increase
DG	493,450	592,100
PV Electricity	83,100	99,700
Total	576,550	691,900

Table 6-6: SSWRF Future Gas Generation (MMBTU/yr)

Fuel	Alt 3 Generation	After 5.7% Increase
DG	493,480	521,600

Conveyance System

The conveyance system is projected to increase flows by 5.7%. Therefore, future energy demand and production are also projected to increase by 5.7%.

Table 6-7: Conveyance System Future Energy Consumption (MMBTU/yr)

Source	Alt 3 Consumption	After 20% Increase
Electricity	9,160	11,000
Gas	2,100	2,520
Total	11,260	13,520

Administration Facilities

The administration facilities are unrelated to future flows and therefore there is no projected increase in energy.

Future Flow Projections Summary

Total energy consumption is projected to increase 35,520 MMBTU/yr. The electricity and gas increases are summarized below.

- Electricity: 17,740 MMBTU/yr
  - Equivalent to an additional 276,000 SF or 3,830 kW of PV installations
- Gas: 17,780 MMBTU/yr
- DG: 28,120 MMBTU/yr
  - 27,000 MMBTU/yr additional generation from increased flows.
  - 1,120 MMBTU/yr additional generation from additional food waste
    - Equivalent to 0.3 tons per day

Appendix A

Energy Review and Renewable

(TM-1)

Energy Plan for MMSD Facilities
Contract No. M03109P01

Technical Memorandum 1: Energy Review & Renewables

Milwaukee Metropolitan Sewerage District

October 26, 2021

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Executive Summary

The Milwaukee Metropolitan Sewerage District (MMSD) developed its 2035 Vision and Strategic Objectives (2035 Vision) in 2010. The 2035 Vision focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency and includes the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal, renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

A preliminary energy plan delivered to MMSD in January 2015 (the 2015 Energy Plan) outlined a roadmap to the 2035 Vision that focused on increasing renewable energy generation and implementing energy conservation measures. Since 2015, MMSD's energy goals, consumption, and generation have changed. Therefore, MMSD has commissioned an updated energy plan which reflects current realities to progress toward the 2035 Vision.

The tasks associated with the energy plan (defined by MMSD) will be presented in a series of technical memoranda. Technical Memorandum No. 1 (TM-1) – Energy Review and Renewables is the first of two technical memoranda which are part of Task B – Energy Planning and Review. TM-1 summarizes the findings of Subtasks B.1 through B.7 that analyze MMSD's energy consumption and generation, previous energy plans and reports, current renewable energy and efficiency practices, new renewable energy technologies, and energy storage opportunities. Additionally, TM-1 provides a recommendation for the core focus of this energy plan moving forward.

1.1 Summary of Work

The following are descriptions of the subtasks which are applicable to TM-1 and a summary of the work performed, including relevant findings:

Subtask B.1 Identification of Relevant Records

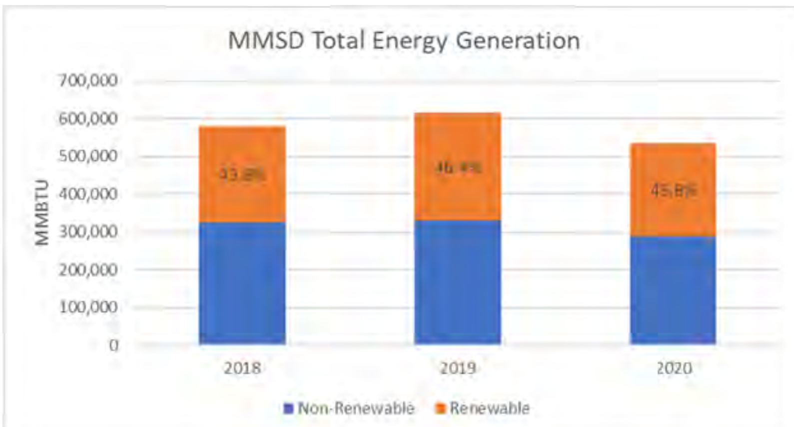
The purpose of Subtask B.1 was to develop a list of relevant records required to perform the study. These records include drawings, reports, previous energy and facility plans, energy consumption and generations records, utility bills, and equipment operations and maintenance (O&M) logs. Some of the records have been used for tasks associated with TM-1, while others will be used in the upcoming technical memorandums.

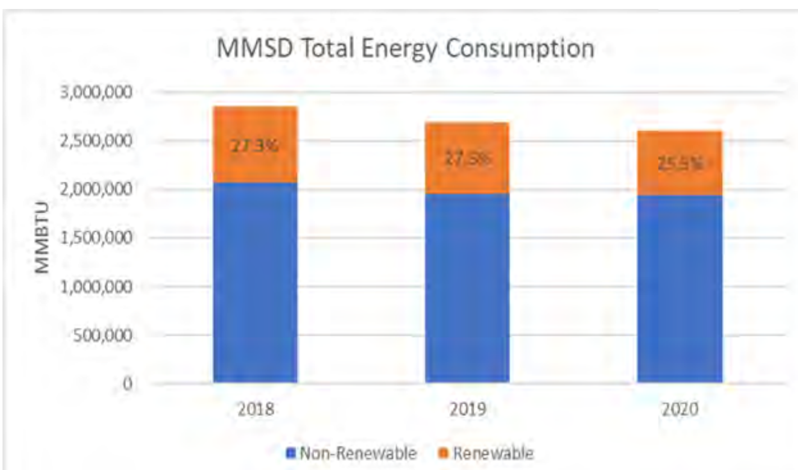
Subtask B.2 2015 Energy Plan Review

The goal of Subtask B.2 was to review alternatives (potential energy efficiency or renewable energy projects) presented in the 2015 Energy Plan and recommend which are suitable for further evaluation under Task C – Preliminary Engineering Services. Of the 97 alternatives reviewed from the 2015 Energy Plan, 67 are recommended to be evaluated further, 19 alternatives are not recommended, and a recommendation for the 11 remaining alternatives will be made after more information is received from MMSD. This list is included in Appendix A and will be updated as the project progresses.

Subtask B.3 Energy Generation and Consumption Analysis

The purpose of Subtask B.3 is to analyze the preceding three years of energy generation and consumption at all MMSD facilities, with a focus on renewable energy sources. Raw energy data for years 2018, 2019, and 2020 was provided by MMSD for each of its three asset areas: Administrative Facilities, Conveyance System, and Water Reclamation Facilities (WRFs). This analysis provides a baseline for current energy demand, generation capacity, and utilization of renewable energy sources, the most crucial indicator of progress towards the energy goals defined by MMSD's 2035 Vision. Renewable energy sources include digester gas (DG), landfill gas (LFG), photovoltaics (PV), wind, and waste heat generated from another renewable energy source. Total energy generation and consumption across all MMSD assets are summarized in the figures below:





Subtask B.4 Current Renewable Energy & Efficiency Practices

Subtask B.4 provides a high-level review of each renewable energy practice currently employed by MMSD in terms of O&M, system requirements, reliability, economics, potential opportunities for expansion, and possible challenges. MMSD currently utilizes renewable resources including LFG, DG, solar energy, and waste heat. At the Jones Island Water Reclamation Facility (JIWRF), LFG is used to fuel some sludge dryers in the Dewatering and Drying (D&D) facility and generate electricity using turbines. Waste heat from the turbines is also captured and directed to the dryers. At the South Shore Water Reclamation Facility (SSWRF), DG is produced by digesters and used to fuel facility boilers and generate electricity using combined heat and power (CHP) engines. At MMSD headquarters, solar energy is used to generate electricity using PV panels.

Subtask B.5 Landfill and Digester Gas Upgrade

LFG and DG are two types of biogas currently used by MMSD to meet a portion of its energy needs. Both are composed of methane (CH_4), carbon dioxide (CO_2), and varying levels of impurities such as siloxanes and hydrogen sulfide (H_2S). Biogas cleaning refers to the removal of impurities, whereas biogas upgrading refers to the removal of CO_2 to generate a product with CH_4 content similar to that of natural gas (NG) (typically 96% or above) known as Renewable Natural Gas (RNG). Therefore, RNG is suitable for end uses that require higher energy density and gas purity than non-upgraded biogas can deliver. MMSD does not currently upgrade biogas. Therefore, the purpose of Subtask B.5 is to evaluate the opportunity to improve biogas utilization by implementing one or more technologies to upgrade LFG and/or DG in support of MMSD's renewable energy goals.

There are several commercial technologies available for biogas upgrading, including membrane permeation, pressure swing absorption, solvent scrubbing, and water scrubbing. While not yet commercialized, Energy Tech Innovations, LLC (ETI) also demonstrated that their proprietary Water Wash process can effectively upgrade biogas according to the results of a pilot system operated at JIWRF. Each technology ultimately yields RNG but carries distinct advantages and disadvantages with varying relevance to individual applications [1]. Factors to consider include capital costs, ongoing operations and maintenance costs, energy intensity, resource intensity, ease of operation, footprint, composition of output RNG, process by-products, and availability of technical support [2]. To quantify the value of upgrading biogas to MMSD, target end uses of RNG should be clearly selected, opportunities for the use of by-products should be assessed, and advantages and disadvantages of different technologies should be compared to MMSD's unique operational needs and preferences.

Subtask B.6 Renewable Energy Technologies

The purpose of Subtask B.6 is to evaluate three renewable energy technologies currently not deployed be MMSD. The technologies include sewer heat recovery, wind energy, and wave energy from Lake Michigan. Additionally, an evaluation of geothermal energy was performed to provide MMSD with sufficient data to exclude this form of energy from future analyses.

Sewer heat recovery can primarily be used for facility heating, ventilation, and air conditioning (HVAC) loads; however, this accounts for a very small percentage of MMSD's total energy consumption (less than 1%). Wind energy is a viable renewable energy technology that is available everywhere at MMSD facilities. Wind power costs have decreased due to technological advancements and are one of the lowest-priced energy sources available today. Wave energy conversion is not presently competitive with other renewable energy sources from an economic standpoint for MMSD. However, it is likely that as the technology progresses, wave energy conversion will become more economically viable in the long term.

Geothermal energy is highly dependent on location and typically limited to parts of the world characterized by volcanic activity or along plate boundaries. Neither of which Milwaukee is near to.

Geothermal has the potential to become a major global energy source, however at the moment it is still held back by its high upfront costs in parts of the world where these geographic resources are not available near to the surface of the earth.

Subtask B.7 Alternative Energy Storage

The purpose of Subtask B.7 is to provide an overview of potential energy storage technologies which could help address variances in energy demand and generation and maximize the use of internally generated renewable energy sources. Types of energy storage include mechanical, electrochemical, thermal technologies, as well as various emerging technologies. Further investigation of technical challenges associated with different types of energy storage, an economic analysis, and coordination with the electric utility (We Energies) to determine system requirements and rate structures would be required to move forward with developing energy storage projects.

1.2 Recommendation

Based on our initial analysis of energy generation and consumption data performed in subtask B.3, MMSD is not currently on course to meet the bold, critical renewable energy goals set by the 2035 Vision. The Energy and Greenhouse Gas Emissions Data Management Final Report prepared for MMSD in 2019 presented a projection of the annual percentage growth rate (compared to the 2005 baseline) required to achieve net 100% renewable energy by 2035 [3]. This projection dictates that renewable energy should account for over 70% of MMSD’s energy consumption today [3]. By contrast, this metric has remained relatively stagnant for the last several years and currently falls more than 40% below the projected target [3]. To achieve the 2035 Vision, MMSD must make increases in renewable energy generation and consumption at an aggressive and unprecedented rate over the next 14 years. Significant financial investment will be needed to achieve MMSD's goals in the current timeline. A dedicated funding source would ensure that sustainability projects do not get passed over. Therefore, Greeley and Hansen (G&H) strongly recommends that the focus on this energy plan be narrowed to only those project alternatives identified in the 2015 Energy Plan with the potential to result in large gains in obtaining, producing, and utilizing renewable energy. Additionally, we recommend that only major process upgrades with the potential to considerably reduce non-renewable energy consumption are evaluated further. The urgency of realizing the 2035 Vision will require resources to be focused on proven, high-impact projects. G&H’s analysis of MMSD assets in Task C will target the energy project alternatives with the highest potential to help close the renewable energy gap.

Subtask B.1: Identification of Relevant Records

1.1 Record Identification and Request

Relevant records and other information necessary for the project were identified, requested, and reviewed as part of Subtask B.1. The information requested is summarized below.

General Information:

- MMSD baseline energy profile and distribution from Hach WIMS – spreadsheets for:
    - Energy consumption
    - Energy generation
        - Turbines
        - CHP systems
        - Solar Panels
    - GHG reporting
- Electrical, Gas, Water Bills for all MMSD Facilities – last 3 years
- MMSD Project M03102 – Biosolids Advanced Facility Plan (BAFP)
- MMSD Project M03029P34 – Biogas Upgrade Study
- MMSD Project – Aeration Process Upgrades at SSWRF
- All drawings and O&Ms for all facilities and equipment at those facilities
- Pump curves, fan curves, for large process equipment at the WRFs
- MMSD Vehicle fleet fuel consumption data/bills

Administrative Facilities:

- Architectural, Mechanical and Electrical Drawings
- Testing and Balancing and Commissioning Reports of HVAC Equipment
- HVAC and Electrical equipment O&M Logs

JIWRF:

- Architectural, Mechanical and Electrical Drawings
- D&D – Dryer Burner Upgrade Project – information on natural gas /LFG consumption
- LFG utilization at JIWRF
- General Electric (GE) turbines energy generation data
- GE turbines fuel consumption data
- GE turbines O&M logs
- Solar turbines energy generation data
- Solar turbines fuel consumption data
- Solar turbines O&M logs
- Boilers fuel consumption data
- Boilers O&M Logs

SSWRF:

- Architectural, Mechanical and Electrical Drawings

- DG generation and utilization at SSWRF, or Digester solids loading data
- White Superior CHP energy generation data
- White Superior CHP fuel consumption data
- White Superior CHP turbines O&M logs
- Caterpillar (CAT) CHPs turbines energy generation data
- CAT CHP fuel consumption data
- CAT CHP O&M logs
- Boilers fuel consumption data
- Boilers O&M Logs

Conveyance System:

- Pumping Stations Drawings
- Pump Operating Curves
- Pumps O&M Logs
- Boilers fuel consumption data
- Boilers O&M Logs

Subtask B.2: 2015 Energy Plan Review

2.1 Introduction

MMSD developed its 2035 Vision in 2010. The 2035 Vision focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency and includes the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal, renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

The 2015 Energy Plan outlined a roadmap to the 2035 Vision that focused on increasing renewable energy generation and implementing energy conservation measures. Since 2015, MMSD's energy goals, consumption, and generation have changed. Therefore, MMSD has commissioned an updated energy plan which reflects current realities in order to remain on course toward the 2035 Vision.

MMSD's objective is to build upon the work completed to date. Therefore, the first step of this project was to review the 2015 Energy Plan, which presented numerous alternatives for potential energy efficiency or renewable energy projects as possible steps toward the 2035 Vision. The goal of this review was to evaluate the 2015 Energy Plan alternatives and recommend which should be evaluated further as part of Task C – Preliminary Engineering Services. Task C will further define MMSD's energy demand, identify alternatives to be implemented, and develop overall energy plans for each of MMSD's asset areas. Multiple meetings were held with MMSD staff to discuss the background of the alternatives, how they fit in with other existing projects, and MMSD's preferences.

2.2 Review of the 2015 Energy Plan

The 2015 Energy Plan identified and evaluated 97 alternatives, including two alternatives that have sub-alternatives a and b, based on the following evaluation criteria:

- Was the alternative appropriate for the 2035 Vision?
- Did the alternative have a significant energy reduction potential (>~500kW, 670 hp, 1.7 MMBTU/HR or ~1% of MMSD energy)?
- Was the alternative implementable without construction capital expenditure?
- Was the alternative implementable for low capital cost (<~$1 to $5M) or have minimal process impacts?
- Did the alternative have strategic value?

Of the alternatives initially evaluated, the 2015 Energy Plan concluded that 37 alternatives would be effective and merited further evaluation by providing:

- A description of the alternative and how it would be implemented
- Estimated capital and operation and maintenance costs
- Estimated amount of renewable energy that could be generated or the amount of energy use reduction

To obtain a better understating of the current status of alternatives identified in the 2015 Energy Plan, three virtual meetings were held with MMSD staff on January 27, February 11, and April 19 of 2021 to review the background, status and correlation with ongoing projects of each alternative. The alternatives were then reviewed qualitatively using information provided during the meetings, with Appendix 5E of the 2050 Facilities Plan, and based on previous experiences with similar alternatives or scenarios.

The results of the review are summarized in Appendix A, which includes the alternative name and number consistent with the 2015 Energy Plan, comments from MMSD, additional comments provided by G&H, and an initial high-level recommendation for further evaluation in Task C.

Of the 97 alternatives reviewed, 67 have been initially identified as potential candidates to be evaluated in detail as part of Task C. Some alternatives should be evaluated in conjunction with other alternatives, as noted in the "G&H Additional Comments" column in Appendix A. With more information and knowledge of MMSD assets in Task C, the evaluation will be narrowed to those alternatives that will substantially increase renewable energy generation and consumption and to the alternatives that can considerably reduce power consumption for energy intensive processes.

Recommendations for 7 alternatives will be made after the BAFP is completed by others. 19 alternatives are not recommended due to requiring a large footprint or overhaul of an existing process, or is a new technology that is not fully proven and has inherent risks. 4 alternatives have already been implemented and do not require a recommendation.

The list of alternatives in Appendix A will be revisited throughout this project to refine the alternatives and recommendations.

Subtask B.3: Energy Generation and Consumption Analysis

3.1 Introduction

The purpose of Subtask B.3 is to analyze the preceding three years of energy generation and consumption at all MMSD facilities, with a focus on renewable energy sources. Raw energy data for years 2018, 2019, and 2020 was provided by MMSD for each of its asset areas, including Administrative Facilities, Conveyance System, and WRFs. The data set is comprised of electric and gas utility bills and internal metering of energy consumption by major equipment, generation by turbines and engines, and waste heat utilization. This analysis provides a baseline for current energy demand, generation capacity, and utilization of renewable energy sources.

Use of renewable fuel sources, including use of electricity generated by renewable fuels, is the most crucial indicator of progress towards the energy goals defined by MMSD's 2035 Vision. Therefore, it is critical to define what constitutes a renewable energy source in order to consistently measure progress over time. The 2015 Energy Plan defined energy derived from DG, LFG, PV cells, wind, and all waste heat as renewable. For the purposes of this energy plan, MMSD has chosen to revise this definition to classify waste heat as renewable only when it has been generated by a renewable energy source (i.e. waste heat collected from a turbine operating on LFG). Waste heat generated by a non-renewable source such as NG will be considered non-renewable.

For ease of comparison, total consumption and generation quantities are presented in MMBTU throughout the analysis. Values are also presented in the units most commonly used to refer to specific forms of energy, i.e. electricity in. kW or MW, gas in therms or Dth, and heat in BTU (Appendix C). Accordingly, values for NG, DG, and LFG are reported in therms. A therm is a unit of energy equivalent to 99,976.1 BTU, or approximately equivalent to the heat energy contained in 100 CF of NG. All calculations in this analysis assume that raw data values reported in therms accurately represent the energy content of the gas irrespective of variations in energy density and volumetric flow rate of the gas stream being metered.

This analysis is divided into sections corresponding to MMSD's asset areas: Administrative Facilities, Conveyance System, and WRFs. Administrative Facilities include the Headquarters Building (260 W. Seeboth St), Administrative Building and Garage (6060 S. 13th St.). The Conveyance System includes all gas and electric utility meter accounts at pump stations or other conveyance system properties, which are listed in Appendix B. WRFs include SSWRF and JIWRF, as well as the Inline Storage System (ISS) pumps.

3.2 Energy Generation

3.2.1 Administrative Facilities

Energy is generated by PV cells located at the Headquarters Building. This energy is considered renewable in its entirety and directly offsets purchased, non-renewable utility electrical energy. Table 1 summarizes the PV energy generation by year.

Table 1: Administrative Facilities Energy Generation by Source

Energy Generation by Source (MMBTU)	
Year	Electricity
2018	24.0
2019	33.5
2020	39.0

3.2.2 Conveyance System

The Conveyance System does not generate any energy.

3.2.3 Jones Island Water Reclamation Facility

JIWRF generates energy with three (3) Solar and two (2) GE turbines. The Solar turbines are dual-fuel and can operate on either LFG or NG. The availability of LFG varies, but it is prioritized when available. Between 2018-2020, the Solar turbines operated on LFG 55% of the time and NG 45% of the time. The GE turbines are also dual-fuel and can operate on either NG or fuel oil. However, NG is used almost exclusively. Currently only GE turbine #1 is permitted to operate. GE turbine #2 is disconnected from fuel supply, combustion air intake, and the power distribution systems. There is an ongoing project to re-commission GE #2 for limited use. Energy generation data was analyzed by fuel source and equipment type. Table 2 and Figure 1 summarize energy generation by source while Table 3 and Figure 2 summarize energy generation by equipment.

Note that total waste heat generated by the turbines is not explicitly measured. Waste heat is captured during turbine operation and conveyed to dryers in the D&D Facility via ductwork or exhausted through a stack. Only the amount of waste heat used beneficially by the dryers is quantified in the raw data set, and it is unknown to what extent excess waste heat is exhausted. Therefore, the values presented in Table 2 and Table 3 for waste heat generation exclude any waste heat that is exhausted or otherwise lost. Therefore, for the purpose of this analysis, waste heat generated is assumed to equal waste heat utilized by the dryers.

Table 2: JIWRF Energy Generation by Source

Energy Generation by Source (MMBTU)			
Year	Electricity (from NG)	Electricity (from LFG)	Waste Heat
2018	109,505	125,254	241,815
2019	178,326	125,574	205,441
2020	219,441	109,318	134,509

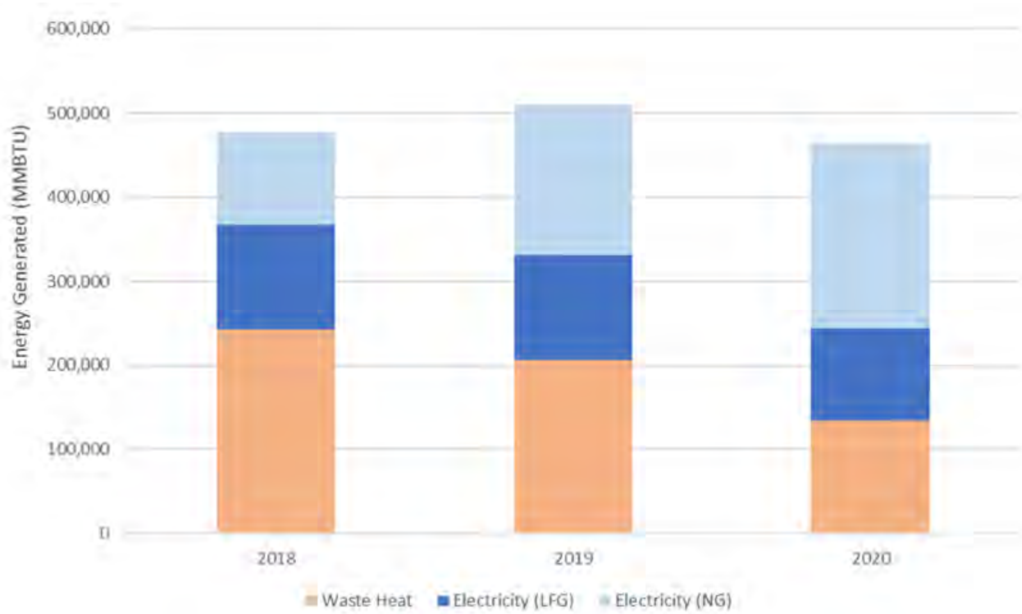


Figure 1: JIWRF Energy Generation by Source

Table 3: JIWRF Energy Generation by Equipment

Energy Generation by Equipment (MMBTU)				
Year	Solar Turbines Electricity (from NG)	Solar Turbines Electricity (from LFG)	Waste Heat (from Solar Turbines)	GE Turbines Electricity (from NG)
2018	78,027	125,254	241,815	31,478
2019	111,835	125,574	205,441	66,492
2020	145,334	109,318	134,509	74,107

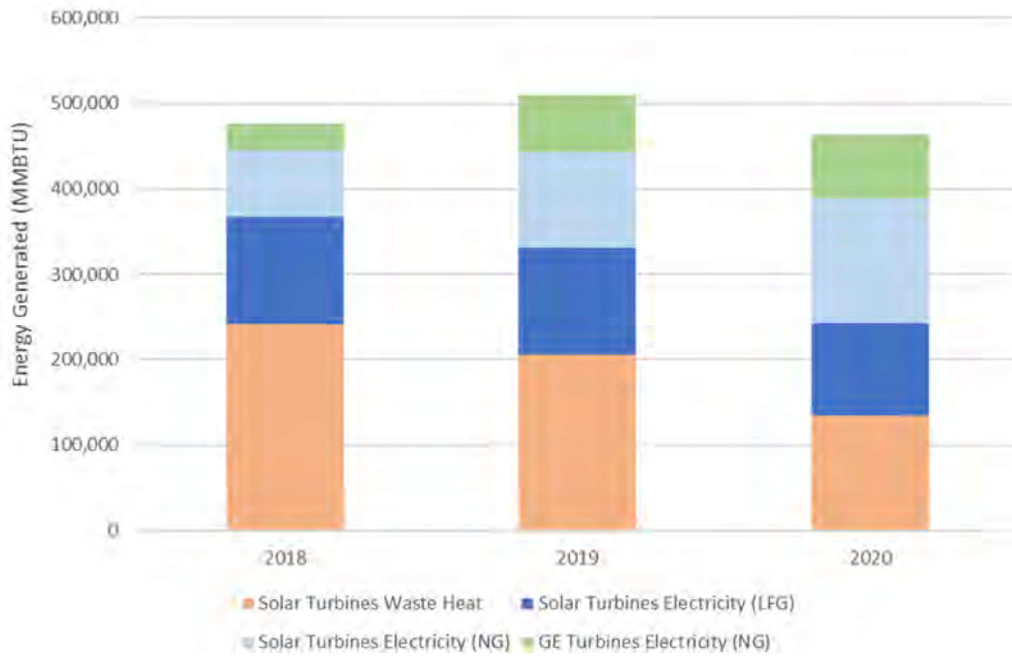


Figure 2: JIWRF Energy Generation by Equipment

3.2.4 South Shore Water Reclamation Facility

SSWRF generates energy with one (1) White Superior and four (4) CAT CHP engines.

Both the White Superior and CAT engines are dual-fuel and can operate on either NG or DG. Between 2018 and 2020, the White Superior engine operated on NG for an average of 66% of the time and DG 34% of the time. Over the same timeframe, the CAT engines operated on NG for an average of 17% of the time and DG 83% of the time. Beginning in March 2020, operations were adjusted to supply 100% of available DG to the CAT engines. The White Superior engine is no longer consistently used. Energy generation data was analyzed by fuel source and equipment type. Table 4 and Figure 3 summarize energy generation by source while Table 5 and Figure 4 summarize energy generation by equipment.

Table 4: SSWRF Energy Generation by Source

Energy Generation by Source (MMBTU)		
Year	Electricity (from NG)	Electricity (from DG)
2018	42,639	61,252
2019	35,515	70,010
2020	11,126	60,531

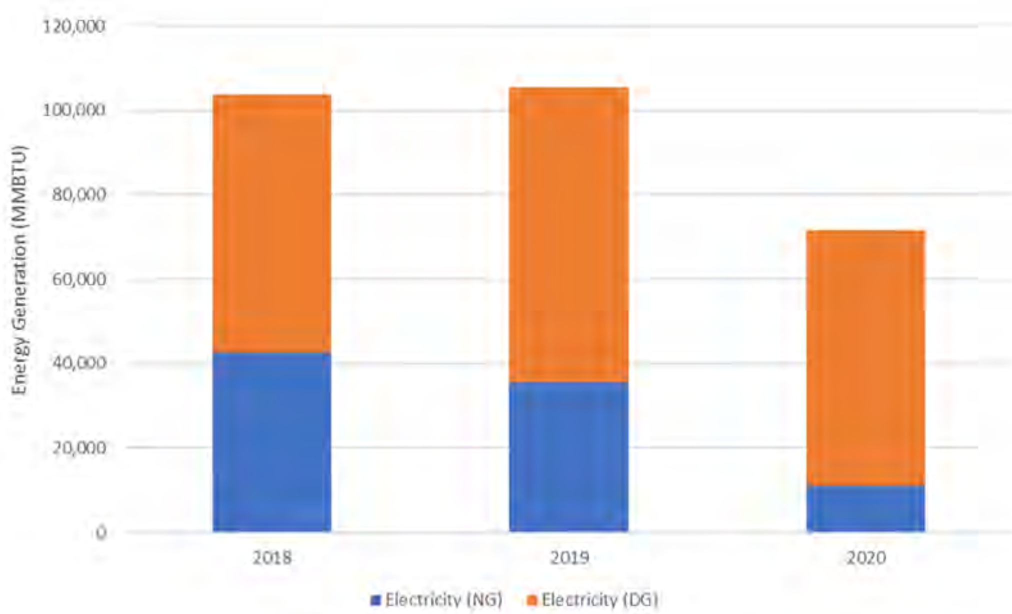


Figure 3: SSWRF Energy Generation by Source

Table 5:SSWRF Energy Generation by Equipment

Energy Generation by Equipment (MMBTU)				
Year	White Superior Electricity (from NG)	White Superior Electricity (from DG)	CAT Electricity (from NG)	CAT Electricity (from DG)
2018	36,062	384	6,193	60,868
2019	8,025	18,933	8,557	51,077
2020	123	2,954	8,050	57,577

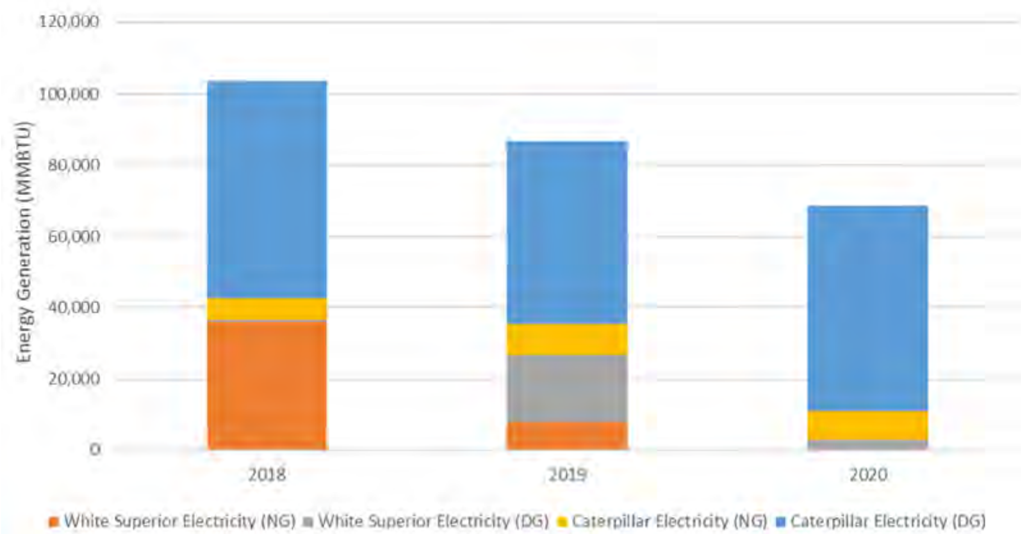


Figure 4: SSWRF Energy Generation by Equipment

3.3 MMSD Total Energy Generation

Total energy generation across all MMSD assets is shown in Table 6 and Figure 5 below.

Table 6: MMSD Total Energy Generation

MMSD Total Energy Generation (MMBTU)				
Year	Non-Renewable	Renewable	Total	% Renewable
2018	326,054	254,435	580,489	43.8%
2019	329,290	285,610	614,900	46.4%
2020	289,789	245,176	534,965	45.8%

Figure 5: MMSD Total Energy Generation

3.4 Energy Consumption

3.4.1 Administrative Facilities

Energy consumed by Administrative Facilities at the Headquarters Building, Administrative Building and Garage includes purchased utility electricity and NG, both from non-renewable sources, and electricity generated internally by PV cells. Table 7 and Figure 6 summarize the administrative facilities energy consumption by Source, per year.

Table 7: Administrative Facilities Energy Consumption by Source

Energy Consumption by Source (MMBTU)				
Year	Electricity		Gas	% Renewable
	Non-Renewable	Renewable	Non-Renewable	
2018	8,559	24	28,570	0.06%
2019	8,801	34	30,710	0.08%
2020	8,054	39	19,250	0.14%

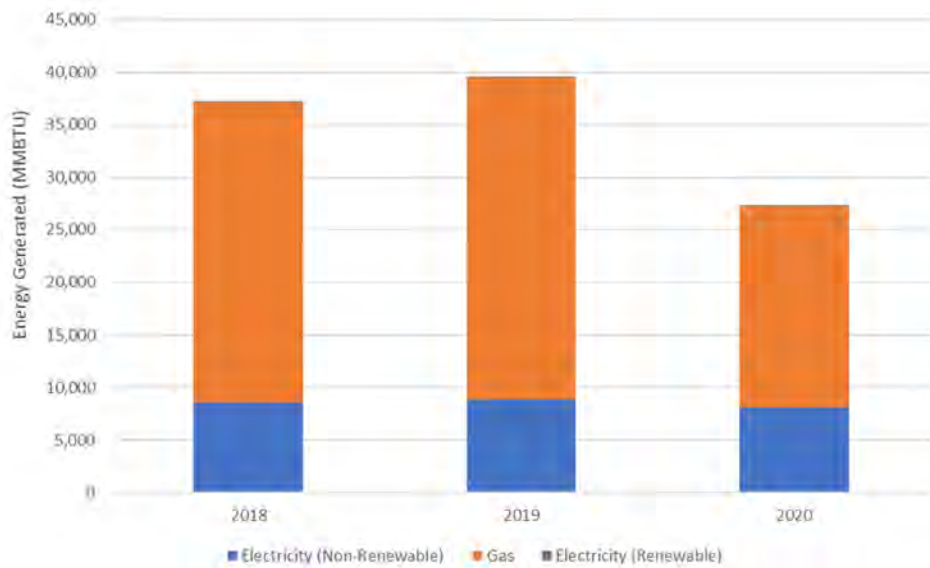


Figure 6:Administrative Facilities Energy Consumption by Source

3.4.2 Conveyance System

Energy consumed by the Conveyance System includes purchased utility electricity and NG. The Conveyance System does not consume energy generated from a renewable source. Table 8 and Figure 7 summarize Conveyance System energy consumption by source.

Table 8: Conveyance System Energy Consumption by Source

Energy Consumption by Source (MMBTU)			
Year	Electricity	Gas	% Renewable
2018	2,991	2,583	0%
2019	3,110	2,367	0%
2020	2,113	1,303	0%

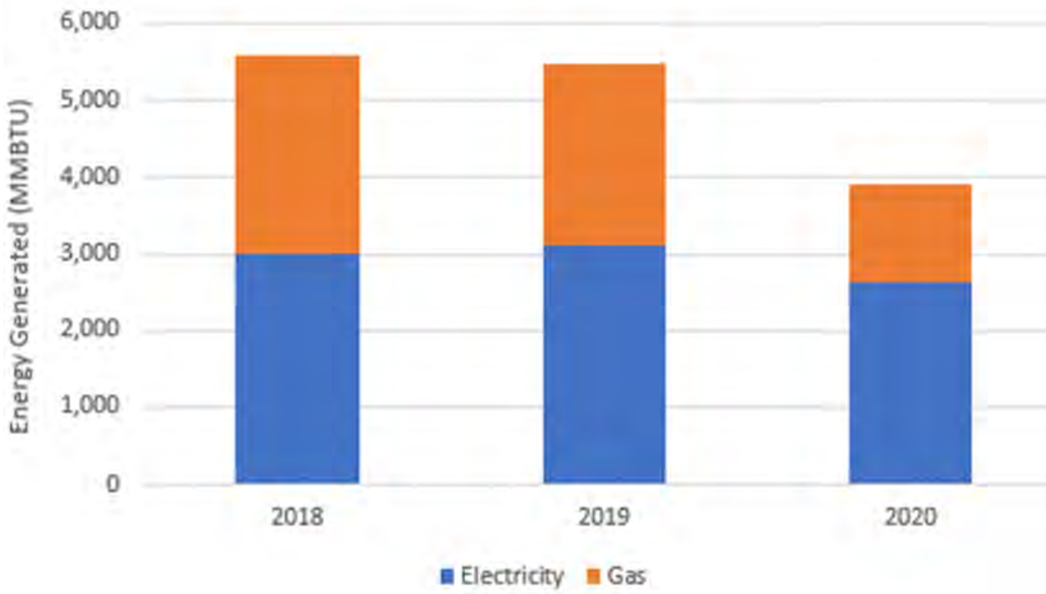


Figure 7: Conveyance System Energy Consumption by Source

3.4.3 Jones Island Water Reclamation Facility

Energy consumed at JIWRF includes purchased electricity, NG, fuel oil, as well as purchased LFG and internally generated waste heat which is considered partly renewable as described before. Major energy consumers metered at JIWRF include drum dryers housed in the D&D Facility, and the ISS pumps which convey stored wastewater to one of the WRFs for treatment. “I3” was referenced in the raw data set and is believed to be a NG meter for miscellaneous HVAC and other loads. The decrease in the percent of renewable energy can be attributed to limited LFG availability due to recovery equipment O&M and downtime. Energy consumption data was analyzed by fuel source and equipment type. Table 9 and Figure 8 summarize energy consumption by source while Table 10 and Figure 9 summarize energy consumption by equipment. On average, about 20% of energy consumed at JIWRF comes from renewable sources.

Table 9: JIWRF Energy Consumption by Source

Energy Consumption by Source (MMBTU)					
Year	Utility Purchased	LFG	Waste Heat		% Renewable
	(Non-Renewable)	(Renewable)	(Renewable)	(Non-Renewable)	
2018	1,721,824	346,805	173,910	67,905	22.54%
2019	1,651,244	335,587	115,448	89,993	20.57%
2020	1,709,052	297,556	59,221	75,287	16.66%

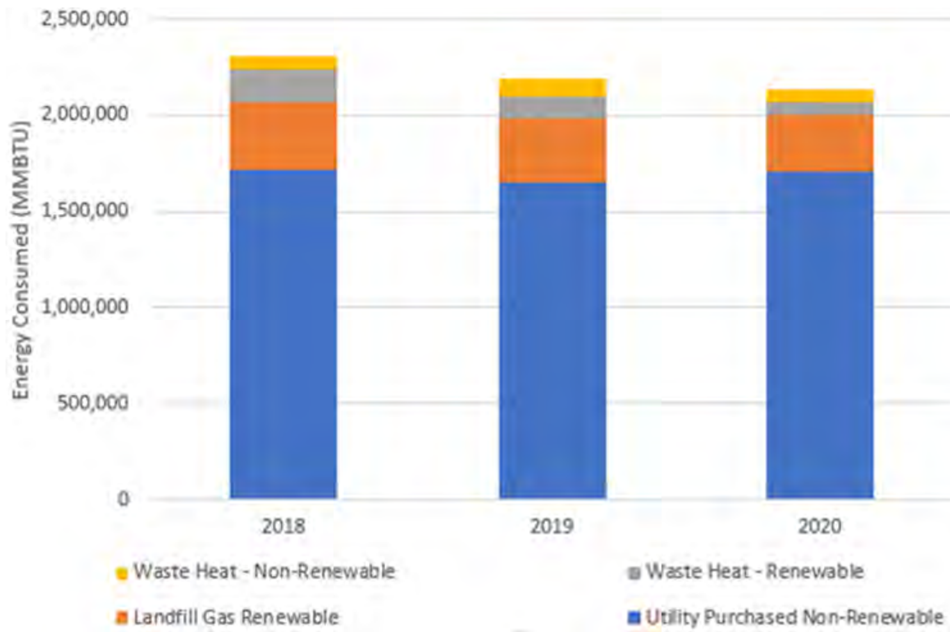


Figure 8: JIWRF Energy Consumption by Source

Table 10: JIWRF Energy Consumption by Equipment

Energy Consumption by Equipment (MMBTU)											
Year	Solar Turbines NG	Solar Turbines LFG	GE Turbines NG	Boilers Oil	Boilers NG	I3 NG	Dryer NG	Dryers LFG	Dryers WH	ISS Pumps Elec	Other
2018	208,679	346,805	637,679	61	13,272	87	675,945	0	241,815	44,491	141,609
2019	294,608	335,587	394,662	322	12,877	88	686,814	0	205,441	60,047	201,826
2020	375,686	287,769	346,400	809	7,344	1,019	760,000	9,787	134,509	49,125	168,668

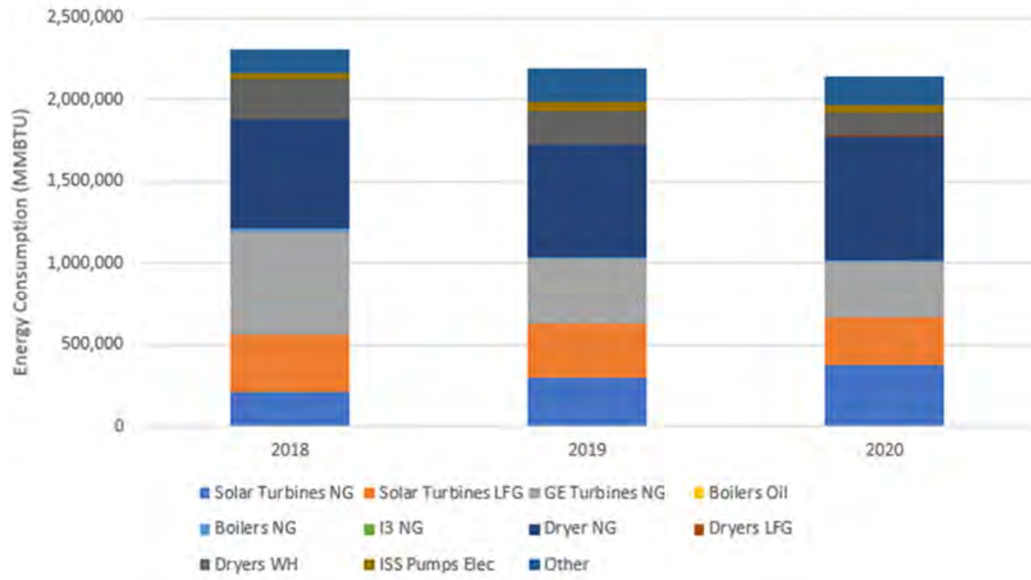


Figure 9: JIWRF Energy Consumption by Equipment

3.4.4 South Shore Water Reclamation Facility

Energy consumed at SSWRF includes purchased electricity, NG, fuel oil, internally generated DG, and internally generated waste heat. Energy consumption data was analyzed by fuel source and equipment type. Table 11 and Figure 10 summary energy consumption by sources while Table 12 and Figure 11 summarize energy consumption by equipment. SSWRF has been consistently increasing the portion of its energy consumption met by renewable sources, growing from about 50% in 2018 to 70% in 2020.

Table 11: SSWRF Energy Consumption by Source

Energy Consumption by Source (MMBTU)			
Year	Utility Purchased (Non-Renewable)	DG (Renewable)	% Renewable
2018	241,849	259,692	51.78%
2019	168,906	290,514	63.23%
2020	127,524	307,334	70.67%

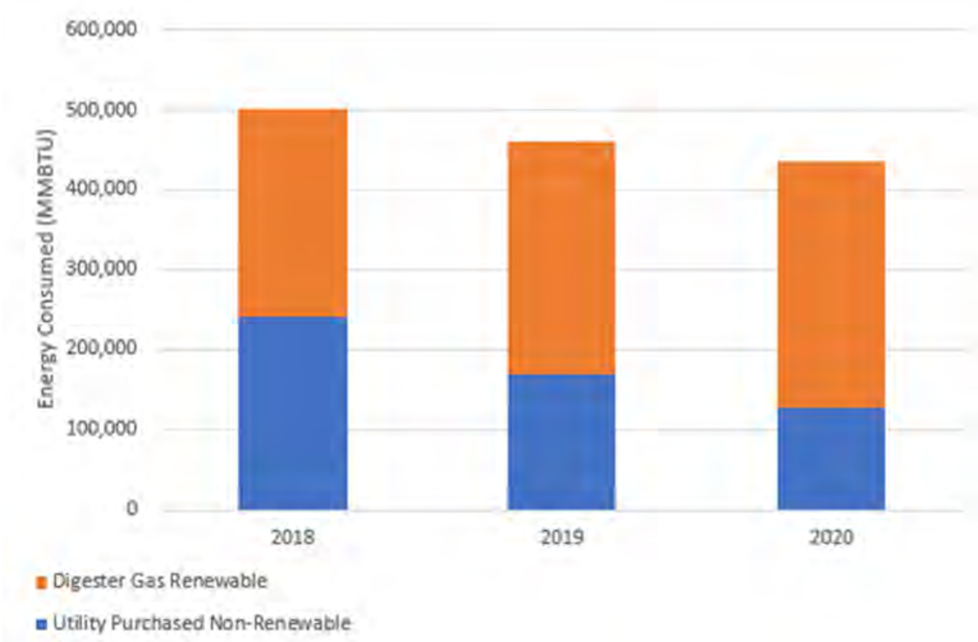


Figure 10: SSWRF Energy Consumption by Source

Table 12: SSWRF Energy Consumption by Equipment

Energy Consumption by Equipment (MMBTU)							
Year	White Superior CHP (NG)	White Superior CHP (DG)	Caterpillar CHP (NG)	Caterpillar CHP (DG)	Boilers (NG)	Boilers (DG)	Other
2018	122,742	1,326	18,903	206,118	12,801	52,248	87,404
2019	26,881	60,105	27,006	171,350	15,169	59,059	99,849
2020	379	8,746	36,240	224,605	12,576	73,983	78,330

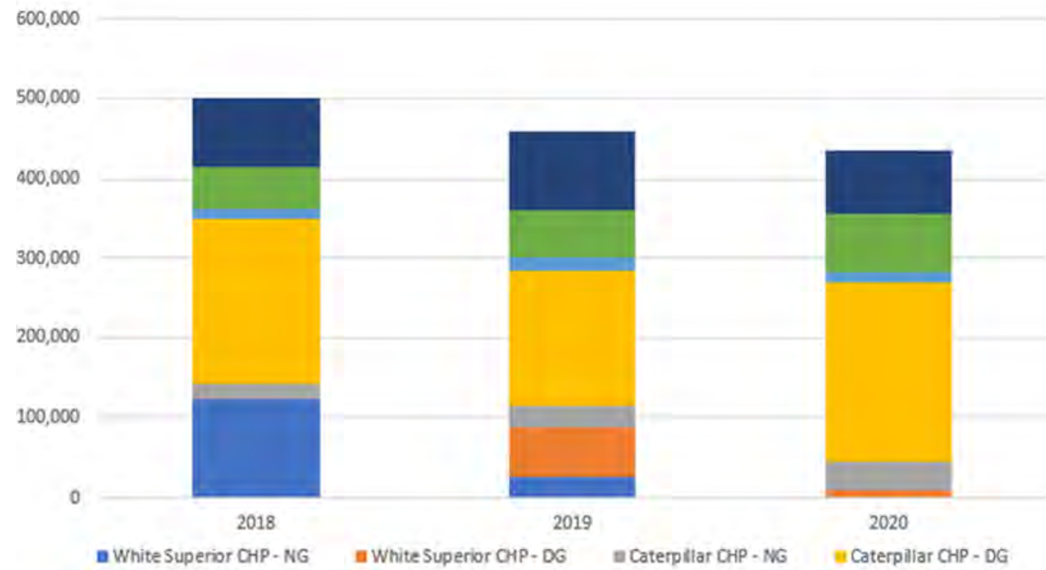


Figure 11: SSWRF Energy Consumption by Equipment

3.5 MMSD Total Energy Consumption

Total energy consumption of non-renewable and renewable energy sources across all MMSD assets is shown in Table 13 and Figure 12 below.

Table 13: MMSD Total Energy Consumption

MMSD Total Energy Consumption (MMBTU)				
Year	Non-Renewable	Renewable	Total	% Renewable
2018	2,074,282	780,431	2,854,713	27.3%
2019	1,955,131	741,582	2,696,714	27.5%
2020	1,943,088	664,150	2,607,238	25.5%

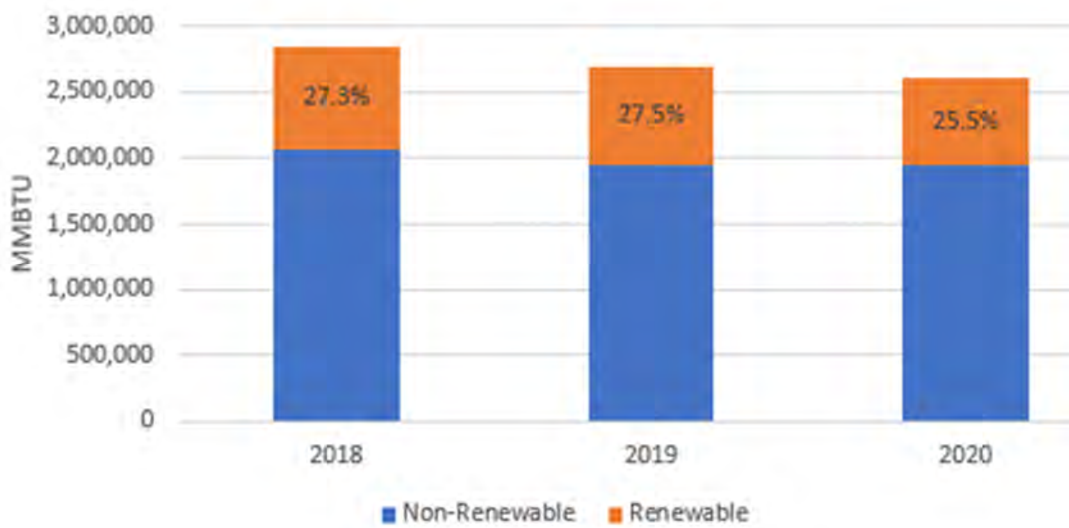


Figure 12: MMSD Total Energy Consumption

Subtask B.4: Current Renewable Energy and Efficiency Practices

4.1 Introduction

The following sections provide a high-level review of each renewable energy practice currently employed by MMSD in terms of O&M, system requirements, reliability, economics, potential opportunities for expansion, and possible challenges. MMSD currently utilizes renewable resources including LFG, DG, solar energy through the use of PV cells, and waste heat.

4.2 Landfill Gas

MMSD uses LFG at the JIWRF which is received via pipeline from the Emerald Park Landfill (EPL). The gas is used primarily by the Solar turbines which generate electricity and waste heat, and three drum dryers which are dual fuel gas fired and dry the solids in the production of MMSD's biosolids Class A, commercially known as Milorganite™. A fourth dual fuel dryer is expected to be available for use in July 2021.

4.2.1 Operations and Maintenance

O&M of the LFG system includes maintaining the LFG pipeline, valves, meters, compressors, and equipment. The system must also be monitored for wear and leaks to prevent hazardous conditions. Leaks can be detected by comparing the oxygen levels at access points throughout the pipeline, monitoring for excessive vacuum loss, and listening for "hissing" or "sucking" sounds in the system. Leaks are also detected by odor as the LFG is odorized and by the methane detection system.

LFG is of lower quality than utility NG which causes increased wear on compressors and combustion equipment, however the extent to which is difficult to predict as it depends on the multiple components of LFG. Wear is primarily due to the increased work to compress the CO2 and N2 present in the LFG. Siloxane build-up also affects the lifetime of the Solar turbine recuperator.

MMSD has an O&M agreement with Utility Safety & Design, Inc. to maintain the pipeline itself. This includes routine inspections, leak surveys, corrosion monitoring, condensate monitoring, odorization checks, and additional emergency services.

4.2.2 System Requirements

The LFG system includes the pipeline from the EPL to JIWRF, metering station, facility distribution piping, and dual fuel consumption equipment including the dual fuel dryers and Solar turbines. Flow between EPL and JIWRF depends on turbine or dryers demand, otherwise excess gas is flared at the EPL.

4.2.3 Reliability

MMSD receives LFG from the EPL via a purchase agreement with GFL Environmental. Gas availability and quality is dependent on landfill loading conditions, environmental factors, and treatment system performance.

Currently the gas contains about 50%-55% methane, however methane content in LFG can vary between 45%-60%. Factors that increase the methane content include increasing organic waste content, higher moisture content, and stable, optimal temperature conditions [4].

4.2.4 Economics

MMSD currently pays $2.112 per MMBTU of LFG, while NG rates have been at historical lows at around $2-$3 per MMBTU and are trending to stay that way. Both values can assume an increase of 1% per year due to inflation.

LFG processing costs are included in the cost of the gas, however O&M costs of conveyance piping, components, and equipment including compressors and turbines are incurred by MMSD. MMSD has a management, operation, maintenance, and emergency response agreement for the pipeline with Utility Safety & Design, Inc. for a fixed fee amount of approximately $27,000 quarterly. This amount does not account for the additional maintenance for processing equipment that may be required due to LFG not being as high quality as NG as well as additional energy consumed by compressors for the Solar turbines.

The equipment O&M cost varies by end use equipment. The estimated O&M costs for the compressors are approximately $16,000 per compressor annually. Estimated costs for maintenance and repairs for turbines are about $0.0144 per kWh generated [5]. Assuming current production, this equates to about $1,050,000 per year of O&M costs. This O&M cost estimate is assumed to be conservative since the turbines split time on NG and LFG and this calculation assumes the entire generation from LFG.

4.2.5 Potential Expansion

The gas available can be increased dependent on landfill loading. There is also the potential to connect additional landfills to the system, greatly increasing the available renewable resource.

4.2.5.1 Opportunities

If LFG is cleaned to RNG quality, there is the potential to blend the RNG with the utility NG distribution system. This would allow additional flexibility for the end use of the gas. However, due to the large consumption of the solar turbines and available dual fuel dryers, this may not be needed.

4.2.5.2 Challenges

LFG is not produced internally. While it does greatly assist in the effort to meet MMSD's goal to meet a net 100% of energy needs with renewable energy resources, it does not help MMSD in meeting the 80% of energy needs with internal, renewable sources. Equipment availability is also a challenge to using LFG. If either equipment at the EPL or JIWRF is down, MMSD cannot utilize this renewable resource.

4.3 Digester Gas

DG is produced and consumed at the SSWRF. The primary gas consumers are the White Superior and CAT CHP engines and the boilers.

4.3.1 Operations and Maintenance

O&M of the DG system is very similar to the LFG system. This includes maintaining the DG pipeline, valves, meters, compressors, and equipment. The system must also be monitored for wear and leaks to prevent hazardous conditions. Leaks can be detected by comparing the oxygen levels at access points throughout the pipeline, monitoring for excessive vacuum loss, and listening for "hissing" or "sucking" sounds in the system.

DG is of lower quality than utility NG which causes increased wear on compressors and combustion equipment, however the extent to which is difficult to predict. Increase wear is due to the additional work required to compress the CO2 in the DG. SSWRF treats the gas and is looking to further clean and potentially upgrade the gas for further efficiency. This treatment reduces the wear on the engines and equipment.

4.3.2 System Requirements

The DG system includes the gas capture components from the digesters, associated piping, compressors, and dual fuel equipment. Subtask B.5 goes into detail regarding an ongoing study to clean the DG, which is another component associated with the DG distribution system.

4.3.3 Reliability

DG is considered a reliable renewable resource. DG production is directly proportional to the facility energy demand as an increase in sewage treatment volume results in increased DG production.

DG contains around 60% methane by volume. This number varies based on the percentage of organics in the digested sludge. As organic material increases, DG production increases.

4.3.4 Economics

DG is produced internally and the only cost associated is to clean the gas, and to maintain the distribution system and equipment. If DG is cleaned and upgraded to RNG it can be used internally to supply equipment that relies on NG or it can be sold externally becoming a consistent source of revenue at a prime value.

The value of RNG is highly dependent on geographic location, end use, and availability. Some large private corporations across the United States have become interested in buying RNG as part of their energy consumption portfolio to demonstrate commitment to the renewable energy and greenhouse gas (GHG) emissions reduction. In those cases, RNG has been sold for as high as $15 per MMBTU. Another common use is in transportation where RNG can fetch as much at $18 per MMBTU due to the Renewable Fuel Standard (RFS) legislation which categorizes RNG from wastewater treatment process as a D3 renewable identification number (RIN). Similar to other commodities, the value of a RIN depends on the market and it's highly volatile as it depends on supply, demand and the policies of the administration on duty [5].

NG rates have been at historical lows at around $2-$3 per MMBTU and are trending to stay that way. Gas values can assume an increase of 1% per year due to inflation.

The cost of DG cleaning and processing is dependent on the process used, cost of electricity, and the volume processed. A water-wash process is currently being evaluated for DG cleaning at MMSD through a pilot system. The preliminary results of this pilot study indicate this process costs approximate $0.043 per MMBTU to upgrade DG to RNG.

O&M costs of conveyance piping, components, and equipment including compressors are incurred by MMSD. The O&M cost varies by end use equipment. The estimated O&M costs for the compressors are approximately $16,000 per compressor annually. Costs for maintenance and repairs for CHP engines are about $0.0298 per kWh generated. This number was provided by MMSD and Veolia from a Black and Veatch study of SSWRF's engine operation and maintenance costs. Assuming current production, this equates to about $600,000 per year. This estimated cost is assumed to be conservative because the engines use both NG and DG and the O&M cost calculation assumes the entire generation is from DG. The O&M costs from using a combination of NG and DG would potentially be lower.

4.3.5 Potential Expansion

All MMSD DG is produced at SSWRF. There is the potential to expand the system to send gas to JIWRF where there is a more consistent load requirement from the dryers at the D&D Facility. This project will represent a major capital investment for MMSD due to the distance between both WRFs. Once DG production exceeds the minimum demand for SSWRF, either on-site storage, conveyance to JIWRF or upgrading to RNG for external stakeholders must be considered.

4.3.5.1 Opportunities

DG can be cleaned to higher quality and connected to facility NG distribution pipe network to serve equipment. This would allow for more flexibility in consumption location and will limit the amount of DG flared which currently accounts for about 40% yearly. SSWRF does have the capacity to use the majority of the DG produced, however the dual fuel CHP engine reliability and uptime has been an issue in achieving this.

DG is a renewable, internally generated source of energy and can significantly assist to meet MMSD's goals of 100% net renewable energy generation and 80% generation from internal, renewable sources.

4.3.5.2 Challenges

DG contains significant amounts of siloxanes, which when combusted, can cause increased operation and maintenance due to silicon buildup in engines or boilers. SSWRFs treatment system to remove siloxanes addresses this challenge. The primary challenge to SSWRF consuming DG is the CHP engine uptime and reliability.

4.4 Solar Panels

4.4.1 Operations and Maintenance

MMSD currently generates energy from solar panels, more specifically known as PV panels, at its Headquarters Building. PV panels work by collecting photons of light from the sun to knock electrons free from atoms, generating an electric current. The energy generated by the PV panels is instantaneously used by building demand from lighting, air conditioning, or other miscellaneous building loads.

PV panels require routine maintenance including ensuring panels are not obstructed from sunlight by vegetation, dirt, or snow. System maintenance includes ensuring all connections are tight, equipment is free from corrosion, and any roof penetrations are watertight. Visual inspections for burn marks, defects, or damage on all components should be performed at least yearly.

Energy generation should be tested yearly to ensure the system is operating at peak efficiency.

4.4.2 System Requirements

The PV system includes the panels, direct current (DC) disconnect, DC breaker, Inverter, alternate current (AC) disconnect, AC beaker connection, electrical distribution wires, and any metering equipment.

All electrical systems require monitoring for efficiency and safety purposes. Energy generation should also be monitored to ensure the system is operating as intended.

4.4.3 Reliability

PV arrays are most efficient and cost effective when in direct sunlight. They are weather dependent and do not produce energy at night. Even with these considerations, solar energy is considered abundant, stable and predictable.

PV panels often include 25-year warranties and can generate electricity reliably for over 30 years. Cell degradation must be considered; however, cells typically lose less than 1% of its efficiency each year. Therefore, after 25 years a panel may be operating at 75%-80% of its installed generation rating.

The inverter typically lasts 10-15 years.

4.4.4 Economics

The cost benchmark for a US commercial scale PV system has been continually decreasing for the past 10 years. For 2018, the installation costs were about $1.83/W-DC installed for a 200 kW-DC system [6, p. vi]. The cost per direct current watt decreases as scale increases.

Yearly operation and maintenance can be averaged to about $18/kW/year. So, a 200 kW-DC system would cost around $3,600 per year to maintain [6, p. 28].

The value of PV energy produced varies by state, utility, time of day, and other factors. It is generally more economical to utilize solar energy produced internally to than sell it. This is because utilities charge consumers more for solar energy than they pay to purchase it from generators. However, once MMSD's energy demand is exceeded by the supply of energy produced from renewable sources, an economic analysis must be performed to determine whether selling or storing excess solar energy is best.

4.4.5 Potential Expansion

There is the potential to install approximately 83,500 m^2 of PV panels above process tanks at both JIWRF and SSWRF. Using Natural Renewable Energy Laboratory's (NREL) PVWatts photovoltaic calculator, this equates to a 13.3 MW-DC system which could produce around 17,750 MWh-AC (60,500 MMBTU) per year. Using the data compiled in Subtask B.3, this equates to about 2.25% of MMSD's total energy consumption. The PVWatts summary sheet is included in Appendix D. This will further be analyzed under Task C of this study.

4.4.5.1 Opportunities

PV energy is a renewable, internally generated source of energy and can assist to meet MMSD's goals of 100% net renewable energy generation and 80% generation from internal, renewable sources.

4.4.5.2 Challenges

Large scale PV systems have a significant footprint. If installed over-active process tanks, the system must be designed for proper maintenance and removal of the PV panels themselves, as well as process equipment below.

4.5 Waste Heat

4.5.1 Operations and Maintenance

Waste heat is recovered from the Solar turbines and conveyed via ductwork to the Dryers in the D&D Facility. Waste heat produced when the Turbines are being fueled from LFG is considered renewable energy. Waste heat generation is monitored by flow meters and temperature probes, and the waste heat recovered is calculated using the specific heat equation and logged.

Waste heat is also recovered from the CHP engines at SSWRF and supply process and building loads via the boiler loop.

O&M at JIWRF includes the turbine exhaust air transmission duct, monitoring devices, and periodic calibration of the heat generation monitoring meters and probes. O&M at SSWRF includes the engine jacket water to heat exchanger, distribution piping, and monitoring devices.

4.5.2 System Requirements

Waste heat recovery systems do not require any ancillary equipment than can contribute to parasitic losses of efficiency. Flow is induced by a temperature differential and the duct is insulated from transmission losses. A monitoring system is required to quantify energy savings. Losses downstream of the monitoring equipment cannot be quantified and are not considered in the calculations. With proper ductwork insulation, these losses can be considered minimal and ignored.

4.5.3 Reliability

The waste heat system is dependent on turbine heat generation and availability. Its renewable energy value is dependent on the availability of LFG fueling the turbines.

MMSD's waste heat system can be considered a reliable energy source due to the constant heat generation from the Solar turbines as well as the constant large heat load required by the dryers at the D&D facility.

4.5.4 Economics

The value of the heat recovered can be directly compared to the cost of NG offset by the heat value. On average 210,000 MMBTU of waste heat energy is recovered and consumed each year. Of that, on average 150,000 MMBTU is renewable energy. Using $2.50 per MMBTU of NG, this equates to $375,000 saved from generating waste heat from LFG, rather than using NG.

4.5.5 Potential Expansion

Currently waste heat is only monitored from the captured heat from the Solar turbines. It may be beneficial to monitor the waste heat lost from the turbines and dryers exhaust flues to determine equipment efficiency. If sufficient volume of high temperature air is exhausted, there is a potential to add additional waste heat recovery systems at JIWRF.

4.5.5.1 Opportunities

Currently, waste heat is captured and beneficially utilized from the Solar turbines at JIWRF and the CHP engines at SSWRF. Additional waste heat recovery from the drum dryer exhaust stacks may be a viable and economical option to recover some of the heat from combustion. This heat can be routed to process loads such as rerouting back through the dryers.

4.5.5.2 Challenges

Waste heat can be difficult to quantify and capture. Typically, only waste heat from high temperature sources such as engines, boilers, or the dryers are areas where waste heat captured is usable.

Subtask B.5: Landfill and Digester Gas Upgrade

5.1 Background

5.1.1 Overview

LFG and DG are valuable renewable resources currently used by MMSD to meet a portion of its energy needs. LFG is obtained by MMSD from Emerald Park Landfill (EPL) through agreements established with GFL Environmental (gas delivery) and Utility Safety & Design, Inc. (pipeline O&M). DG is generated internally by MMSD from sludge digesters at SSWRF. The use of LFG and DG reduces demand for purchased fossil fuels and their associated carbon dioxide (CO_2) emissions. The capture and use of LFG, which contains approximately 50% methane (CH_4) by volume, prevents the emission of that methane to the atmosphere [7]. This is notable because CH_4 has approximately 25 times more global warming potential than CO_2 [8]. Although the unused CH_4 is currently flare and turned into CO_2. Further optimizing the use of LFG and DG at MMSD facilities is an important part of meeting MMSD's goals of 100% net renewable energy use with 80% generated from internal sources and contributes to critically important emissions reductions.

The implementation of systems to clean and upgrade LFG and DG (gas processing) is one of the cornerstones of maximizing their use. There are a variety of technologies available to clean and/or upgrade gas, the most common of which will be discussed here. Strategies for conveying processed gas (gas delivery) and the ability of equipment to effectively use it (dual-fuel assets) are also critical considerations. Differing approaches to gas delivery and outfitting dual-fuel assets will also be discussed.

5.1.2 ETI Water Wash Pilot Demonstration

Energy Tech Innovations, LLC began a pilot demonstration of a proprietary "Water Wash" gas purification process at JIWRF in 2018 (contract M03029P34). The pilot was continued through 2019 and the results were summarized by ETI in a multi-part report provided to MMSD in September 2020.

The purpose of the pilot was to demonstrate the operation and efficacy of two versions of the ETI Water Wash technology by processing incoming LFG and recording the resulting gas content and resource consumption under various conditions. The report provides details of the piloted technology, documents data collected, presents comparisons with alternative gas processing technologies, provides economic projections, and identifies opportunities for the use of cleaned and/or upgraded gas and process by-products in MMSD facility operations. Details of the report will be referenced as they relate to the following sections.

5.2 Gas Cleaning and Upgrading

5.2.1 Background

LFG and DG are both forms of biogas composed primarily of methane (CH_4) and carbon dioxide (CO_2) and varying levels of impurities such as siloxanes and hydrogen sulfide (H_2S). LFG incoming to JIWRF also contains nitrogen (N_2) and oxygen (O_2), whereas DG produced at SSWRF does not [9]. Biogas cleaning refers to the removal of impurities. Biogas upgrading refers to the removal of CO_2, which results in a greater percentage of CH_4, the primary component of NG, by volume [2]. Upgraded biogas with similar CH_4 content as NG (typically 96% or above) is considered RNG and can generally function as a substitute for NG [9]. Different end uses may require varying levels of RNG purity or be particularly sensitive to certain raw biogas constituents. Selection of a cleaning and/or upgrading system should consider end use to balance RNG composition requirements with other cost, maintenance, and operational considerations.

5.2.2 Current Practices

LFG incoming to JIWRF is cleaned, dried, compressed, and odorized at EPL. EPL gas cleaning includes removal of H2S and siloxanes, but some of these impurities remain in the incoming LFG stream, in addition to some N_2 and O_2 [9]. LFG is not further cleaned or upgraded by performing CO_2 removal at JIWRF prior to its distribution, other than that upgraded by the ETI Water Wash pilot. Additional moisture is removed from LFG by a chiller on each turbine compressor skid. DG generated by digesters at SSWRF is pre-treated to remove moisture and reduce siloxanes using an activated carbon treatment. H_2S levels in DG are limited by a Chemically Enhanced Primary Treatment (CEPT) process utilizing ferric chloride. Currently, DG is not upgraded.

5.2.3 ETI Water Wash Pilot

5.2.3.1 Concept

The ETI Water Wash process is a particular form of the biogas treatment method more broadly referred to as water scrubbing, which will be discussed further in Section 5.2.4.4. The ETI Water Wash process functions by creating contact time between biogas and water, either in a vertical or horizontal configuration. In a vertical configuration, incoming biogas rises from the bottom of a vessel while water falls in the opposite direction from the top of the vessel. In a horizontal configuration, biogas and water flow in the same direction through an extended length of tubing. In both cases, the water absorbs undesirable gas constituents that are more readily soluble (H_2S, Siloxanes, CO_2) while the majority of CH_4 remains unabsorbed and is collected. Note that N_2 and O_2, when present, are not absorbed and also remain in the product gas stream. Water discharged from the system can be directed to other treatment processes which may benefit from the addition of CO_2 or passed through a desorption column to separate and release the CO_2 gas. Figure 13 and Figure 14 illustrate the JIWRF Water Wash pilot schematically in the vertical and horizontal configurations, respectively [9]. Figure 15 shows the actual pilot installation near the Landfill Gas Pipeline Metering Station at JIWRF [9].

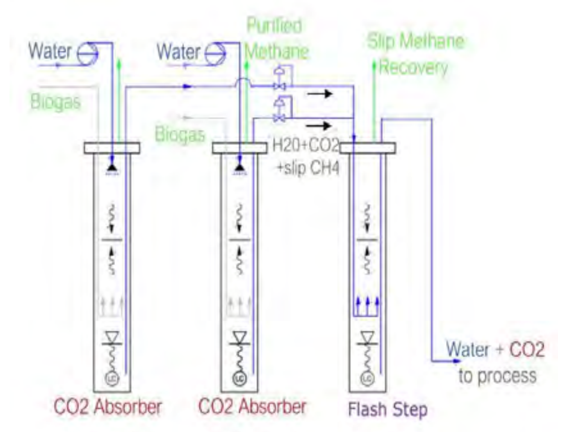


Figure 13 Water Wash Pilot Schematic, Vertical

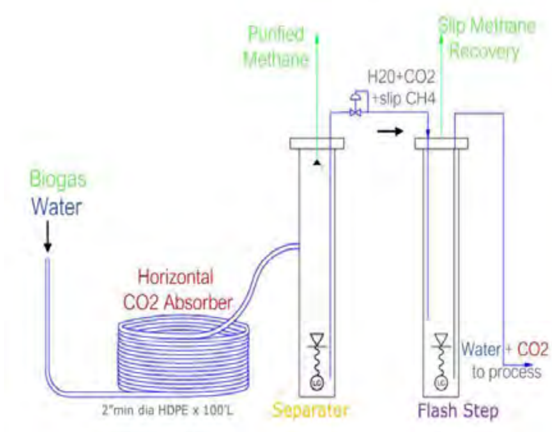


Figure 14 Water Wash Pilot Schematic, Horizontal

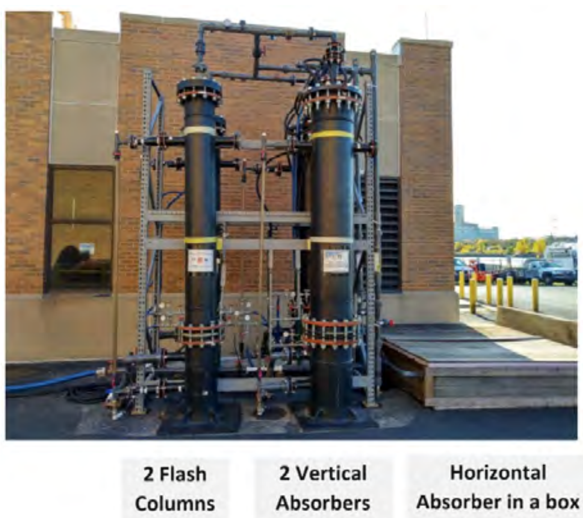


Figure 15 ETI Pilot Installation, JIWRF

5.2.3.2 Equipment

The ETI Water Wash process has only a small number of essential components, including one or more CO_2 absorbers which can be vertical or horizontal, flow control valves, flow meters, water level controls, and gas quality meter. Depending on the application, additional components including flash columns meant to recover small amounts CH_4 absorbed in previous steps, CO_2 desorption columns which separate CO_2 from water for collection, gas polisher which removes residual CO_2 in upgraded LFG, and gas drying may be desired. If CO_2-rich water discharged from the system is beneficially reused in other existing treatment processes, equipment would also include piping, valves, and monitoring of that flow. No chemicals or consumable media are used.

5.2.3.3 Operation

Notably, the ETI Water Wash process does not require the use of booster pumps or gas compressors to operate effectively, instead relying on the available pressures of plant water lines (either City Water or Plant Effluent) and the incoming LFG pipeline. Variances in properties of the water supply such as pressure, temperature, residual CO_2, pH, and total dissolved solids can be accommodated by varying the gas to water mixing ratio (G:W) to achieve the targeted amount of CO_2 removal. If CO_2-rich water discharged from the system is beneficially reused in other existing treatment processes, operations would also include monitoring that flow. Overall, the simplicity of the equipment involved makes operation and maintenance of the ETI Water Wash system straightforward.

5.2.3.4 Outcomes

The reported results of the ETI Water Wash pilot demonstrate that the technology can effectively remove siloxanes, H_2S, CO_2. LFG sampled at the inlet and outlet of the pilot in September 2019 was found to contain siloxanes in the amount of 0.35 ppmv at the inlet and 0.16 ppmv at the outlet, a more than 50% reduction. The same sample was found to contain H_2S in the amount of 93.4 ppmv at the inlet and 0.182 ppmv at the outlet, a more than 99% reduction [9].Note that current levels of siloxanes and H_2S fall within allowable limits, but reductions are still beneficial.

LFG upgraded by the pilot system was found to have a methane content of 86%, limited almost exclusively by the presence of N_2 and O_2. For this reason, the same system is expected to achieve a methane content of about 98% if used to upgrade SSWRF's DG, which does not contain significant amounts of N_2 and O_2 [9].

5.2.4 Other Available Technologies

While not an exhaustive list, the four most common technologies used to upgrade biogas are membrane permeation, pressure swing adsorption (PSA), solvent scrubbing, and water scrubbing [1]. Each technology ultimately yields RNG but carries distinct advantages and disadvantages with varying relevance to individual applications [1]. Factors to consider include capital costs, ongoing operations and maintenance costs, energy intensity, resource intensity, ease of operation, footprint, composition of output RNG, and availability of technical support [2]. To illustrate their relative prevalence, Figure 16 shows the distribution of technologies used to upgrade LFG according to Argonne National Laboratory's database of US RNG projects in 2018 [1].

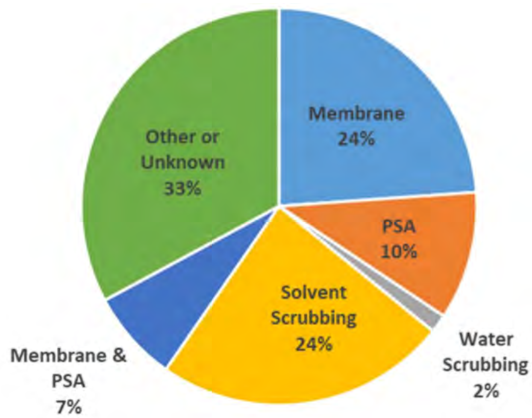


Figure 16 Upgrading Technologies used in LFG-to-RNG Projects (2018) [1, p. Fig. 7]

The following sections will provide brief overviews of the aforementioned technologies, highlighting their potential advantages and disadvantages, and comparing with the ETI Water Wash pilot.

5.2.4.1 Membrane Permeation

Membrane permeation systems function by directing biogas through a material (membrane) with a specific pore size that is smaller than molecules of CH_4, but larger than molecules of contaminants or otherwise undesired constituents such as H_2S, O_2, and CO_2 [2] [1]. As illustrated in Figure 17, CH4 does not pass through the membrane and is collected as purified biogas, while more permeable constituents pass through the membrane and are discharged [2].

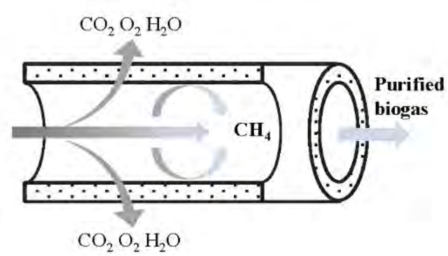


Figure 17 Membrane Permeation Schematic [2]

Membrane permeation systems may be single pass or multi-pass, depending on the purity requirements of the end use and the volume of incoming biogas. Single pass systems, typically used in smaller volume applications, can capture approximately 60% to 80% of CH_4 and retain some O_2 and inert gases in the product RNG stream [1]. Multi-pass systems, typically feasible only for large volume applications, can capture approximately 96% to 99% of CH_4 [1].

Advantages of membrane permeation include a small footprint, low equipment cost, and simple operation. Disadvantages of membrane permeation include ongoing costs to replace membranes and low CH_4 purity resulting from a typical single pass system [2]. The capital investment required for a multi-pass system generating higher levels of CH_4 purity is often infeasible for applications of than large scale vehicle fueling [1].

ETI's Water Wash process shares the advantage of simple operation but is able to achieve relatively high CH_4 purity, depending on levels of N_2 and O_2 in raw biogas, and has a low capital investment due to the simplicity of equipment involved.

5.2.4.2 Pressure Swing Adsorption

Pressure Swing Adsorption (PSA) systems utilizes adsorbent media in series of pressurized vessels to capture undesired biogas constituents. The gas absorption rate of the media is pressure dependent. At high pressures, impurities such as CO_2, N_2, and O_2 are adsorbed by the media and un-adsorbed CH_4 is collected from the vessel. Next, after the media has been saturated, it is regenerated by lowering the pressure and releasing the adsorbed constituents [2]. This process of pressurization, depressurization, and regeneration is repeated until 95% to 98% of CH_4 has been captured [1]. Figure 18 illustrates the PSA process [2].

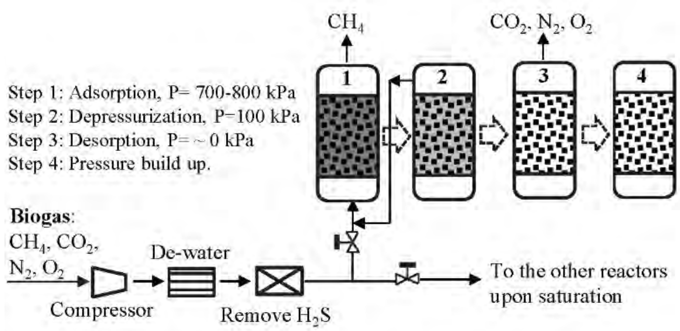


Figure 18 PSA Schematic [2]

Advantages of PSA systems include low energy input and the ability to repeatedly regenerate adsorption media. A disadvantage of PSA systems is that adsorbent media can be damaged by H_2S or water, requiring pre-treatment of biogas and contributing to increased capital costs [2].

ETI's Water Wash process also requires low energy input, but is able to remove H_2S effectively in the same simple process used for CO_2 removal [9].

5.2.4.3 Solvent Scrubbing

Solvent scrubbing systems function by using a chemical solvent to adsorb CO_2 and H_2S. Depending on the solvent used, it may be regenerated by either heating or depressurizing it to desorb the capture impurities [1]. Amine solvents, which are especially effective adsorbers of CO_2, are commonly used for solvent scrubbing processes [1]. Solvent scrubbing systems typically capture approximately 97% to 99% but can exceed 99% if amine solvents are used [2].

Advantages of solvent scrubbing include low amounts of CH4 lost and production of high-quality CO_2 by-product. A disadvantage of solvent scrubbing is that the process is energy intensive [2].

ETI's Water Wash process also results in relatively low methane loss (0.5% in the discharge water stream was detected when pilot was tested) but is far less energy intensive because it operates using the available line pressures of the water and gas supplies [9].

5.2.4.4 Water Scrubbing

Water scrubbing is a relatively straightforward process that exploits the difference in solubility of common biogas constituents in water [2]. At a given pressure (typically 110-140 psi) CO_2 and H_2S can be easily diluted into water, whereas CH_4 will not be diluted [10]. Therefore, water scrubbing systems function by passing compressed biogas through water, typically flowing in the opposite direction of gas flow. CO_2 and H_2S are absorbed into the water stream, while CH_4 passes into the product RNG stream [1]. Water used in the scrubbing process can be stripped in a separate vessel and reused in a loop, leaving the gases removed from the biogas to be released or flared [10].Other auxiliary components such as water pumps or gas driers may be included depending on the application. Water scrubbing systems typically achieve CH_4 capture efficiencies of more than 99% [1]. Figure 19 illustrates a flow schematic for a typical water scrubbing system.

Advantages of the water scrubbing process include no required chemical use, no consumable media, and low-complexity equipment. A potential disadvantage of water scrubbing is its inability to remove biogas contaminants such as oxygen (O_2) and nitrogen (N_2) which may be present in varying amounts depending on the source of the biogas. The presence of O_2 and/or N_2 lowers the energy density of the product gas stream (lower percentage of CH_4 by volume) or be unsuitable for certain end uses [10].

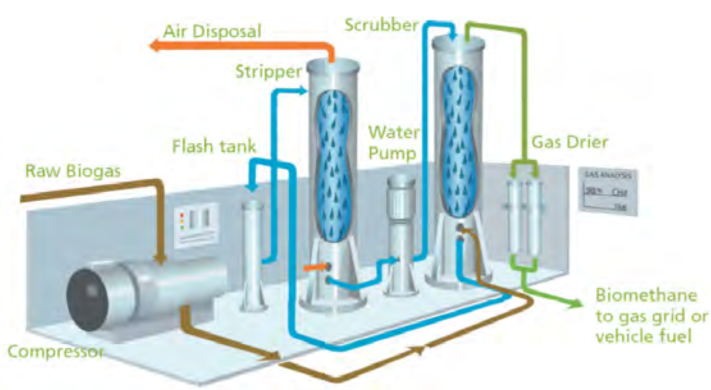


Figure 19 Water Scrubbing Flow Schematic [10, pp. Fig. 3-13]

The ETI Water Wash process is distinguished from other typical water scrubbing systems because it uses the available pressures of the water and gas supplies rather than relying on booster pumps or gas compressors, allowing it to be even simpler, lower energy process than its counterparts [9].

5.3 Gas Delivery

5.3.1 Background

There are two approaches to delivering different fuel types to the same assets. The first is dual-fuel piping, in which two distinct sets of piping designed to convey fuel to the same equipment. This arrangement allows pipes to be sized appropriately to convey the volume of gas required to deliver the energy demanded by the end use. A gas with lower energy density will require a greater volumetric flow rate to delivery the same amount of energy as a gas that is more energy dense, and pipes must be sized accordingly. The second approach is single point fuel blending, where different fuels sharing similar energy densities are blended seamlessly at a specific point after which they are conveyed by a common pipe or manifold.

5.3.2 Current Systems

Currently, JIWRF utilizes the dual-fuel piping approach to deliver LFG to equipment because LFG is not upgraded and cannot be blended with NG. Of the twelve existing sludge dryers at JIWRF, a recent project installed new LFG header piping to ten dryers and upgraded the burner systems of four dryers to allow combustion of LFG. [9] Burner system upgrades include burners, combustion air fan, control valves, flow meters, sensors, and connecting piping to the associated dryer.

5.3.3 ETI Water Wash Proposal

In conjunction with presenting the results of the pilot study, ETI also presented a strong case for the advantages of single point fuel blending at JIWRF after LFG is upgraded using the Water Wash process [9, pp. Part 2, Figure B]. By blending upgraded LFG with NG and delivering to dual-fuel assets in a common manifold, MMSD would have the flexibility to fuel any eligible asset (including all twelve dryers) with LFG, easily responding to fluctuations in supply over time and accommodating equipment outages or replacement while maximizing LFG use without interruption [9].

5.4 Dual Fuel Assets

In addition to creating opportunities for operational flexibility, the use of upgraded LFG has significant benefits on an asset-by-asset scale. Cleaner LFG reduces maintenance associated with the build-up of contaminants, reduces pollution resulting from the combustion of contaminants, and reduces compressor energy consumption by delivering more energy per unit volume [9].

5.4.1 Current Assets

Assets that currently utilize LFG at JIWRF include:

- Solar Turbines
- (4) Sludge Dryers

5.4.2 Potential Assets

MMSD assets, with some modifications, that could potentially utilize LFG by adopting a blended fuel approach include [9]:

- Additional (8) Sludge Dryers
- GE Turbines
  - Currently the Solar Turbines are prioritized because they are more efficient. If there is an increase in LFG recovery the GE Turbines will operate.
- Boilers

5.5 Summary

Upgrading biogas is a key step in maximizing and sustaining its beneficial use. There are several commercially available technologies with varying strengths and weaknesses that should be carefully considered. While not yet commercialized and tested on a large scale, the ETI Water Wash pilot demonstrated the efficacy of the technology and a thoughtful analysis of how the process can function in synergy with existing plant resources (plant effluent water supply) and processes (treatment benefits of CO_2 by-product). To further explore the potential value of upgrading biogas to MMSD, target end uses should be clearly selected, importance of commercial technical support should be considered, and potential opportunities for use of by-products should be assessed.

Subtask B.6: Renewable Energy Technologies

6.1 Introduction

The purpose of Subtask B.6 is to evaluate three renewable energy technologies currently not deployed by MMSD. The technologies, selected in agreement with MMSD, include sewer heat recovery, wind energy, wave energy, and geothermal energy.

6.2 Sewer Heat Recovery

6.2.1 Background

Sewer heat recovery works by extracting heat from the wastewater in sewers and using it to supply building heating loads. The process works by installing a heat exchanger at the wastewater pipe where refrigerant extracts or rejects heat from the sewer water. The refrigerant then passes through a series of equipment where it changes phases from liquid to gas (or vice versa) performing a refrigeration cycle or also known as the Carnot cycle in Thermodynamics. In the heating, ventilating and air conditioning (HVAC) industry, this technology is called heat pump .

6.2.2 Opportunities

Large sewer heat recovery systems are capable of significantly offsetting building HVAC and process heating loads operating on a heating/cooling loop, such as JIWRF's boiler loop. The boilers consume about 2,700 to 3,000 mBTU/hr when averaged over a peak heating month. A large sewer heat recovery system can produce about 4,500 mBTU/hr which would cover the entire boiler load. Smaller systems are also available which can cover 100-400 mBTU/hr of heat loads [11].

6.2.3 Challenges

This technology is most economically feasible for buildings that have large heating and cooling loads and HVAC systems operating on hydronic loops. Because many MMSD facilities do not require cooling and there is no district hydronic loop, there is likely not enough demand to justify the capital expense of a sewer heat recovery installation.

It should also be noted that the boilers at JIWRF account for less than 1% of the facility energy loads. Therefore, if the entire boiler loop were converted to a sewer heat recovery system, the total renewable energy created would move the needle less than 1% towards MMSD's net 100% renewable energy goal.

6.3 Wind Energy

6.3.1 Background

Wind energy is a renewable energy source captured using turbines that convert mechanical power from wind into electricity. Wind power generation is a proven technology and is currently used for applications including telecommunications, radar, pipeline control, water pumping, weather stations, private homes, and businesses etc. The most common application is large-scale power generation. Large-scale turbines are turbines with capacities greater than 100 kW and are typically installed in large, multi-turbine wind farms connected to the national power grid [12]. The major components of a wind turbine are the blades, rotor, gearbox, and generator. Typically, a transformer is located at the base of the turbine for integration with the power system [13].

Wind energy is advantageous because it is a free resource which requires no extraction, transportation, or processing. Wind turbines release no emissions or pollutants during operation and are relatively low maintenance. A large-scale wind turbine can last up to 20 years before requiring major maintenance activities [14]. The marginal cost of wind energy is typically less than 1-cent per kWh [15]. Wind energy costs are also more predictable than traditional power generation subject to volatile fossil fuel prices.

Although O&M costs are relatively low, large-scale wind turbine projects require a large upfront capital cost for planning, design, and construction. Regulations and the cost associated with permitting, approvals, etc. can significantly impact project planning costs. Continuing advancements in wind turbine technology resulting in higher energy yields, economies of scale, and O&M cost reductions have all contributed to a downward trend in cost. The global weighted-average cost of electricity generated by new onshore wind farms in 2019 was 5.3-cents per kWh [13]. The levelized cost of energy (LCOE) is a measure of the average net present cost of electricity generation for a generating plant over its lifetime. Figure 20 shows that the LCOE for onshore (land-based) wind generation has been steadily decreasing and is expected to continue decreasing over the next decade [16].

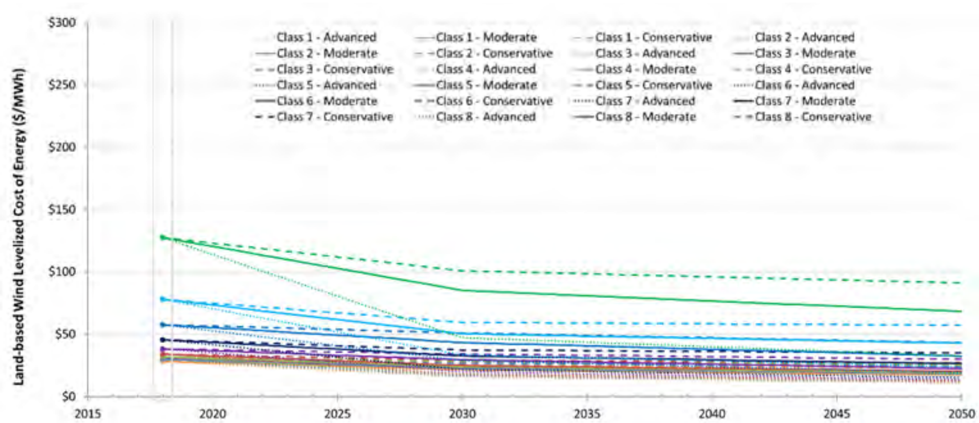


Figure 20: Past & Projected LCOE for Land-based Wind Energy (2020) [16]

In Wisconsin, wind energy currently makes up almost one-third of the state's renewable electricity generation, which represents approximately 3% of total generation [17]. Since 2015, Wisconsin has increased generation from wind from 648 MW using 17 wind turbines to 735 MW using 435 wind turbines today [18]. Figure 21 Net Generation from Wind Energy, Wisconsin Figure 21 shows the increase in Wisconsin's net generation from wind over the last 15 years [17].

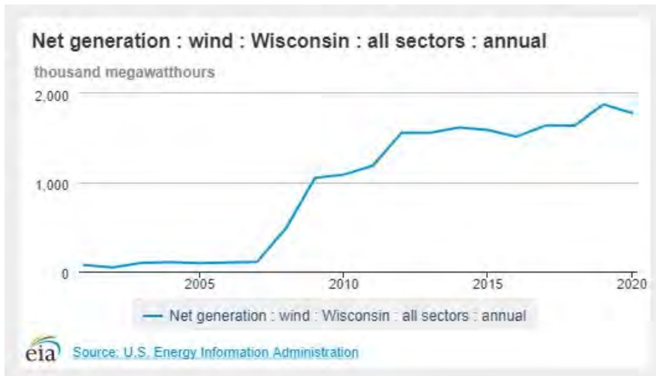


Figure 21 Net Generation from Wind Energy, Wisconsin [17]

6.3.2 Suitability

The suitability of wind turbines for use at a given location depends on local wind speeds, available land area, surrounding power infrastructure, capability to perform O&M, and economics. Wind energy technologies may be possible to apply at MMSD facilities due to satisfactory local wind speeds, robust power distribution infrastructure, and willingness to invest resources into renewable energy technologies make wind despite limited land area.

<u>Local Wind Speeds</u>
The greatest wind energy potential in Wisconsin is located along the coast of Lake Michigan and in isolated areas in the western part of the state. Wind speeds in the Milwaukee region vary within an average range of 6.5-7.5 m/s [19]. A minimum wind speed of 6.5 m/s at 80 meters above grade is generally required for an economically feasible large-scale turbine installation [20].

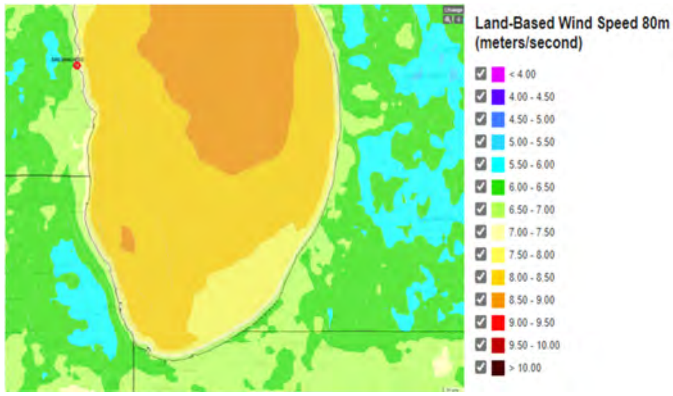


Figure 22: Milwaukee Region Land-based Wind Speeds [19]

Available Land Area

Direct permanent land use for wind turbines is approximately 0.7-1.5 acres per MW of rated capacity [21]. Detailed siting and spacing requirements must also be followed to ensure regulatory compliance and adequate air flow characteristics. Some potential locations for wind turbines at JIWRF and SSWRF were identified in the 2015 Energy Plan, but space is limited and unlikely to accommodate large-scale or multiple turbines easily.

Power Infrastructure

JIWRF and SSWRF have a large amount power distribution infrastructure in place. These systems may be able to accommodate the addition of a large-scale wind power generation system with only moderate modifications to the existing system, potentially leading to more cost-effective connection of the wind turbine(s) to the power grid.

O&M Capability

While wind turbines require less intensive O&M than many other forms of power generation, the installation of wind turbines would require investment in staff training, equipment, and parts to properly perform maintenance.

Economics

Many factors including current market conditions, government incentives, and cost of utility electricity can greatly impact the relative cost of installing wind turbines. A detailed economic analysis would be required to determine whether a large-scale wind turbine installation at MMSD's facilities economically feasible, particularly with respect to the large capital investment required.

6.3.3 Challenges

Other specific challenges to wind energy's implementation at MMSD facilities include wind performance, foundation requirements, regulatory and land use requirements, impacts on wildlife, and public perception.

Wind Performance

While average wind speeds at JIWRF and SSWRF meet the minimum required for an economically feasible large-scale project, they may not be sufficient to maximize generating efficiencies. Wind also varies uncontrollably over time, and electrical output from wind turbines varies accordingly. JIWRF and SSWRF have a large enough baseline energy demand they will likely be able to instantaneously utilize the generated electricity on-site. Energy storage solutions may offer additional flexibility but introduce additional costs and complexities.

Foundation Requirements
The foundation requirements for large wind turbines can be extensive. For example, to support a 2 MW turbine, a 15 to 20-foot-deep concrete foundations is typically constructed [22]. Since JIWRF is built on a mostly artificial island, this could pose a challenge and should be evaluated by a geotechnical and structural engineer.

Regulatory and Land Use Requirements
Wind turbines may be considered obstructions to air navigation and subject to approval by regulating bodies such as the Federal Aviation Administration. Local government bodies or public commissions may also require adherence to specific siting criteria.

Impacts on Wildlife
Wind turbines can impact bird populations. Protected species with migratory patterns in the Milwaukee area should be identified and potential impacts should be considered.

Public Perception
Depending on their size, wind turbines can alter the appearance of a landscape in ways that may be undesirable to residents of the surrounding community.

6.3.4 Summary

Wind energy is inexhaustible and emissions-free. Wind energy costs continue to decrease as turbine technology improves, and wind generation may be more economically feasible today than in years prior. While there are challenges to implementing wind energy at MMSD's facilities, electricity generation from wind could contribute meaningfully to achieving the renewable energy goals associated with the 2035 Vision.

The following are next steps to investigate implementation of wind energy generation at MMSD facilities:

- Choose locations for wind turbines on MMSD property
- Determine electrical connection points and modifications require to existing power distribution infrastructure
- Coordinate with We Energies
- Determine estimated capital expenditure and conduct economic analysis
- Establish dialogue with turbine Manufacturers and project developers.
- Evaluate zoning and permitting requirements.
- Secure agreement to meet O&M needs

6.4 Wave Energy

6.4.1 Background

Wave energy is the energy harnessed from wave action in oceans, seas, or lakes. Wave motion is a form of kinetic energy that can be utilized for electricity generation, power plants, or pumping of water. Wave energy is a form of renewable energy and can be extracted without producing any greenhouse gases or other contaminants. Wave Energy Converters (WEC) are mechanical devices which convert the potential energy of waves into electrical power.

The cost of wave energy extraction can typically be divided into four categories: fabrication, installation (which involves mooring), maintenance, and connection to the grid. Wave energy technologies are in the early stages of commercial development compared to more established renewable energy technologies. Most current installations are protypes used for research and development. Limited data indicates wave energy cost currently falls around 7.5 cents per kWh, which is significantly higher than more established renewable energy technologies [23]. However, improvements in technology and economies of scale are likely to lower the cost of electricity from wave energy over time.

6.4.2 Suitability

The suitability of WECs for use a given location depends on the wave energy potential of the nearest body of water and the proximity of the relevant facilities to the body of water. Although Lake Michigan has modest wave energy potential overall, low wave energy potential in the Milwaukee region specifically limits the suitability of WECs to serve JIWRF or SSWRF despite their proximity to the coast.

Wave Energy Potential

Ocean coastal regions generally have the greatest wave energy potential, but WECs can also be applied to smaller bodies of water that also have wave action. A 2018 study concluded that storm surges in Lake Michigan contain enough potential wave energy to generate significant amounts of electricity [24]. However, the Milwaukee region is not in the area of highest potential, as illustrated by a map of monthly mean wave power available in Lake Michigan**Error! Reference source not found.** [24].

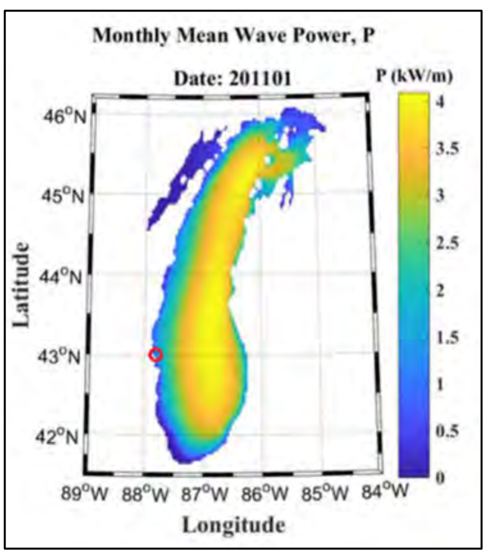


Figure 23: Lake Michigan Monthly Mean Wave Power (2011) [24]

Facility Proximity

JIWRF and SSWRF are both located along the coast of Lake Michigan. JIWRF is located along Milwaukee Bay, which is protected by breakwater structures. Potential WECs would need to be installed beyond the breakwater structures, towards the center of the lake.

6.4.3 Challenges

Other specific challenges to wave energy's implementation at MMSD facilities include commercial availability of WEC technology, variability in wave performance, potential impacts on ecosystems, and complex construction.

Commercial Availability

Wave energy technologies have not been widely accepted by the energy generation industry because few commercial installations exist to demonstrate cost effective power generation. Not many proven devices are commercially available, so costs remain extremely high.

Wave Performance

Consistent, powerful wave action is required to predictably generate a significant amount of wave power. Lake Michigan experiences unreliable wave behavior, so power generation from waves would fluctuate considerably with large impulse peaks. To accommodate power oscillations, installation of a WEC would likely need to be paired with an energy storage system (discussed further in Subtask B.7).

Ecosystem Impacts

Installation of a WEC could impact the surrounding marine ecosystem. For example, marine mammals could collide with WECs or become entangled in mooring cables.

Complex Construction

Offshore construction of the elements required for a WEC is complex, including installation of deep foundations and power cables to transmit energy captured by a WEC to the electrical power distribution system onshore. The farther offshore the WEC is located, the more costly it would be to provide the electrical connection. This requires balancing improved wave performance and with the challenges of increasing the offshore distance.

6.4.4 Summary

Wave energy technologies are not currently competitive with other renewable energy sources in terms of commercial technology development and economic feasibility. Today, wave energy is not viable as a potential addition to MMSD's energy portfolio. However, wave energy remains a vast, largely untapped resource and WECs will likely become more prevalent more over time as technology advances and costs decrease.

6.5 Geothermal Energy

6.5.1 Background

Geothermal energy is heat energy stored deep in the Earth. Geothermal energy is a renewable energy source because heat is constantly produced by the radioactive decay of materials in the earth's core. Heat from the magma deep underground is absorbed by rocks and water closer to the earth's surface, where it can be captured and used to supply heat to applications such as HVAC and electricity generation.

Low-temperature geothermal energy is obtained from pockets of heat about 150° C (302° F) located just a few meters below ground in some locations [25]. Ground source heat pumps can access this heat to serve direct-use applications like heating and cooling [26]. Comparatively, deep and enhanced geothermal technologies take advantage of a much deeper, higher temperature geothermal resource to generate electricity.

Geothermal energy currently represents 0.4% of all electricity generation in the U.S. [26]. Significant geothermal resources are generally concentrated in the western U.S. as shown by Figure 24 [26]. Properly locating geothermal plants in areas with sufficient geothermal resources and balancing the rate of energy extraction with the natural heat recharge rate is critical.

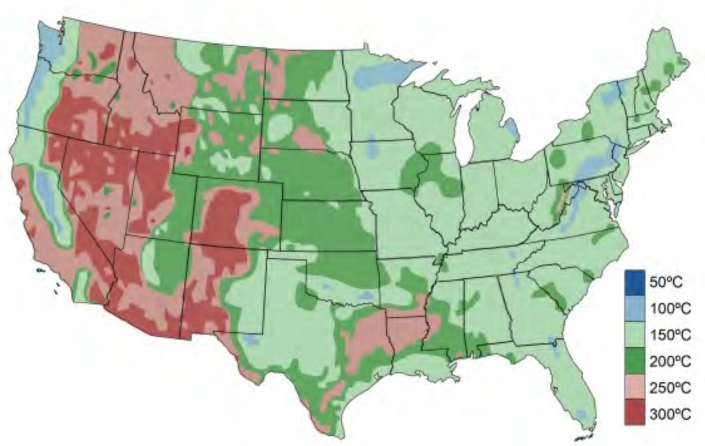


Figure 24 : "U.S. Geothermal Resources at 10 km Depth" [26]

Hydrothermal energy, typically supplied by underground water reservoirs, is the main source of thermal energy used in electricity generation [26]. There are three different types of geothermal power plants: flash steam, binary cycle, and dry steam [27]. While each operates in a different way, all implement the same fundamental design of drawing hot water and steam from the ground to spin turbines which then generate electricity. Geothermal power plants are relatively compact and require less land per GWh than coal, wind, and solar PV [28].

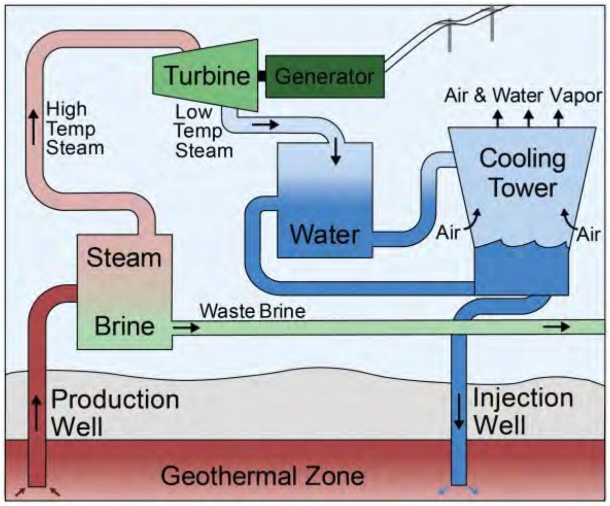


Figure 25: Flash Steam Geothermal Plant Schematic

After installation, the costs of geothermal plant operation is relatively low. O&M cost ranges from $0.01 to $0.03 per kWh for an average geothermal power plant in the US [29]. However, geothermal plants can have high capital costs. Installed costs of geothermal power plants include exploration and assessment of resources; well drilling; field infrastructure; construction of production facilities and grid connection. Initial costs for land acquisition and construction of a geothermal plant in the U.S. is approximately $2500 per installed kW [29]. The smallest geothermal plant in the U.S. is a 4.4 MW geothermal power plant in Wabuska, Nevada [30].

6.5.2 Suitability

The suitability of a geothermal plant for energy generation at a given location depends almost entirely on the heat content of the accessible geothermal reservoirs in that area. Other factors include land availability, proximity to existing power distribution infrastructure, and available of make-up water. A lack of geothermal reservoirs with sufficient heat content in Wisconsin makes MMSD facilities an unlikely application for geothermal energy use.

<u>Geothermal Resources</u>
Geothermal electricity generation plants are typically viable only when geothermal reservoirs have a temperature between 150ºC to 370ºC or greater [27]. In the U.S., these conditions generally exist only in the western states. Figure 26 indicates that Milwaukee has deep geothermal temperatures of only 100-150°C [31]

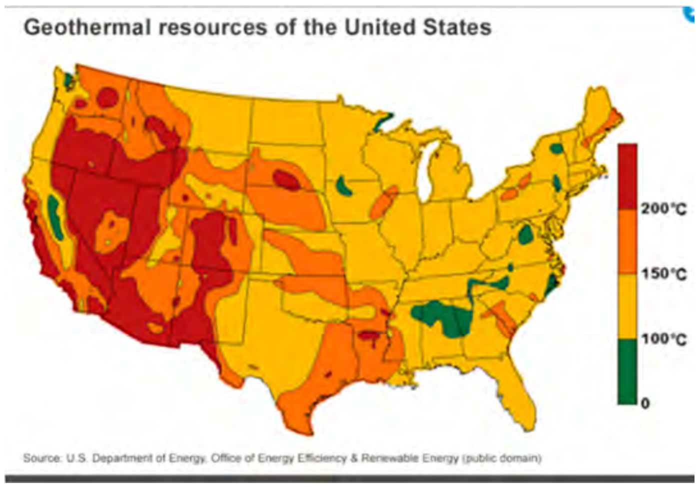


Figure 26: U.S. Geothermal Resource Map [31]

6.5.3 Challenges

Other specific challenges associated with geothermal energy plants include managing reservoir depletion rates and capital investment.

Reservoir Depletion
Geothermal fluid needs to be recharged in underground reservoirs faster than it is depleted to remain sustainable. Careful understanding of the properties of the reservoir being utilized, planning, and ongoing monitoring are required to maintain a balance between reservoir depletion and natural recharge rates.

Capital Investment
Geothermal plants are expensive to construct, with initial costs ranging from around $2-$7 million for a plant with a 1-MW capacity [32]. Careful selection of applications for geothermal plants is required to ensure long term recovery of the investment. [32]

6.5.4 Summary

Locating and developing geothermal resources can be challenging. This is especially true for the high-temperature resources needed for generating electricity. Geothermal electricity generation plants are generally located in the western U.S. where geothermal temperatures are higher and easier to access. JIWRF and SSWRF are in geographic areas with relatively low geothermal temperatures, so installation of a geothermal plant is likely infeasible.

Subtask B.7: Alternative Energy Storage

7.1 Introduction

Energy storage refers to the capture of energy produced in excess of demand at a given time that is stored for future use during periods when demand exceeds production. The goal of energy storage is to reconcile imbalances between energy demand and production. For example, wind power generation is irregular and may not align with demand. Similarly, solar power generation varies with cloud cover and is only available during daylight hours, while demand often peaks after sunset.

Energy exists in a variety of forms including chemical, gravitational potential, electrical potential, temperature differential, latent heat, and kinetic. Energy storage entails converting energy from forms that are difficult to store to forms that are more easily stored. There are many different types of energy storage, including mechanical, electrochemical, and thermal.

Mechanical
Mechanical energy storage is the storage of kinetic or potential energy by physical means. For example, potential energy can be stored by pumping water to a basin at a higher elevation (pumped hydropower) or compressing air in a vessel. Alternatively, flywheels convert electricity into kinetic energy maintained by high rotational inertia.

Electrochemical
Batteries convert electricity into electrochemical energy. Batteries consist of one or more cells filled with chemical media. Lead-acid and lithium-ion batteries are the most common types used for utility scale storage applications.

Thermal
Thermal energy storage is the transfer of heat to or from a storage medium to direct use applications or to induce a temperature differential used to drive power producing turbines.

Overall, the most common type of energy storage used at a utility scale is pumped hydropower, which accounts for more than 95% of all energy storage in use today [33]. Electrochemical storage is most frequently coupled with PV or wind turbines. Though less common, the unique properties of compressed air or flywheels can sometimes make them well-suited to specific situations. Utility-scale battery storage operating in the United States has reportedly quadrupled from a total of 214 MW at the end of 2014 to 899 MW (through March 2019) [34]. The U.S. Energy Information Administration (EIA) expects U.S. utility-scale battery storage capacity to grow to perhaps 2,500 MW by 2023 [34].

7.2 Suitability

This section evaluates alternative energy storage that can be utilized in conjunction with renewable technologies covered in Sections B.4 and B.6. The minimum hourly average energy demand for MMSD facilities is currently higher than the hourly maximum average on-site renewable energy generation. Per data recorded at JIWRF, the minimum average demand is approximately 88 MMBTU/h (25.76 MW), with an average on-site renewable generation value of 22.6 MMBTU/h (6.6 MW). Per data recorded at

SSWRF, the minimum average demand is approximately 53.63 MMBTU/h (15.72 MW), with an average on-site renewable generation value of 7.3 MMBTU/h (2.14 MW). This means MMSD is always supplementing internal, renewable generation with external, non-renewable sources to meet facility demands. Energy storage for renewable energy is not currently applicable since renewable energy generated is instantaneously used on-site. The identified paths to exceeding the demand with renewable energy generation include:

- Increase capacity of on-site renewable energy generation
- Reduce baseline energy consumption
- Demand management

Energy storage may be a viable option once MMSD produces more instantaneous renewable energy than consumption. The energy stored could be used to offset consumption during periods of peak demand when utility-provided non-renewable sources would otherwise be consumed. Renewable energy generation capacity will need to be increased to meet the goals of MMSD's 2035 Vision. To reach the goal of 80% of energy needs by internal, renewable sources, renewable power generation capacity will be higher than the minimum demand but will likely be lower than the maximum demand. This means there will be more generating capacity than demand during some but not all times. Once excess renewable energy is available, there are three ways MMSD can utilize the energy:

- Temporarily shift demand
- Export excess energy to the utility
- Store excess energy on-site and use during peak demand times

The portfolio of renewable energy sources MMSD will utilize in the future to meet the 80% goal is currently unknown. If renewable sources are required to meet 80% or greater of instantaneous facility demand, the amount of on-site generation needed would be significantly greater during peak demand times such as wet weather. To meet 80% renewable sources during peak demands the baseline renewable energy generation would need to be increased or supplemental energy storage would be required.

MMSD's excess renewable energy would likely be in the form of electricity or biogas. Excess electricity could be generated from renewable sources such as PV and wind turbines or produced by gas turbines utilizing LFG or DG. Excess biogas can be stored with the use of gas tanks or converted to electricity for storage. This evaluation focuses on the application of electrical energy storage.

Excess renewable electrical energy generated at MMSD's smaller facilities can be directly sold to We Energies, so storage is not as beneficial. However, due to the large gap between minimum and maximum demand, if excess renewable energy is generated at JIWRF or SSWRF it is likely at the utility-scale (1 MW or greater in capacity) and may be economical to store instead of selling to We Energies. In addition, electrical energy storage is more complex due to dynamic rate structures. A detailed tariff and interconnection agreement analysis would be required to determine if utility-scale electricity storage is feasible. Coordination and collaboration with We Energies will be critical as renewable energy generation capacity increases to determine the right balance of exporting energy back to the grid or storing for future use.

Identifying the most suitable energy storage technology will depend on MMSD's future renewable energy portfolio. Evaluation of possible alternatives will include at a minimum the following considerations:

- **Technology Evaluation:** Selection of the technology is largely dependent on the specific goals for energy storage projects. Established large-scale technologies, such as pumped hydropower and compressed air energy storage, are capable of long discharge times (tens of hours) and high capacity. In contrast, various electrochemical batteries and flywheels are better suited for lower power applications or those requiring shorter discharge times (a few seconds to several hours).

- **System Size Calculations:** Storage of energy is measured in terms of the maximum rated power capacity (instantaneous charge/discharge, MW) and total energy storage capacity over time (MWh). The design of system size will depend on many factors. The major challenge is the difficulty in predicting instantaneous energy production and demand due to their dynamic nature. There are also compounded impacts, such as during rainy days when the plant has a high energy demand and is less likely to produce large amounts of solar energy. Among the major considerations include the charging duration and rate. How quickly the energy storage technology can recharge may also influence when and how often recharging of the system is accomplished.

7.3 Challenges

A key initial challenge for application of electrical energy storage system for MMSD is the preliminary engineering required to identify the right system. Energy storage systems vary greatly in their applications and each technology has benefits and drawbacks. Selection of the technology and system size is critical to success of an energy storage project. Given the unknown future portfolio of internal renewable sources, it is difficult to predict specific applications of energy storage. Some challenges for deployment of electric energy storage systems recognized by the U.S Department of Energy include the following:

- **System Installation and O&M Cost:** The physical components of energy storage technologies account for approximately 30-40% of the overall system cost [35]. Remaining costs include engineering services, construction, and integration with electrical distribution infrastructure. It is important to acknowledge that electrochemical batteries have shorter lifespans (10 to 15 years) compared to solar or wind energy assets which may last twice as long. Similar to PV modules, electrochemical batteries lose efficiency as they age. It is critical to understand the factors that impact a battery's ability to store energy as it ages and to factor in the cost of replacement. Understanding the intricacies of asset management and optimization is highly complex.

- **Regulatory Uncertainty:** Variations in application of energy storage technologies allows for uncertainty in the regulations that apply to a given project [35]. Regulatory uncertainty is an investment risk [35]. MMSD will be required to follow the interconnection rules of the Public Service Commission of Wisconsin and meet all We Energies tariff requirements. We Energies allows for interconnections of systems up to 15 MW. Discussions with We Energies would be required to determine utility-scale electrical energy storage requirements.

- **Stakeholder Coordination:** Cooperation of a wide variety of stakeholders is necessary to execute an energy storage project. Stakeholders may include electric utilities, technology experts, project engineers, developers, facility owners, and the local community [35].

- **Performance and Safety:** An energy storage system must be reliable and safe for operators and in terms of its potential impact on the overall electric grid [35].

7.4 Summary

Energy storage will be an integral component to meeting MMSD's 2035 Vision. Further investigation is required to address the challenges and weigh the costs and benefits of an energy storage project. As energy technologies improve over time, energy storage will become more economically viable. Detailed discussions with We Energies would also be required to determine system requirements and rate structures.

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Appendix A: Task B.2 2015 Energy Plan Alternatives Matrix

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
1	Process Modifications	Optimize biosolids transfer between plants for energy generation and use	Recommended	Cary Solberg (CS) comment: IPS pumping pressure is ~2X higher and pumps use significantly more energy than when system was first started. IPS pipelines were not routinely pigged nor cleaned, if ever. Project P01005 will clean and pig all pipelines in 2022-2023. Pipeline cleaning should reduce pump pressure and reduce energy consumptions. Veolia will have to routinely pig pipeline to keep in clean moving forward. Dave Woznicki has more info if you need it.	South Shore Water Reclamation Plant (SSWRF) has 1200HP of pumping to Jones Island Water Reclamation Plant (JIWRF). JIWRF has similar for pumping to SSWRF. 2015 Energy Plan shows that it would save costs.
2	Process Modifications	Optimize influent flow split between plants	Recommended	Previously this was found to not be feasible, however GH should evaluate in the conveyance system analysis of the Energy Plan CS comment: GH to evaluate during conveyance assets analysis	IPS pump station is located at JIWRF and pumps have two head tanks. One for pumping to JIWRF and one for pumping to SS. The height the SS head tank is about 50 feet higher than JIWRF so pumping is higher. If possible, tunnel water should be treated at JIWRF to save this incremental energy. JIWRFpower totals include IPS tunnel pumping which is actually part of Conveyance.
3	Process Modifications	Purchase more green energy from WE	Recommended	Is in MMSD back pocket – up to 20% of portfolio	N/A
4	Process Modifications	Bypass JI high-level screw pumps	Not recommended	Not applicable - Based on memo to CCO need to wait to motor upgrades are complete.	If treatment is possible without High Pumps allot of energy could be saved. Qty 4 Low Level screw pumps each have 350HP drive motor. Qty 5 High Level screw pumps each have 350HP drive motor. Not recommended based on MMSD comments.
5a	Process Modifications	Decrease number of aeration basins online	Recommended	Part of J02012	PAC Blower 1 was replaced with a High Eff Blower and 4,500HP Motor in 2013 contracts (Procurement J02008C02 Install J02008C03.) PAC Blowers 2,3,4 are constant speed 5500HP with inlet guide vanes to control capacity. Could look at how much energy could be saved with VFDs on existing 5500HP synchronous motors or replacing blowers and motors like PAC 1. Based on 2015 Energy Plan, doing this would require decreasing SRT, which would impact nutrient removal. Also would cause more WAS that needs to be treated so would need to coordinate with Alternative 1.
5b	Process Modifications		Recommended	Will be addressed in the S02015 aeration project. CS comment: I don't understand this recommendation. Not sure S02015 is addressing this.	Project is upgrading aeration basins and media. Existing Blowers are siemens turblex constant speed with inlet guide valve to control capacity. Could look at how much energy could be saved by changing to VFDs. Qty 4 Blowers each with 1600HP Induction Motor.

Legend:

Recommended
Not recommended
To be analyzed after BAFP
Already implemented

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
6	Facility Optimization	Optimize pumping energy using PLCs	Recommended	PLCs and VFDs upgrades leading to energy savings. MMSD to obtain more information. CS comment: Project J02013 identified RAS control improvements and will test 2' secondary clarifier blanket during dry weather (instead of 1') to save energy and chemicals during thickening. Project S02018 will replace 5 RAS pumps (already have VFDs). This project is modeling the RAS system to confirm conditions for the replacement pumps. System model could be used to ID best ways to operate pumps to maintain WRF performance and minimize energy use.	GH will evaluate pumps that have not had PLC ugrades.
7	Process Modifications	Use CEPT to reduce aeration energy and increase primary sludge/digester gas	Recommended	S01013 will be evaluating	Would need to implement chemical systems. Also would produce more primary sludge, so would need to evaluate with Alternative 1.
8	Process Modifications	Modify/optimize activated sludge process for energy	Recommended	Part was done by Donohue S02008 and further touched under 2015. Not sure what this will do for us for energy purposes. CS comment: S02008 (Capacity Improvements) restored step operation in basins 1, 2, 27, and 28, and will replace baffles and skirts in front secondary clarifiers to improve performance in wet weather. Project S02015 (Aeration Improvements) is includes scope to optimize aeration control.	SSWRF RAS pumps have VFDs. JIWRF RAS pumps have VFDs. Could look to see if control strategies to lower return rates are used.
9	Facility Optimization	Optimize waste heat pressure control	Recommended	JIWRF waste heat boiler. This will not be addressed in the biosolids project. They will mention how much waste heat they plan to use. GH to evaluate.	It might be good to minimize use the waste heat boilers and direct as much waste heat as possible to Milorganite drying.
10	Process Modifications	Increase SRT to reduce solids processing energy	Recommended	SRT South Shore defined from 2015 project driven by process. Implementing newer control strategies. May have some benefit there but nothing with JIWRF at the moment.	Negatively impacts phosphorus removal. Need input on the District's permit limits and preferences.
11	Process Modifications	Decrease activated sludge SRT	Recommended	S02015 project. Setting the SRT. M03102 - BAFP	Negatively impacts phosphorus removal. Need input on the District's permit limits and preferences.
12	Process Modifications	Increase belt press feed solids concentration to increase cake solids	Recommended	There has been some work to provide more consistent belt filter press solids. Limited to what screws and dryers can handle. May be touched in biosolids facilities plan. CS comment: Project J04037 is also evaluating this - either by additional thickening and sludge mixing at SSWRF before sending to JIWRF via IPS, or by installing 5th GBT in building 256. We are coordinating activities in this project with M03102 BAFP. Moving forward with installation of 5th GBT - by end of 2023.	Energy Plan says this is already being evaluated by MMSD and it seems there's multiple projects already looking into this too.

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
13	Non-Process Facility Optimization	Improved control of plant-wide HVAC control	Recommended	HVAC control considered at both JIWRF and SSWRF. General building by building approach and projects addressing it. Headquarters have recently updated. 13th street under design. No district wide plan. As needed. Improve Plant Wide HVAC control at JIWRF MCRR? JIWRF has Johnson Controls Metasys building management system (BMS) for HVAC only. Many JIWRF buildings on the JCI Metasys network, but not sure if the HVAC systems are proactively monitored or controlled by VWM. SSWRF has Honeywell BMS with some buildings on the network, but not sure if the HVAC systems are proactively monitored or controlled by VWM.	N/A
14	Facility Optimization	Automate real-time energy optimization control and monitoring	Recommended	MMSD implemented software to bring SSWRF on-line if there is a power outage (Enercon). It currently doesn't work properly and needs to be fixed before real-time control can be implemented. Other major equipment has monitoring, but CHP, and MCCs don't have it. MMSD would like to have this level of monitoring. CS comment: I don't understand relationship of the bold text to this alternative. We are troubleshooting/improving the relay protection and generator system controls to recover from a utility power outage more efficiently. However, I don't understand why energy optimization control and monitoring is dependent on our ability to recover from a power outage. CHP definitely has power monitoring. We know how much electricity energy and heat the units deliver. 1st step is to make sure we can monitor power use at appropriate points in our system. Some SWGR and MCCs have power monitoring linked to the Historian, but Rockwell technology has not been reliable and needs to be replaced. Currently, Lauren Abramczyk is now primarily responsible to improve our ability to monitor power at MCCs and SWGR. However, MMSD effort to date has primarily been via O&M budget and capital project work has been higher priority. Newer (say last 5-8 yrs) VFDs 50 HP and larger provide power use data to the Historian.	Recommended based on meeting minutes.
15a	Process Modifications	Improve JI primary treatment efficiency	Recommended	J01027 just kicked off which will evaluate this. This is a planning project to establish construction project later. J1026 may have been painting or rehabbing piping.	Evaluate with Alternatives 1 and 7.
15b	Process Modifications	Improve JI primary clarifier operations/removal efficiency	Recommended		Evaluate with Alternatives 1 and 7.

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
16	Process Modifications	Heat sludge and polymer solution to improve cake solids	To be analyzed after BAFP	Kevin Jankowski (KJ): I am unfamiliar of any work investigating heating sludge and polymer to achieve this. There is interest and efforts to increase the BSD %TS from 3.25 to 4% going to the BFPs. I believe the intent is to then reduce the volume in the BFPs and in turn increase the cake solids.	This process modification will make sense if heat is recovered from other sources.
17	Process Modifications	Use waste heat to heat biological process at JI	Not recommended	JIWRF has such a large use of heat with dryers that there is no need to use waste heat in aeration basins. Benefit is to make waste heat more efficient. Marginal gains for aeration may not be worth it.	Not recommended based on meeting minutes.
18	Equipment Improvements	Install high-efficiency plant lighting	Recommended	Completed at D&D and 13th street. Not all buildings at JIWRF have been upgraded. Definitely a benefit and easy to update but it is a slow process. Classified areas are more challenging. CS comment: D&D Completed. PRS should have the latest on this. 13th/College has LED. I think site lighting is now LED. Portions of select buildings now have LED. J01013 Preliminary Facility Electrical Upgrade will provide LED in some areas of the building where lighting needs to be upgraded to meet NFPA requirements.	Recommended based on meeting minutes.
19a	Non-Process Facility Optimization	Maximize SS digestion: optimize digestion, no co-digest	Recommended	Biosolids advanced facility plan (BAFP) will be looking to make improvements – these recommendations will probably make energy recommendations as well. District converted an old storage tank (130,000 cu. ft.) into a HSW receiving station. They do receive HSW from InSinkErator. TS- 10%. Airport deicing waste also fed in – propylene glycol. Cannot receive fats, oils and grease (FOG) in that system which restricts what they can take in. Funding policy has prevented MMSD from bringing in more HSW. Have to allow people within service area to contribute in order to allow additional use. S04031 looked at using digester gas for vehicle fueling but MMSD wasn't in favor due to all digester gas being used for this. Could be a potential for how to use excess gas at SSWRF while taking advantage of the Renewable Fuel Standard. Comparison of solar vs HSW when trying to get to 100%. M03102 - BAFP as requires upgrade to dryers and infrastructure. CS comment: Project S04035 replacing mixers in Digesters 6 and 8. New mixers are linear motion and use less energy than old draft tube mixers. Linear motion mixers are estimated to save ~130,000 kWh of electricity per year. The draft tube mixers were very old, so digester performance and gas production will improve because of the new linear motion mixers.	N/A
19b	Non-Process Facility Optimization	Maximize SS digestion: HSW to meet 4 MW power production	Recommended		N/A

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
20	Energy Generation Improvements	Solar power generation	Recommended	Nothing new has been constructed. 2050 FP recommended installing solar panels as SSWRF. Internally MMSD is looking at whether they want to do solar or HSW or other options with the investment. Many of the buildings at JIWRF already have solar when roof space is available. CS comment: Some analysis complete - will provide info.	Recommended based on meeting minutes.
21	Energy Generation Improvements	Wind energy generation	Recommended	Karen Sands (KS) provided info regarding why the wind energy opportunity was found to be not feasible for MMSD, Brittany Hess (BH) to share that information with GH. Horizontal wind turbines were analyzed. JI wouldn't generate enough energy for windmill. Former PM looked at advertising to cover investment but MMSD was concerned that it could be used for political advertisement, so the ideas was turned. KS mentioned its worthwhile to revisit generation in the 2020 EP. CS comment: Some analysis complete - will provide info.	GH has received and reviewed the Wind Energy Site Assessment prepared by Kettle View Renewable Energy.
22	Process Modifications	Recover heat from dryer exhaust	Recommended	They have not considered recovering heat from dryer exhaust. Dryer exhaust is treated so there are no pollution issues. There should be total airflow and temperature data from dryer exhaust (1000F).	This is the heat that is going up the stack at JIWRF. Waste heat comes out of dryers goes through ID Fans which keep slight negative pressure in Dryers goes through Electrostatic Precipitators and then goes out through JIWRF stack.
23	Equipment Improvements	Capture more heat from combustion engines	Recommended	Has not been explored yet. KJ doesn't remember it being evaluated in the 2050 FP. Already capturing heat from engines jackets; however, cannot be beneficially utilized during summer due to no need for heating loads. KJ is not sure if they have absorption chillers. CS comment: All SS engine-generators have engine jacket cooling as Kevin notes above. Engine-generators 1-4 also have heat capture on engine exhaust. Not sure about Gen 5.	N/A
24	Equipment Improvements	Implement JI aeration control using DO and Ammonia	Recommended	J02012 would cover this alternative. Old SS DO meters were moved to JIWRF. Not every basin has them and they are not integrated for control. Failure of probes at SSWRF raises questions for possibility of system at JIWRF. BH to provide additional background. CS comment: J02012 scope is evaluating improved DO probes and control, but not ammonia/nitrate probes or control.	DO Control is necessary if serious about energy savings. DO probes are always a maintenance issue but new LDO type are much better than old types.

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
25	Equipment Improvements	Implement SS aeration control using DO and Ammonia	Already implemented	This has been completed. Basins are undersized based ton loading; therefore, basins are still inefficient. SR2015 improving basins will improve this – in design (30% efficiency goal from this project for the aeration system). CS comment: S02015 - SS Aeration Project A primary goal of S02015 is energy efficiency	Already done based on meeting minutes
26	Equipment Improvements	Install turbine waste heat landfill gas duct burners	Not recommended	(about 40% of digester gas is flared) (LFG gas if flared is flared at the landfill) CS comment: Duct burners should not be pursued. J06037 looked at alternatives to use more LFG, including duct burners, and concluded the best way to use more is dryer burners. We will have 4 dryer burners in June 2021 and could expand to more dryers if there is enough LFG. We have enough equipment at JI and SS to use all available LFG and DG. Best way to use all DG and LFG is to improve our equipment uptime so it is available to use it. If we need to invest, we should manage equipment maintenance as proactively as possible. Some of the LFG flared is due to performance issues at the Emerald Park Landfill that MMSD cannot control.	2015 Energy Plan said this was evaluated separately from the 2015 Energy Plan. Not recommended based on MMSD comments.
27	Equipment Improvements	Install air heater to use landfill gas	Not recommended	CS comment: See item 26 above.	2015 Energy Plan said this was evaluated separately from the 2015 Energy Plan. Not recommended based on MMSD comments.
29	Energy Generation Improvements	Implement SS UV disinfection	Not recommended	S03113 evaluating disinfection. Meeting E-Coli permit in future. UV may be investigated in the future. Currently they use chlorination.	UV is energy intensive and would not reduce energy.
30	Non-Process Facility Optimization	Influent heat recovery using heat pumps	Recommended	Sewer heat recovery discussion to continue during the renewables meeting. There is a potential for HVAC loads. This may be applicable at conveyance system sites. CS comment: J06083 HVAC project will evaluate east side central heat system for B234, 235 and 243 using effluent heat pumps.	N/A
31	Non-Process Facility Optimization	Large scale effluent heat pumps	Recommended		N/A
32	Energy Generation Improvements	Thermal energy generation in collection system	Recommended		N/A
33	Equipment Improvements	Recuperative sludge thickening at SS	Recommended	Veolia bundle project from 2010 and 2012 – Cost reduction technique	N/A

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
34	Equipment Improvements	Change JI channel mixing to large bubble mixers	Recommended	Nothing has been done. J02012 aeration consideration. Difficulty with accessing the panels because basins are always in service. Better to add diffusers. GH to check 2015 EP if numbers are still relevant. CS comment: J02012 included preliminary engineering by MMSD staff (Bill Farmer and now Elaina Plinke). The benefit in energy savings does not outweigh the cost at this time. Changing mixing in the aerated channels is not cost effective until the existing diffuser system needs to be replaced, because access into the covered channels is difficult with major capacity reductions to do the work. J02012 is still looking at low hanging fruit to reduce energy use for aeration at JI.	N/A
35	Equipment Improvements	Increase waste heat boiler efficiency	Recommended	Waste heat boiler is specific to JIWRF which is used for boiler loop heating demands. (may be steam of hot water).	Coordinate with Alternatives 22 and 23.
36	Facility Optimization	Increase use of waste heat from internal combustion engines	Recommended	N/A	Evaluate with Alternative 23.
37	Facility Optimization	D&D process energy optimization	To be analyzed after BAFP	Waiting on results from BAFP Also see alternative #12 above.	N/A
38	Facility Optimization	Evaluate potential ventilation energy savings in D&D building	Recommended	CS comment: Will the D&D dust modeling project evaluate the air imbalance in D&D? GH response: No, evaluating overall air imbalance in D&D is not part of the scope of work.	This requires a holistic ventilation analysis with all process ventilation equipment, including the dryers, the dust collection system and the make-up air system for the entire building. During the J04073E01 contract, it was determined that the D&D building is maintains a significant negative pressure differential in the winter season which leads to additional ventilation issues in buildings connected through the tunnel to the D&D. Improving make-up air in the D&D will demand additional heat, therefore we recommend including this alternative as part of this energy plan.
39	Equipment Improvements	Replace JI panel diffusers with membrane diffusers to increase oxygen transfer efficiency and better match aeration demands	Recommended	CS comment: This alternative may gain traction when condition of existing panel diffuser system dictates a full system replacement is needed (e.g. SS S02015). KJ Comment: Agree, although we find there isn't an increase in OTE, but a better use of air where we need it.	Comment in 2015 Energy Plan says panel diffusers were not replaced but were tested. Coordinate with Alternative 43.
41	Equipment Improvements	Install variable frequency drives for pumps, fans, and other equipment	Recommended	CS comment: J04046 installed VFDs on D&D Dryer ID fans. Received FOE grant. I can provide info. S03004 will replace soft-starts on 3 effluent pumps with VFDs. The other 2 pumps already have VFDs. I am not aware of any other projects that will replace major VFDs.	N/A

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
42	Equipment Improvements	Install high efficiency blower	Recommended	CS comment: MMSD should serious consider install of 2nd high-efficiency blower on VFD at JIWRF. Single high-efficiency blower at JI is under-utilized because of operational constraints, plus older Allis-Chalmers blowers and exciters continue to deteriorate. Older blowers limit our ability to save energy. Older blowers cannot turn down below average DO loading, so if we want to operate DO control during lower loading periods to save energy, we can only use high-efficiency blower. KJ Comment: Agree, both a type of blower (probably PAC 1 w/VFD) and quantity question.	Comment in 2015 Energy Plan says this has already been implemented. Recommended based on MMSD comments.
43	Equipment Improvements	Replace SS existing diffusers with more efficient diffusers to increase oxygen transfer efficiency and better match aeration demands	Recommended	CS comment: S02015 scope includes full diffuser system replacement at SSWRF. Energy efficiency is a focus of S02015.	Comment in 2015 Energy Plan says panel diffusers were not replaced but were tested. Coordinate with Alternative 39. Recommended based on MMSD comments.
44a	Energy Generation Improvements	Send excess heat to nearby industries, commercial buildings, and residences: captured heat to nearby industry	Recommended	N/A	N/A
44b	Energy Generation Improvements	Send excess heat to nearby industries, commercial buildings, and residences: use heat onsite	Recommended	N/A	N/A
45	Process Modifications	Anaerobic sludge pretreatment and conditioning methods	Recommended	N/A	N/A
46	New Process Facilities	Ostara/ANITA™ Mox – Biosolids Bundle Project #3	Recommended	N/A	N/A
47	Energy Generation Improvements	Algae bioreactor for biofuel production (large scale)	Recommended	N/A	N/A
48	New Process Facilities	Change anaerobic digestion operation (e.g., from mesophilic to thermophilic or acid-gas)	Recommended	N/A	N/A
49	Facility Optimization	Consolidate process facilities	Not recommended	Not applicable - based work that was done under the 2050 FP	Not recommended based MMSD comments
50	New Process Facilities	Low energy ammonia removal (e.g., ANAMMOX) – mainstream at SS and JI	Recommended	N/A	N/A
51	New Process Facilities	Algae bioreactor for P removal	Recommended	N/A	N/A
52	New Process Facilities	Microbial fuel cells	Not recommended	N/A	N/A
53	New Process Facilities	Anaerobic secondary treatment	Not recommended	Not applicable - this can be disregarded	Not recommended based MMSD comments
54	New Process Facilities	Solar drying	Not recommended	N/A	N/A
55	New Process Facilities	Composting (including numerous composting technologies)	To be analyzed after BAFP	N/A	N/A
56	New Process Facilities	Geothermal energy (large scale)	Not recommended	N/A	N/A
57	New Process Facilities	Geothermal energy from Lake Michigan or river coupled with heat pumps (large scale)	Not recommended	N/A	N/A
58	New Process Facilities	Hydroelectric energy from Lake Michigan wave action (large scale)	Not recommended	N/A	N/A
59	Energy Generation Improvements	Drying gasification to produce synthetic gas (syngas)	To be analyzed after BAFP	N/A	N/A
60	Energy Generation Improvements	Pyrolysis of excess Milorganite for heat energy recovery and create biochar	To be analyzed after BAFP	N/A	N/A

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
61	Equipment Improvements	Reconfigure diffuser densities	Recommended	CS comment: S02015 scope includes full diffuser system replacement at SSWRF. Diffuser density and energy efficiency is a focus of S02015. J02012 studied this at JI and this alternative likely not cost effective until diffuser system condition dictates a full system replacement is needed (e.g. SS S02015).	Comment in 2015 Energy Plan says this has already been implemented.
62	Equipment Improvements	Pump base influent flow with higher efficiency pump	Recommended	KJ comment: We did consider non-screw pump type pumps for the raw influent at JIWRF and found marginal benefit. The robustness of the screw pumps was a desirable benefit. The operation still may gain efficiency by modifying the controls of the system to closely match the flows.	Evaluate with Alternatives 4 and 6.
63	Equipment Improvements	Install more efficient lift station pumps	Recommended	KJ comment: I am not sure what this is referring to.	Evaluate with Alternatives 2 and 6.
64	Equipment Improvements	Install high-efficiency motors for pumps, fans, and other equipment at JFWRF	Recommended	N/A	N/A
65	Process Modifications	Energy tariff/demand-side management	Not recommended	KJ comment: We sort of modify our operations to minimize the demand change (primarily the on-peak demand charge), but that is only a cost equation and really doesn't impact overall efficiency or % renewable energy	Not recommended based MMSD comments
66	Process Modifications	Optimize biogas use by having 3rd shift powerhouse operator	Already implemented	KJ comment: We have made improvements to the system in S04031 since the 2015 Energy Plan. Now all conditioned digester gas goes through the spheres and there is a wider operating pressure to help increase storage and minimize flaring. I believe this comment refers the practice of not turning equipment on/off without an operator, so if the spheres filled during off-peak periods the remainder would be flared.	Comment in 2015 Energy Plan says this will be implemented.
67	Process Modifications	Energy savings with improved RAS pumping rates and control	Recommended	N/A	Evaluate with Alternative 6.
68	Non-Process Facility Optimization	HVAC control at major remote sites (conveyance system)	Recommended	N/A	N/A
69	Process Modifications	JI fuel gas compression system energy improvements	Already implemented	N/A	Comment in 2015 Energy Plan says this has been implemented.
70	Equipment Improvements	Improved digester mixing for greater biogas generation	To be analyzed after BAFP	KJ comment: Digester 10, 12, 6, and 8 have new mixers. Digester 9 and 11 have the old atari type mixers. There will most likely be a AD project recommendation from the BAFP that also include mixer upgrades when needed.	Comment in 2015 Energy Plan says this is being implemented.
71	Energy Generation Improvements	Solar power at flow measuring stations or lighting at other low wattage facilities (conveyance system)	Recommended	N/A	N/A
72	Equipment Improvements	General energy/water conservation measures	Recommended	GH to evaluate what measures are applicable.	N/A
73	Non-Process Facility Optimization	Increase natural light in buildings	Recommended	N/A	N/A
74	Non-Process Facility Optimization	Alternative fuel fleet vehicles (i.e., NG, DG, solar, electricity)	Recommended	MMSD prefers to prioritize internal utilization of digester gas and landfill gas before using in fleet vehicles.	GH to further analyze in Task C based on a market analysis and Renewable Fuel Standard opportunities. Evaluate with Alternative 19a.
75	Equipment Improvements	Install new JI Milorganite dryers that use less energy	To be analyzed after BAFP	N/A	N/A
76	New Process Facilities	Dry weather load equalization	Recommended	N/A	Evaluate with Alternatives 82 and 92.
77	Process Modifications	Consolidate or downsize non-process/ administrative facilities	Recommended	GH to evaluate based on the opportunities for space consolidation or downsizing.	N/A

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
78	Energy Generation Improvements	Large-scale hydrokinetic turbines/micro hydropower	Not recommended	N/A	N/A
79	Energy Generation Improvements	Hydroelectric energy from river flow (large scale)	Not recommended	N/A	N/A
80	Process Modifications	Sidestream storage for dewatering or other treatment at convenient time	Recommended	N/A	Evaluate with Alternatives 72, 82, and 92.
81	Equipment Improvements	Install new air flow control valves on aerated channels	Already implemented	CS comment: There was an issue with older gate valves, but J02008 aeration project installed butterfly valves downstream of gate valves provide capability adjustment. KJ comment: there will be a limit as a minimum airflow has to be provided to the ceramic diffusers.	Comment in 2015 Energy Plan says this has already been implemented.
82	Equipment Improvements	Use smaller pumps for dewatering ISS between rain events and diversions	Recommended	N/A	Evaluate with Alternative 76 and 92.
83	Equipment Improvements	75 hp air compressor replacement on SS blend tanks	Not recommended	N/A	Capital investment for this compressor should be because of process needs, not for energy savings necessarily because the savings associated with a 75 hp motor would be minimal.
84	Equipment Improvements	Address landfill gas air pipe leaks and pressure losses	Recommended	CS comment: LFG air pipe leaks, if they exist, are on the LFG collection system at the landfill. MMSD has no control over landfill collection system, other than maximum 2% O2 limit in LFG contract with the landfill. Pressure losses are dependent on the amount of LFG delivered to MMSD. More gas delivered = more pressure loss. Not sure what else could be done given the infrastructure is in place. I am not aware of any significant pressure losses.	N/A
85	Energy Generation Improvements	Alternative method of powering effluent pumps	Recommended	N/A	N/A
86	Equipment Improvements	Repair aeration header tasks	Recommended	CS comment: J02012 continuing evaluation of leaks in JIWRF west aeration header (formerly VWM/CCO MCRR). We S02017 evaluating condition of SSWRF air header. S02017 will replace branch pipes between blowers and header.	Comment in 2015 Energy Plan says this has already been implemented.
87	Process Modifications	Optimize non-process aeration uses	Recommended	KJ comment: I am not sure what this means, is it talking about low-pressure air being used anywhere outside the aeration basins (aerated channels)? Or is it talking about the leaks?	Comment in EP says this has been evaluated with Alternative 39 and ties in with Alternative 34.
88	Energy Generation Improvements	Low energy ammonia removal (e.g., ANAMMOX sidestream at SS)	Recommended	N/A	Same as Alternative 50.
89	Energy Generation Improvements	Recover hydropower in collection system (large-scale)	Not recommended	N/A	When the water drops 200-300 ft to the tunnel, there is a lot of energy there. However, to take advantage of hydroelectric power, there is a need for flow. This is not consistent during normal dry weather events.
90	Energy Generation Improvements	Solar hot water generation	Not recommended	CS comment: Agreed - not recommended. If we do solar, it should be for electricity because we can use it year round.	N/A
91	Equipment Improvements	Install more efficient effluent pumps	Recommended	N/A	Evaluate with Alternatives 6, 31, 41, 64 and 85.
92	Process Modifications	Throttle back influent gates	Recommended	N/A	Evaluate with Alternative 76 and 82.

2015 Energy Plan Alternatives Matrix Analysis

Alternative No.	Type of Alternative	Description	Recommendation for Evaluation	MMSD Comments	GH Team Additional Comments
93	Equipment Improvements	Modify CISCO network switches	Not recommended	CS comment: Projects J06068 and S06040 recently upgraded networks at JIWRF and SSWRF, respectively and I believe we replaced switches (Scott Guzlecki can confirm and provide more info, if needed).	Network switches are part of the controls architecture. Switches by themselves do not provide energy savings.
94	Energy Generation Improvements	Recover heat from turbine cooling water	Recommended	CS comment: We recover heat from the engine-generator cooling water at SSWRF for digesters and building heat.	Evaluate with Alternative 17.
95	Energy Generation Improvements	Increase JI landfill gas volume	Recommended	CS comment: Evaluated/Implemented J06061 upgraded 4 Milorganite dryers to use LFG, in addition to NG, to improve use of available LFG from Emerald Park Landfill. Project P02004 would provide improvements at WM's Metro Landfill and GFL's Emerald Park Landfill, to get more LFG from Metro, fully treat it at Emerald Park, and then deliver it via MMSD's LFG pipeline to JIWRF. Need to reach LFG agreements with WM and GFL, before we can make improvements to get more LFG. Can covert more dryers to use more LFG, if it is available.	N/A

Appendix B: Conveyance Utility Accounts

Electric Account	Address
WE Elec. Acct. 4160481	2425 E Saint Francis Ave - Saint Francis
WE Elec. Acct. 66092760	4082 N 124th St - Milwaukee
WE Elec. Acct. 223767468	3974 N 51st Blvd - Milwaukee
WE Elec. Acct. 223920134	5581 S New Berlin Rd - Hales Corners
WE Elec. Acct. 244262093	1370 E Chambers St - Milwaukee
WE Elec. Acct. 248032831	7861 N Port Washington Rd - Fox Point
WE Elec. Acct. 255645508	2431 S 124th St - New Berlin
WE Elec. Acct. 257055539	Corner E Oklahoma Ave BTW U I-794 - Milwaukee
WE Elec. Acct. 274781985	4703 N Wilson Dr - Whitefish Bay
WE Elec. Acct. 412749458	3701 N 28th St - Milwaukee
WE Elec. Acct. 444910178	11000 W College Ave - Franklin
WE Elec. Acct. 463186441	8201 W Main St - Milwaukee
WE Elec. Acct. 492156171	1300 W Clybourn St - Milwaukee
WE Elec. Acct. 694974591	8020 W Grange Ave - Greendale
WE Elec. Acct. 809561840	1359 S 84th St - Milwaukee
WE Elec. Acct. 818368955	3460 W Loomis Rd - Greenfield
WE Elec. Acct. 874552735	1123 E Vienna Ave - Milwaukee
WE Elec. Acct. 847737615	Forest Hill Ext E of Chicago Ave - Oak Creek
WE Elec. Acct. 880431201	4021 N 31st St - Milwaukee
WE Elec. Acct. 1033051241	9520 S Pennsylvania Ave - Oak Creek
WE Elec. Acct. 1041169841	4580 S Whitnall Ave - Saint Francis
WE Elec. Acct. 1044297600	4002 N 35th St - Milwaukee
WE Elec. Acct. 1045842350	162 N 44th St - Milwaukee

Gas Account	Address
WE Gas Acct. 1053176267	2702 S 6th St - Milwaukee
WE Gas Acct. 1255256208	510 W Green Tree Rd - Glendale
WE Gas Acct. 2086862564	9409 N Lake Dr - Bayside
WE Gas Acct. 3006783403	2211 S Bay St - Milwaukee
WE Gas Acct. 4604978738	8000 W Wisconsin Ave - Wauwatosa
WE Gas Acct. 6828526107	7509 N Beach Dr - Fox Point
WE Gas Acct. 7039522638	3070 S 6th St - Milwaukee
WE Gas Acct. 7216584027	162 N 44th St - Milwaukee
WE Gas Acct. 7276622093	5101 W Hampton Ave - Milwaukee
WE Gas Acct. 7287026436	7007 N River Rd - River Hills
WE Gas Acct. 7457691116	4830 N 32nd St Unit A - Milwaukee
WE Gas Acct. 7462952519	4830 N 32nd St - Milwaukee
WE Gas Acct. 7693618340	5800 S Howell Ave - Milwaukee
WE Gas Acct. 8627521099	3620 S Clement Ave Side - Milwaukee
WE Gas Acct. 9298451929	1701 N Lincoln Memorial Dr - Milwaukee

Electric Account	Address
WE Elec. Acct. 1055383788	3366 N 51st Blvd - Milwaukee
WE Elec. Acct. 1062725689	1349 E Park Pl - Milwaukee
WE Elec. Acct. 1216304685	1500 S 124th St - West Allis
WE Elec. Acct. 1217989155	8002 W Oklahoma Ave - West Allis
WE Elec. Acct. 1289207497	6001 W Cascade Dr - Franklin
WE Elec. Acct. 1432172767	3203 S 27th St - Milwaukee
WE Elec. Acct. 1479966367	301 N 42nd St - Milwaukee
WE Elec. Acct. 1484995129	1300 W Green Tree Rd - River Hills
WE Elec. Acct. 1640916857	8002 N Whitney Rd - Fox Point
WE Elec. Acct. 1647366631	6019 W State St - Wauwatosa
WE Elec. Acct. 1648209706	9910 W Silver Spring Dr 56N - Milwaukee
WE Elec. Acct. 1650703264	2701 S Chase Ave - Milwaukee
WE Elec. Acct. 1657829163	6310 N Teutonia Ave - Milwaukee
WE Elec. Acct. 1676934812	4298 W Monarch Pl - Milwaukee
WE Elec. Acct. 1828433139	6605 W Brown Deer Rd 88N - Brown Deer
WE Elec. Acct. 1826700913	S 74th St & W Oklahoma Ave - Milwaukee
WE Elec. Acct. 1828499904	3500 S 116th St - Greenfield
WE Elec. Acct. 1844360613	3499 N Cambridge Ave - Milwaukee
WE Elec. Acct. 1865295817	10720 W Coldspring Rd - Greenfield
WE Elec. Acct. 1894095250	1944 N Commerce St - Milwaukee
WE Elec. Acct. 2029936625	2801 W Villard Ave - Milwaukee
WE Elec. Acct. 2030635899	6005 W Mitchell St - West Allis
WE Elec. Acct. 2038660045	7239 W Drexel Ave - Franklin

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 2048768567	5800 W Roosevelt Dr Approx - Milwaukee
WE Elec. Acct. 2250622310	2750 W Silver Spring Dr N56 - Milwaukee
WE Elec. Acct. 2269921728	4341 N 30th St - Milwaukee
WE Elec. Acct. 2292885380	5420 N 76th St - Milwaukee
WE Elec. Acct. 2295310479	10001 W Bluemound Rd - Milwaukee
WE Elec. Acct. 2295339063	715 E Erie St - Milwaukee
WE Elec. Acct. 2436183650	7600 Cedar Creek Rd - Cedarburg
WE Elec. Acct. 2498412885	2409 E Puetz Rd - Oak Creek
WE Elec. Acct. 2624047036	3160 S Vermont Ave - Milwaukee
WE Elec. Acct. 2625045509	11600 W Fairview St - West Allis
WE Elec. Acct. 2667002808	8600 N Green Bay Rd - Brown Deer
WE Elec. Acct. 2819379892	4231 S Honey Creek Dr - Milwaukee
WE Elec. Acct. 2844149535	6245 N 101st St - Milwaukee
WE Elec. Acct. 2866126107	1100 N Hawley Rd - Milwaukee
WE Elec. Acct. 2895452974	1800 E Ontario St - Milwaukee
WE Elec. Acct. 2899234847	1980 W Ryan Rd - Oak Creek
WE Elec. Acct. 3006783403	2211 S Bay St - Milwaukee
WE Elec. Acct. 3026313550	7043 N 91st St - Milwaukee
WE Elec. Acct. 3090294682	4645 N Wilson Dr 6E - Whitefish Bay
WE Elec. Acct. 3239048431	1804 W Bradley Rd - River Hills
WE Elec. Acct. 3241609382	2323 S 1st St - Milwaukee
WE Elec. Acct. 3246376851	2737 W Mill Rd - Milwaukee
WE Elec. Acct. 3265868436	3102 S 11th St - Milwaukee

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 3268352775	6550 W Loomis Rd - Greendale
WE Elec. Acct. 3271980854	1810 W Mill Rd 64N - Glendale
WE Elec. Acct. 3284122991	5367 N Long Island Dr 20W - Milwaukee
WE Elec. Acct. 3400100917	475 W Howard Ave - Milwaukee
WE Elec. Acct. 3410946961	9911 W Concordia Ave - Milwaukee
WE Elec. Acct. 3440041773	2675 N Menomonee - Wauwatosa
WE Elec. Acct. 3461611480	9199 N Green Bay Rd - Brown Deer
WE Elec. Acct. 3471218437	4300 S Barland Ave - Saint Francis
WE Elec. Acct. 3477284471	9415 N Lake Dr - Bayside
WE Elec. Acct. 3496538672	2700 W Canal St - Milwaukee
WE Elec. Acct. 3496646893	8950 W Watertown Plank Rd - Milwaukee
WE Elec. Acct. 3497419818	1701 N Lincoln Memorial Dr - Milwaukee
WE Elec. Acct. 3497959291	3947 N 36th St - Milwaukee
WE Elec. Acct. 3616278162	5901 S Howell Ave - Milwaukee
WE Elec. Acct. 3621342651	171 W Hampton Ave - Milwaukee
WE Elec. Acct. 3683263955	2200 W Van Beck Ave - Milwaukee
WE Elec. Acct. 3863069786	548 W Laramie Ln - Bayside
WE Elec. Acct. 4044123957	N Point Dr & Indian Crk Pkwy - Fox Point
WE Elec. Acct. 4054656598	8874 N Regent Rd - Bayside
WE Elec. Acct. 4601178030	2290 Underwood Pkwy - Elm Grove
WE Elec. Acct. 4604978738	8000 W Wisconsin Ave - Wauwatosa
WE Elec. Acct. 4086532214	10450 W Coldspring Rd - Greenfield
WE Elec. Acct. 4089283978	10600 W Fisher Pkwy - Wauwatosa

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 4211196033	3705 W Good Hope Rd 72N - Milwaukee
WE Elec. Acct. 4247768238	942 N Hawley Rd - Milwaukee
WE Elec. Acct. 4250268578	5270 N Milwaukee River Pkwy - Milwaukee
WE Elec. Acct. 4270086803	11510 W Watertown Plank Rd - Wauwatosa
WE Elec. Acct. 4275673397	650 E Erie St - Milwaukee
WE Elec. Acct. 4288603523	5133 S 76th St - Greenfield
WE Elec. Acct. 4414193154	6312 S 92nd St SE Cor - Greendale
WE Elec. Acct. 4499288750	9180 W Bradley Rd 80N - Milwaukee
WE Elec. Acct. 4668065052	W156N8501 Pilgrim Rd - Menomonee Falls
WE Elec. Acct. 4672359898	2237 N Menomonee River Pkwy - Milwaukee
WE Elec. Acct. 4806474255	5022 N Port Washington Rd - Glendale
WE Elec. Acct. 4811367356	2120 S 4th St - Milwaukee
WE Elec. Acct. 4832238887	100 W Cherry St - Milwaukee
WE Elec. Acct. 4867486855	3203 E Edgerton Ave Approx - Cudahy
WE Elec. Acct. 4872394659	8000 W Wisconsin Ave - Wauwatosa
WE Elec. Acct. 4896039511	401 N Water St - Milwaukee
WE Elec. Acct. 4899576708	3701 W Juneau Ave - Milwaukee
WE Elec. Acct. 5008128439	3710 S Clement Ave - Milwaukee
WE Elec. Acct. 5017151295	199 N 25th St - Milwaukee
WE Elec. Acct. 5018078688	3507 W Roosevelt Dr - Milwaukee
WE Elec. Acct. 5026684190	4762 N 60th St - Milwaukee
WE Elec. Acct. 5042280478	702 N 9Th St - Milwaukee
WE Elec. Acct. 5046669671	8710 W Denver Ave - Milwaukee

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 5049257575	Montclaire Ave & N Lydell - Milwaukee
WE Elec. Acct. 5062017953	4703 S Howell Ave - Milwaukee
WE Elec. Acct. 5065622483	8000 W Dickinson St - Milwaukee
WE Elec. Acct. 5079931093	9523 N Broadmoor Rd - Bayside
WE Elec. Acct. 5081965385	SW Corner E Layton Ave & I-794 - Milwaukee
WE Elec. Acct. 5232575142	1600 E Rawson Ave # 1675S - Oak Creek
WE Elec. Acct. 5233536603	8401 N Range Line Rd - River Hills
WE Elec. Acct. 5237572347	5901 W State St - Milwaukee
WE Elec. Acct. 5247904397	E College 1700N on Row W OF Penn - Cudahy
WE Elec. Acct. 5427071159	8400 W Wisconsin Ave - Milwaukee
WE Elec. Acct. 5432844922	2207 S 61st St - West Allis
WE Elec. Acct. 5471652664	4390 N Richards St - Milwaukee
WE Elec. Acct. 5492718854	5441 W Ryan Rd - Franklin
WE Elec. Acct. 5614802617	5701 W Hampton Ave - Milwaukee
WE Elec. Acct. 5616879732	4998 N Lydell Ave - Milwaukee
WE Elec. Acct. 5630696780	2701 W Ryan Rd - Franklin
WE Elec. Acct. 5659186094	S 84th & W Walker St - Milwaukee
WE Elec. Acct. 5686674318	2955 S Chase Ave - Milwaukee
WE Elec. Acct. 5805673237	9314 W Edgewater Dr - Milwaukee
WE Elec. Acct. 5816652388	2103 S 81st St - Milwaukee
WE Elec. Acct. 5861212512	2616 W Villard Ave - Milwaukee
WE Elec. Acct. 6092603182	3500 N Menomonee River Pkwy - Milwaukee
WE Elec. Acct. 6215532260	5706 W Rawson Ave - Franklin

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 6248053578	310 N 40th St - Milwaukee
WE Elec. Acct. 6249725920	4021 S 27 St Approx # - Milwaukee
WE Elec. Acct. 6255872458	6151 W Dickinson St - Milwaukee
WE Elec. Acct. 6257987532	8502 N Seneca Rd - Fox Point
WE Elec. Acct. 6263604231	5200 N Milwaukee River Pkwy - Milwaukee
WE Elec. Acct. 6279966028	10518 W Grantosa Dr - Milwaukee
WE Elec. Acct. 6403938023	301 E Erie St - Milwaukee
WE Elec. Acct. 6409509259	9801 W Green Tree Rd - Milwaukee
WE Elec. Acct. 6412508828	N Lovers Lane Rd & W Hampton Ave - Milwaukee
WE Elec. Acct. 6416927285	8399 Portland Ave - Milwaukee
WE Elec. Acct. 6422703844	2909 E Forest Hill Ave - Oak Creek
WE Elec. Acct. 6434585954	16252 W Rogers Dr - New Berlin
WE Elec. Acct. 6456776093	759 S 12th St - Milwaukee
WE Elec. Acct. 6460386605	11601 W Greenfield Ave - Milwaukee
WE Elec. Acct. 6480448919	6312 S 92nd St East - Greendale
WE Elec. Acct. 6622803503	Grange Ave & WE Row W OF Penn - Cudahy
WE Elec. Acct. 6648769202	360 E Brown Deer Rd - Bayside
WE Elec. Acct. 6657183836	4470 S Pennsylvania Ave - Saint Francis
WE Elec. Acct. 6813847733	3105 N Menomonee River Pkwy - Milwaukee
WE Elec. Acct. 6825728154	3301 W College Ave - Franklin
WE Elec. Acct. 6828526107	7509 N Beach Dr - Fox Point
WE Elec. Acct. 6832439000	4002 N Humboldt Blvd - Milwaukee
WE Elec. Acct. 6848951204	3755 S 6th St - Milwaukee

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 6860687338	10672 Underwood Pkwy - Milwaukee
WE Elec. Acct. 6886897192	4300 S Barland Ave NE Corner - Saint Francis
WE Elec. Acct. 7023919054	2601 W Pioneef Rd - Mequon
WE Elec. Acct. 7039522638	3070 S 6th St - Milwaukee
WE Elec. Acct. 7042053339	5101 W Hampton Ave - Milwaukee
WE Elec. Acct. 7056065409	1711 N Commerce St - Milwaukee
WE Elec. Acct. 7070768176	9225 N Green Bay Rd - Milwaukee
WE Elec. Acct. 7082694029	450 N 44th St - Milwaukee
WE Elec. Acct. 7206038429	S 60th St & KK River Pkwy - Milwaukee
WE Elec. Acct. 7215414624	2403 W Dean Rd W85 - River Hills
WE Elec. Acct. 7274829647	2411 S Saint Clair St - Milwaukee
WE Elec. Acct. 7438961844	S Ryan Green Ct - Franklin
WE Elec. Acct. 7444358077	2644 S Chase Ave - Milwaukee
WE Elec. Acct. 7448705223	2200 S Bay St - Milwaukee
WE Elec. Acct. 7454952292	1610 W Canal St - Milwaukee
WE Elec. Acct. 7455531582	9401 S Howell Ave - Oak Creek
WE Elec. Acct. 7459385871	11060 W Hampton Ave - Milwaukee
WE Elec. Acct. 7467280698	5901 W State St - Milwaukee
WE Elec. Acct. 7634462746	1883 N Water St Rear - Milwaukee
WE Elec. Acct. 7655281965	3421 N Cambridge Ave - Milwaukee
WE Elec. Acct. 7662623008	12308 W Underwood Pkwy - Wauwatosa
WE Elec. Acct. 7675307611	6223 W Forest Home Ave - Milwaukee
WE Elec. Acct. 7693618340	5800 S Howell Ave - Milwaukee

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 7802259040	5025 W Lincoln Ave - Milwaukee
WE Elec. Acct. 7805890490	2685 S 43rd St - Milwaukee
WE Elec. Acct. 7808283497	101 N 25th St - Milwaukee
WE Elec. Acct. 7835237232	2200 N 113th St - Wauwatosa
WE Elec. Acct. 7881261942	4200 N Eastbrook Pkwy - Shorewood
WE Elec. Acct. 7885487200	4900 W Burnham St - West Milwaukee
WE Elec. Acct. 8003616213	9381 N Pheasant Ln - Bayside
WE Elec. Acct. 8008058015	7100 N Milwaukee River Pkwy - Glendale
WE Elec. Acct. 8009037458	6501 W Ryan Rd - Franklin
WE Elec. Acct. 8015130808	830 W Ryan Rd - Oak Creek
WE Elec. Acct. 8016211777	4302 W Dean Rd - Brown Deer
WE Elec. Acct. 8017040398	2440 S Lincoln Memorial Dr - Milwaukee
WE Elec. Acct. 8027943619	5790 W State St - Milwaukee
WE Elec. Acct. 8035357707	4300 W Selig Way - Milwaukee
WE Elec. Acct. 8046127313	504 E Bruce St - Milwaukee
WE Elec. Acct. 8051367650	20th St & W Garfield Ave - Milwaukee
WE Elec. Acct. 8059276156	5040 S Howell Ave - Milwaukee
WE Elec. Acct. 8068663256	2644 S Chase Ave - Milwaukee
WE Elec. Acct. 8079612292	1901 N Menomonee River Pkwy - Wauwatosa
WE Elec. Acct. 8094573009	4950 W National Ave - West Milwaukee
WE Elec. Acct. 8209519146	S 108 St & W Kelm Rd SW Cor - Hales Corners
WE Elec. Acct. 8226244004	1240 N Old World 3rd St - Milwaukee
WE Elec. Acct. 8252816683	6691 S 68th St - Franklin

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 8256980479	1651 Menomonee River Pkwy - Wauwatosa
WE Elec. Acct. 8263599746	5739 W Rita Dr - Milwaukee
WE Elec. Acct. 8400706745	2121 N Humboldt Ave - Milwaukee
WE Elec. Acct. 8408714105	1600 E College Ave - 2250 S on RO - Oak Creek
WE Elec. Acct. 8409361162	WEPCO Row 1000 ft S OF E - Cudahy
WE Elec. Acct. 8417073242	3500 W Manitoba St - Milwaukee
WE Elec. Acct. 8435318913	2894 S Root River Pkwy - West Allis
WE Elec. Acct. 8438050427	Silver Spring & N 52 St Median - Milwaukee
WE Elec. Acct. 8466257454	510 W Green Tree Rd - Glendale
WE Elec. Acct. 8603495065	5196 N 124th St - Milwaukee
WE Elec. Acct. 8627521099	3620 S Clement Ave Side - Milwaukee
WE Elec. Acct. 8682872535	2966 S 35th St - Milwaukee
WE Elec. Acct. 8802805132	3891 S 27th St - Milwaukee
WE Elec. Acct. 8803801129	4400 N Port Washington Rd - Milwaukee
WE Elec. Acct. 8805295816	2795 E Puetz Rd - Oak Creek
WE Elec. Acct. 8833961281	600 W Ryan Rd N Side - Oak Creek
WE Elec. Acct. 8843753835	4830 N 32nd St - Milwaukee
WE Elec. Acct. 8846130772	N 46th & W State St - Milwaukee
WE Elec. Acct. 8851135814	2433 S 43rd St - Milwaukee
WE Elec. Acct. 8852206910	4183 S Pennsylvania Ave - Saint Francis
WE Elec. Acct. 9000309427	575 W Warnimont Ave - Milwaukee
WE Elec. Acct. 9001552057	9671 S Nicholson Rd - Oak Creek
WE Elec. Acct. 9034960676	3500 N Morris Blvd - Milwaukee

Gas Account	Address

Electric Account	Address
WE Elec. Acct. 9036356661	7900 Portland Ave - Milwaukee
WE Elec. Acct. 9040741338	2809 N Menomonee River Pkwy - Milwaukee
WE Elec. Acct. 9213519431	6000 W Martin Dr - Milwaukee
WE Elec. Acct. 9217586385	100 E Lincoln Ave - Milwaukee
WE Elec. Acct. 9225863908	206 S Underwood Creek Pkwy - West Allis
WE Elec. Acct. 9283599832	2224 S 84th St - West Allis
WE Elec. Acct. 9295965622	5601 S Howell Ave - Milwaukee
WE Elec. Acct. 9406277280	2199 E Montana Ave - Oak Creek
WE Elec. Acct. 9411412362	3020 E Ramsey Ave - Cudahy
WE Elec. Acct. 9445065939	6020 W Arthur Ave - West Allis
WE Elec. Acct. 9453904365	300 W Seeboth St - Milwaukee
WE Elec. Acct. 9487956257	6620 W Loomis Rd - Greendale
WE Elec. Acct. 9494612019	2690 S 6th St - Milwaukee
WE Elec. Acct. 9498383797	W Hayes & S 81st St NW Cor - West Allis

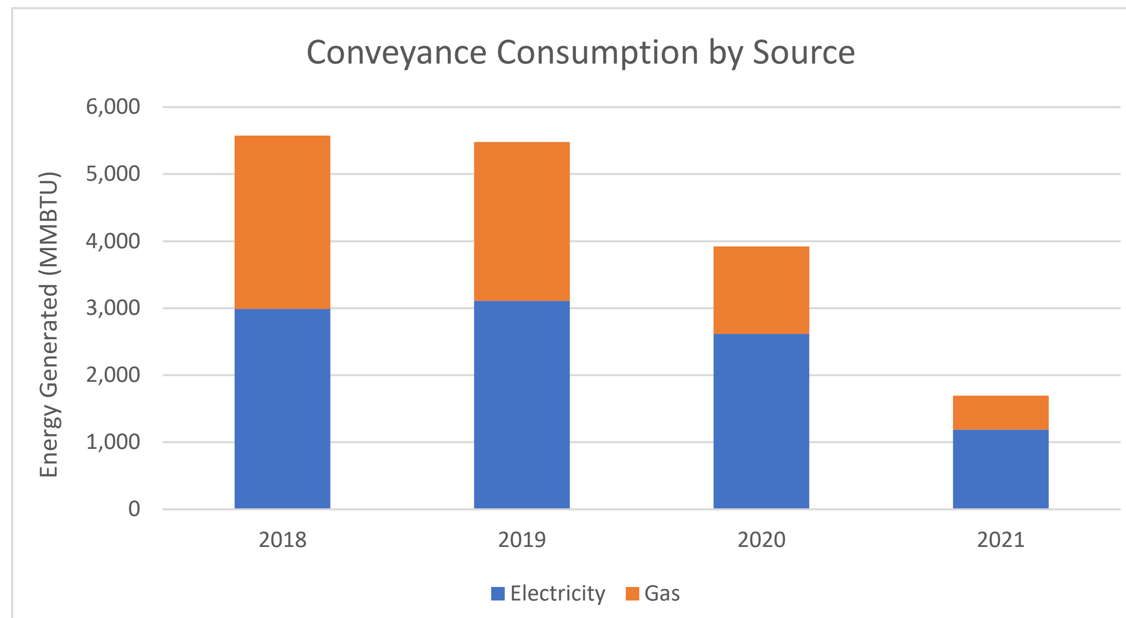
Gas Account	Address

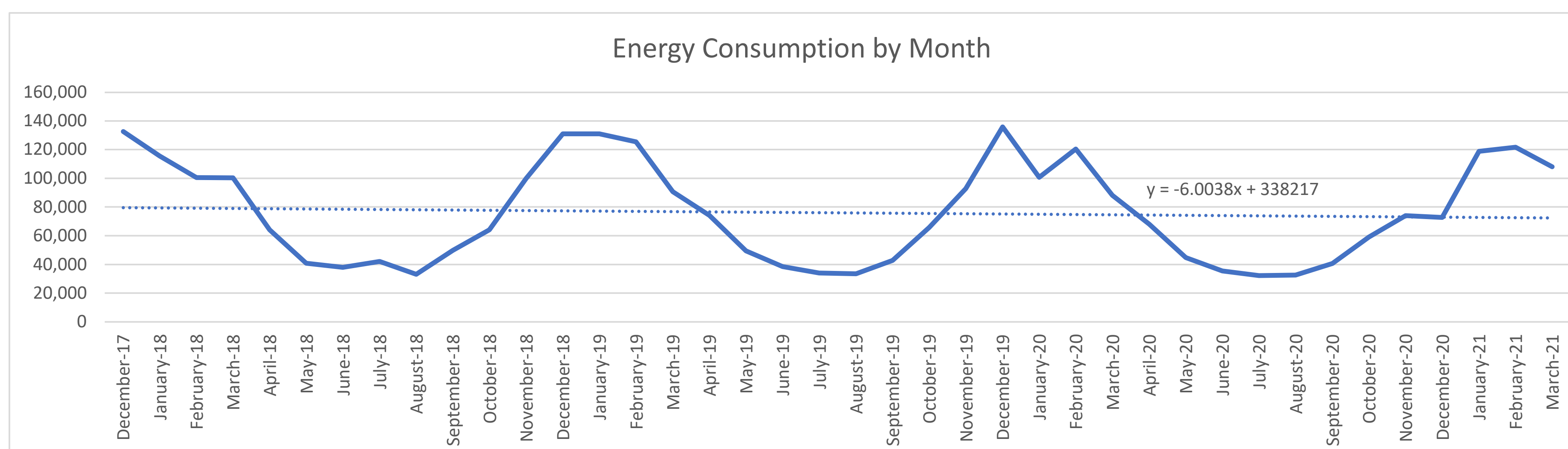
Appendix C: Task B.3 Data Analysis Sheets

Conveyance					
Month	Electricity		Gas		Total
	Total		Total		
	kWh	MMBTU	Therms	MMBTU	MMBTU
December-17	131,996	450	6,318	631.649	132,628
January-18	115,144	393	3,615	361.4136	115,505
February-18	100,098	342	3,542	354.1153	100,452
March-18	100,107	342	3,134	313.3251	100,420
April-18	63,995	218	1,785	178.4573	64,173
May-18	40,833	139	312	31.19254	40,864
June-18	37,926	129	380	37.99092	37,964
July-18	42,040	143	213	21.29491	42,061
August-18	33,048	113	322	32.1923	33,080
September-18	49,610	169	920	91.97801	49,702
October-18	63,769	218	2,666	266.5363	64,036
November-18	99,460	339	4,283	428.1976	99,888
December-18	130,527	445	4,667	466.5885	130,994
January-19	130,410	445	5,289	528.7736	130,939
February-19	125,044	427	3,743	374.2105	125,418
March-19	90,361	308	2,204	220.3473	90,581
April-19	73,980	252	1,302	130.1689	74,110
May-19	49,392	169	564	56.38652	49,448
June-19	38,388	131	396	39.59054	38,428
July-19	34,010	116	699	69.88329	34,080
August-19	33,433	114	580	57.98614	33,491
September-19	42,603	145	950	94.9773	42,698
October-19	65,597	224	2,014	201.3519	65,798
November-19	92,603	316	2,766	276.5339	92,880
December-19	135,593	463	3,169	316.8243	135,910
January-20	100,304	342	3,265	326.422	100,630
February-20	120,253	410	1,951	195.0534	120,448
March-20	87,972	300	2,094	209.34	88,181
April-20	67,904	232	725	72.48267	67,976
May-20	44,741	153	158	15.79622	44,757
June-20	35,495	121	125	12.49701	35,507
July-20	32,297	110	279	27.89333	32,325
August-20	32,504	111	100	9.99761	32,514
September-20	40,523	138	559	55.88664	40,579
October-20	59,039	201	734	73.38246	59,112
November-20	73,845	252	1,520	151.9637	73,997
December-20	72,606	248	1,519	151.8637	72,758
January-21	118,598	405	2,405	240.4425	118,838
February-21	121,452	414	1,780	177.9575	121,630
March-21	107,941	368	898	89.77854	108,031

Energy Conversion Factors					
Natural Gas	1000	CF	=	10	Therms
Fuel Oil #2	1	Gal	=	1.3963	Therms
Energy	1	kWh	=	3412.142	BTU
	1	Therm	=	99976.1	BTU

Summary of Consumption by Source, Per Year (MMBTU)			
Year	Electricity	Gas	% Renewable
2018	2,991	2,583	0%
2019	3,110	2,367	0%
2020	2,619	1,303	0%
2021	1,187	508	0%

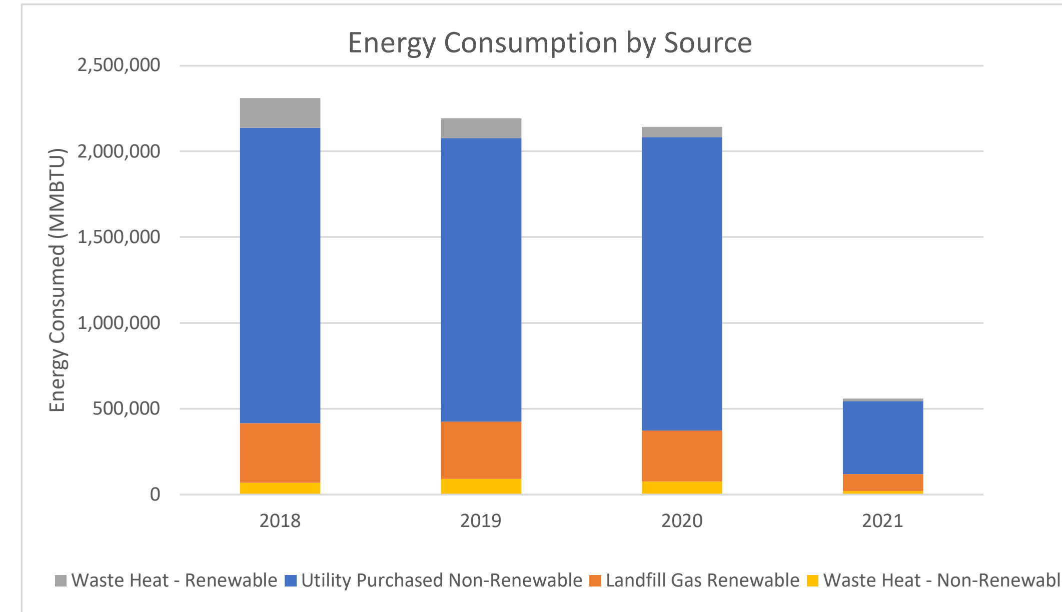




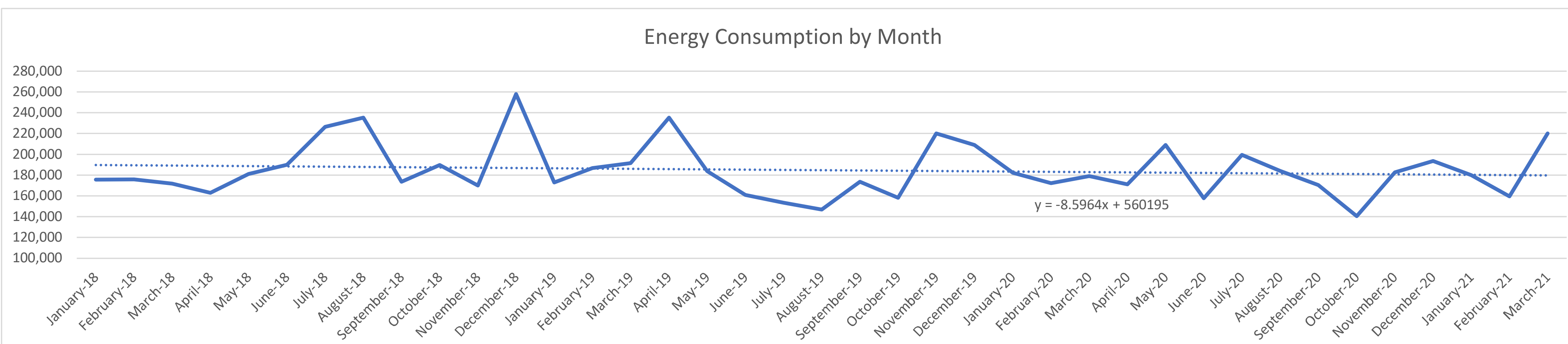
Jones Island Consumption by Source																	
	Total	Purchased							Land Fill		Waste Heat						% Renewable
		Electricity		NG		Oil		Total	LFG		Renewable		Non-Renewable		Total		
Month	MMBTU	kWh	MMBTU	Therms	MMBTU	Gal	MMBTU	MMBTU	Therms	MMBTU	Therms	MMBTU	Therms	MMBTU	Therms	MMBTU	
January-18	175,585	863,955	2,948	1,225,873	122,558	0	0	125,506	380,289	38,020	68,399	6,838	52,226	5,221	120,625	12,060	24.6%
February-18	175,882	1,070,250	3,652	1,244,432	124,413	39	5	128,071	337,144	33,706	89,171	8,915	51,910	5,190	141,081	14,105	22.1%
March-18	171,839	1,590,400	5,427	1,201,631	120,134	40	6	125,567	339,600	33,952	66,134	6,612	57,097	5,708	123,231	12,320	23.1%
April-18	162,918	1,264,973	4,316	1,067,598	106,734	32	4	111,055	388,066	38,797	73,160	7,314	57,530	5,752	130,690	13,066	27.3%
May-18	181,120	2,006,253	6,846	1,196,054	119,577	0	0	126,422	421,477	42,138	76,106	7,609	49,524	4,951	125,630	12,560	26.0%
June-18	189,902	2,127,470	7,259	1,313,381	131,307	160	22	138,588	244,841	24,478	159,792	15,975	108,629	10,860	268,421	26,836	18.6%
July-18	226,524	440,305	1,502	1,529,486	152,912	0	0	154,414	278,479	27,841	432,744	43,264	10,046	1,004	442,791	44,268	12.7%
August-18	235,376	516,664	1,763	1,867,182	186,674	0	0	188,437	209,231	20,918	209,668	20,962	50,606	5,059	260,274	26,021	11.0%
September-18	173,554	3,253,166	11,100	1,228,123	122,783	0	0	133,883	268,630	26,857	74,506	7,449	53,666	5,365	128,172	12,814	18.6%
October-18	189,738	1,899,035	6,480	1,370,197	136,987	0	0	143,467	272,307	27,224	115,233	11,521	75,281	7,526	190,514	19,047	18.3%
November-18	169,973	1,498,020	5,111	1,289,906	128,960	130	18	134,089	195,852	19,581	105,884	10,586	57,184	5,717	163,069	16,303	14.9%
December-18	258,033	442,985	1,512	2,108,583	210,808	36	5	212,324	132,963	13,293	268,717	26,865	55,512	5,550	324,229	32,415	7.3%
January-19	172,828	1,382,868	4,719	1,108,647	110,838	419	58	115,615	421,058	42,096	106,771	10,675	44,435	4,442	151,206	15,117	26.9%
February-19	186,799	1,761,346	6,010	1,294,232	129,392	1,806	252	135,654	258,925	25,886	132,177	13,215	120,466	12,044	252,643	25,258	20.3%
March-19	191,612	2,029,906	6,926	1,237,943	123,765	0	0	130,691	389,088	38,899	115,729	11,570	104,537	10,451	220,266	22,021	25.8%
April-19	235,274	1,001,801	3,418	1,601,189	160,081	38	5	163,504	273,257	27,319	363,363	36,328	81,254	8,123	444,617	44,451	15.1%
May-19	183,839	7,582,676	25,873	1,158,637	115,836	0	0	141,709	386,268	38,618	21,776	2,177	13,352	1,335	35,128	3,512	21.7%
June-19	160,967	6,602,638	22,529	969,467	96,924	0	0	119,453	359,228	35,914	34,957	3,495	21,055	2,105	56,012	5,600	23.6%
July-19	153,333	2,630,651	8,976	1,076,450	107,619	0	0	116,595	283,011	28,294	35,728	3,572	48,724	4,871	84,452	8,443	21.6%
August-19	146,887	1,916,077	6,538	1,083,264	108,301	0	0	114,838	235,756	23,570	36,399	3,639	48,406	4,839	84,805	8,478	19.3%
September-19	173,589	1,137,856	3,883	1,260,981	126,068	0	0	129,950	252,832	25,277	80,326	8,031	103,328	10,330	183,654	18,361	20.5%
October-19	158,131	1,185,359	4,045	1,196,716	119,643	42	6	123,693	269,116	26,905	35,153	3,514	40,191	4,018	75,344	7,533	19.6%
November-19	220,131	629,864	2,149	1,830,364	182,993	0	0	185,142	72,203	7,219	117,822	11,779	159,952	15,991	277,774	27,771	10.5%
December-19	208,883	678,315	2,315	1,721,247	172,084	0	0	174,398	155,931	15,589	74,553	7,454	114,451	11,442	189,004	18,896	12.9%
January-20	182,151	1,258,419	4,294	1,393,373	139,304	100	14	143,612	257,527	25,747	51,510	5,150	76,446	7,643	127,956	12,793	18.3%
February-20	172,133	1,617,895	5,520	1,284,977	128,467	391	55	134,042	250,103	25,004	52,237	5,222	78,659	7,864	130,896	13,086	19.1%
March-20	178,972	1,304,815	4,452	1,362,428	136,210	2	0	140,663	296,749	29,668	35,780	3,577	50,655	5,064	86,436	8,642	19.4%
April-20	171,096	894,409	3,052	1,288,486	128,818	5,293	739	132,609	330,061	32,998	27,922	2,792	26,987	2,698	54,909	5,490	20.9%
May-20	208,958	1,330,007	4,538	1,625,009	162,462	0	0	167,000	222,729	22,268	76,948	7,693	119,997	11,997	196,945	19,690	16.4%
June-20	157,806	2,101,590	7,171	1,134,513	113,424	0	0	120,595	254,281	25,422	50,527	5,051	67,385	6,737	117,912	11,788	20.4%
July-20	199,431	1,773,040	6,050	1,451,461	145,111	0	0	151,161	247,418	24,736	106,187	10,616	129,212	12,918	235,398	23,534	18.9%
August-20	184,099	1,929,116	6,582	1,317,278	131,696	1	0	138,279	252,122	25,206	98,715	9,869	107,475	10,745	206,190	20,614	19.5%
September-20	170,494	534,373	1,823	1,173,004	117,272	1	0	119,096	363,881	36,379	73,377	7,336	76,848	7,683	150,225	15,019	25.8%
October-20	140,558	821,830	2,804	1,130,705	113,043	0	0	115,848	208,615	20,857	19,152	1,915	19,391	1,939	38,543	3,853	16.2%
November-20	182,726	920,493	3,141	1,694,985	169,458	0	0	172,599	101,298	10,127	0	0	0	0	0	0	5.5%
December-20	193,572	629,748	2,149	1,723,194	172,278	5	1	174,428	191,489	19,144	0	0	0	0	0	0	9.9%
January-21	179,858	1,363,864	4,654	1,409,197	140,886	34	5	145,544	343,222	34,314	0	0	0	0	0	0	19.1%
February-21	159,469	1,363,864	4,654	1,037,847	103,760	5,584	780	109,193	361,411	36,132	71,420	7,140	70,047	7,003	141,466	14,143	27.0%
March-21	219,992	1,363,864	4,654	1,658,932	165,854	0	0	170,507	270,621	27,056	86,121	8,610	138,222	13,819	224,342	22,429	18.6%

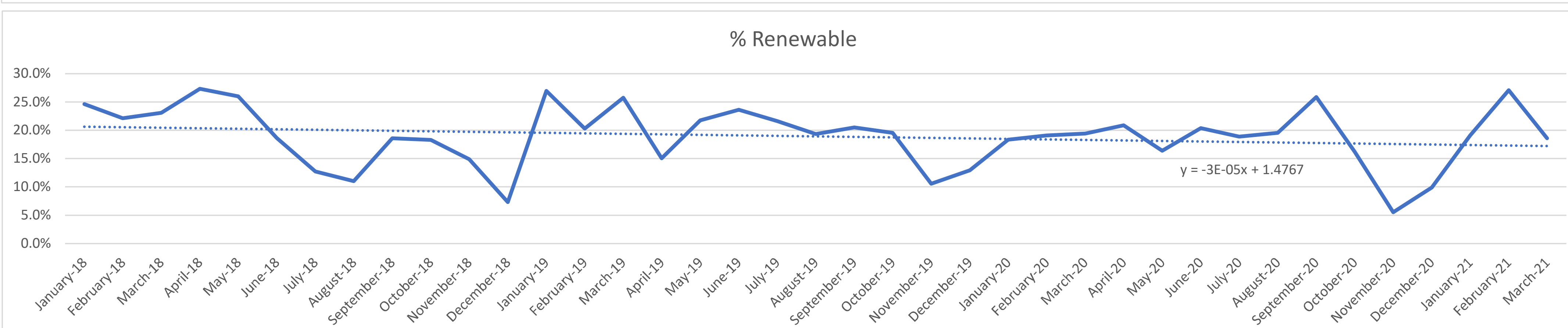
Energy Conversion Factors					
Natural Gas	1000	CF	=	10	Therms
Fuel Oil #2	1	Gal	=	1.3963	Therms
Energy	1	kWh	=	3412.142	BTU
	1	Therm	=	99976.1	BTU

Summary of Consumption by Source, Per Year (MMBTU)			
	Non-Renewable	Renewable	% Renewable
2018	1,789,729	520,715	22.54%
2019	1,741,238	451,035	20.57%
2020	1,785,218	356,778	16.66%
2021	446,067	113,252	20.25%



Summary of Consumption by Source, Per Year (MMBTU)							
Year	Utility Purchased			Landfill Gas	Waste Heat		% Renewable
	Electricity	Natural Gas	Oil	Renewable	Renewable	Non-Renewable	
2018	57,916	1,663,847	61	346,805	173,910	67,905	80.54%
2019	97,380	1,553,542	322	335,587	115,448	89,993	70.65%
2020	51,577	1,657,545	809	297,556	59,221	75,287	73.77%
2021	13,961	410,499	784	97,502	15,750	20,822	76.50%

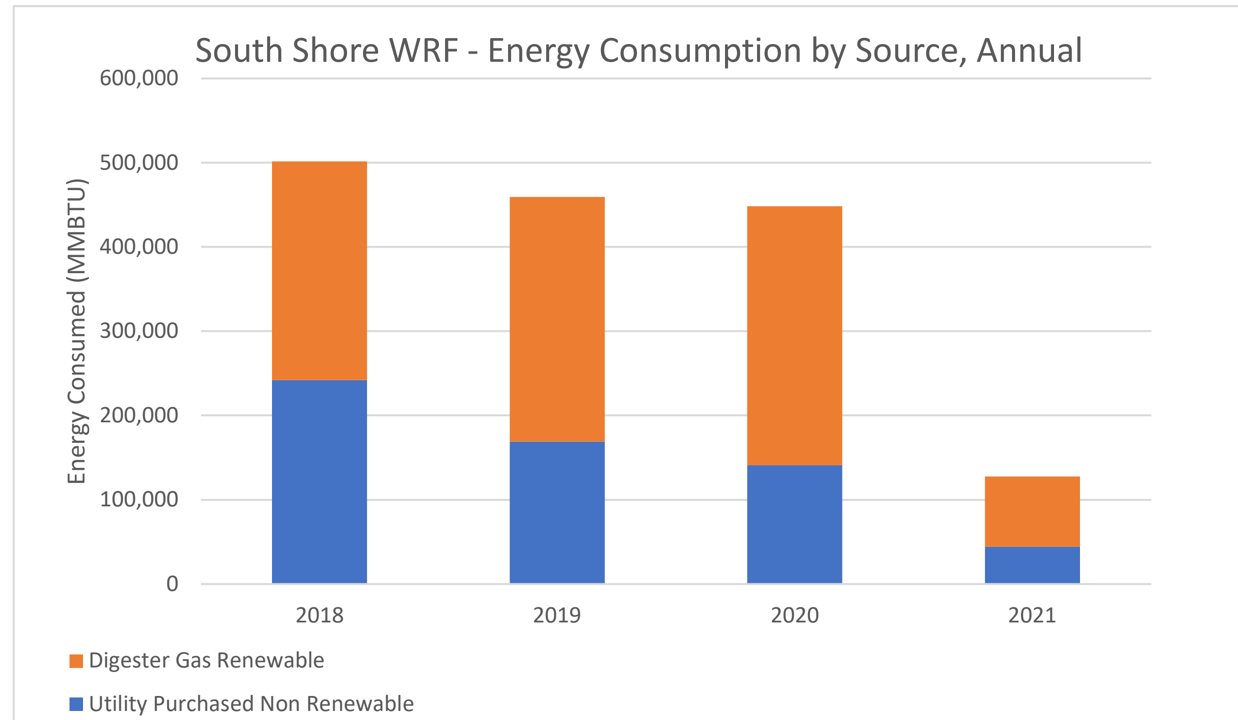


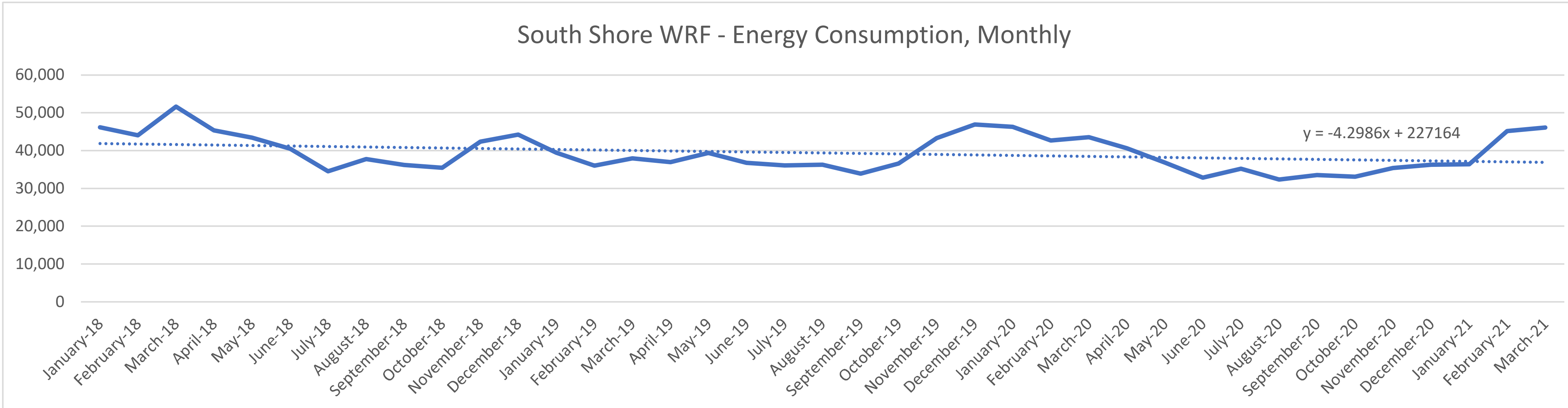


South Shore Consumption by Source									
	Total	Purchased					DG		% Renewable
		Electricity		NG		Total			
Month	MMBTU	kWh	MMBTU	Therms	MMBTU	MMBTU	Dtherms	MMBTU	
January-18	46,151	1,393,835	4,756	232,037	23,198	27,954	18,201	18,197	39.4%
February-18	44,057	1,111,512	3,793	214,646	21,459	25,252	18,810	18,805	42.7%
March-18	51,632	749,913	2,559	201,386	20,134	22,693	28,946	28,939	56.0%
April-18	45,360	945,052	3,225	162,001	16,196	19,421	25,945	25,939	57.2%
May-18	43,396	1,285,722	4,387	110,087	11,006	15,393	28,010	28,003	64.5%
June-18	40,511	1,709,538	5,833	120,724	12,070	17,903	22,614	22,608	55.8%
July-18	34,510	2,054,181	7,009	123,166	12,314	19,323	15,191	15,187	44.0%
August-18	37,724	2,377,097	8,111	35,504	3,550	11,661	26,070	26,064	69.1%
September-18	36,201	2,413,113	8,234	120,911	12,088	20,322	15,883	15,879	43.9%
October-18	35,438	1,279,513	4,366	166,008	16,597	20,963	14,479	14,476	40.8%
November-18	42,344	1,531,484	5,226	157,254	15,722	20,947	21,402	21,397	50.5%
December-18	44,216	821,304	2,802	172,197	17,216	20,018	24,204	24,198	54.7%
January-19	39,416	2,175,319	7,422	103,648	10,362	17,785	21,637	21,631	54.9%
February-19	36,010	1,706,955	5,824	132,169	13,214	19,038	16,976	16,972	47.1%
March-19	37,928	2,452,923	8,370	119,618	11,959	20,329	17,603	17,599	46.4%
April-19	36,966	2,563,487	8,747	28,234	2,823	11,570	25,402	25,396	68.7%
May-19	39,381	2,250,083	7,678	107,729	10,770	18,448	20,938	20,933	53.2%
June-19	36,751	1,951,413	6,658	12,478	1,248	7,906	28,852	28,845	78.5%
July-19	36,068	2,037,996	6,954	4,823	482	7,436	28,639	28,632	79.4%
August-19	36,258	1,007,098	3,436	70,726	7,071	10,507	25,757	25,750	71.0%
September-19	33,859	1,138,951	3,886	38,184	3,817	7,704	26,161	26,155	77.2%
October-19	36,547	1,772,866	6,049	92,672	9,265	15,314	21,238	21,233	58.1%
November-19	43,314	1,299,749	4,435	126,824	12,679	17,114	26,206	26,200	60.5%
December-19	46,923	1,876,651	6,403	93,538	9,352	15,755	31,175	31,168	66.4%
January-20	46,257	1,816,583	6,198	58,810	5,880	12,078	34,187	34,179	73.9%
February-20	42,660	1,289,502	4,400	74,078	7,406	11,806	30,862	30,854	72.3%
March-20	43,508	1,313,190	4,481	69,542	6,953	11,433	32,082	32,075	73.7%
April-20	40,623	1,155,162	3,942	84,959	8,494	12,435	28,195	28,188	69.4%
May-20	36,808	1,238,721	4,227	86,222	8,620	12,847	23,967	23,961	65.1%
June-20	32,812	1,190,128	4,061	63,395	6,338	10,399	22,418	22,413	68.3%
July-20	35,168	1,592,568	5,434	56,428	5,641	11,076	24,098	24,093	68.5%
August-20	32,369	2,671,102	9,114	63,225	6,321	15,435	16,938	16,934	52.3%
September-20	33,498	2,099,745	7,165	61,964	6,195	13,360	20,144	20,139	60.1%
October-20	33,066	2,018,303	6,887	10,217	1,021	7,908	25,164	25,158	76.1%
November-20	35,351	1,912,552	6,526	22,218	2,221	8,747	26,611	26,604	75.3%
December-20	36,240	2,522,040	8,606	49,000	4,899	13,504	22,742	22,736	62.7%
January-21	36,358	34	0	67,950	6,793	6,793	29,571	29,564	81.3%
February-21	45,156	3,355,800	11,450	85,457	8,544	19,994	25,168	25,162	55.7%
March-21	46,057	1,907,689	6,509	109,800	10,977	17,487	28,577	28,570	62.0%

Energy Conversion Factors					
Natural Gas	1000	CF	=	10	Therms
Fuel Oil #2	1	Gal	=	1.3963	Therms
Energy	1	kWh	=	3412.142	BTU
	1	Therm	=	99976.1	BTU

Summary of Consumption by Source, Per Year (MMBTU)				
Year	Utility Purchased Non Renewable		Digester Gas	% Renewable
	Electricity	Natural Gas	Renewable	
2018	60,300	181,549	259,692	81.16%
2019	75,864	93,042	290,514	79.29%
2020	71,039	69,989	307,334	81.23%
2021	17,960	26,314	83,296	82.26%




South Shore WRF - Energy Consumption, Monthly
60,000
50,000
40,000
30,000
20,000
10,000
0
y = -4.2986x + 227164
January-18
February-18
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December-18
January-19
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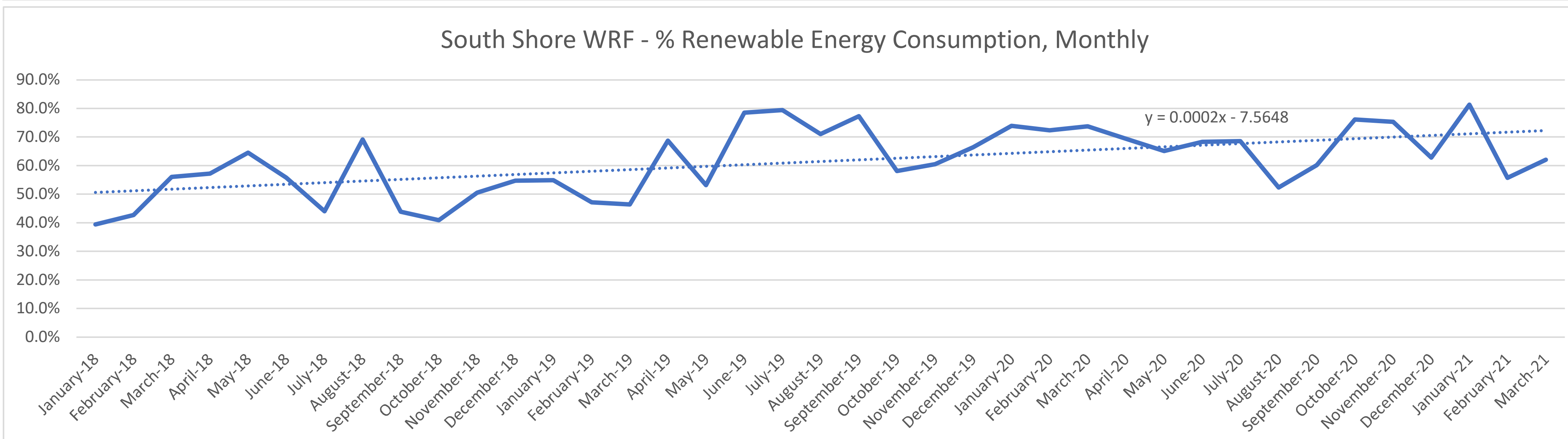
February-21
March-21


South Shore WRF - % Renewable Energy Consumption, Monthly
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
y = 0.0002x - 7.5648
January-18
February-18
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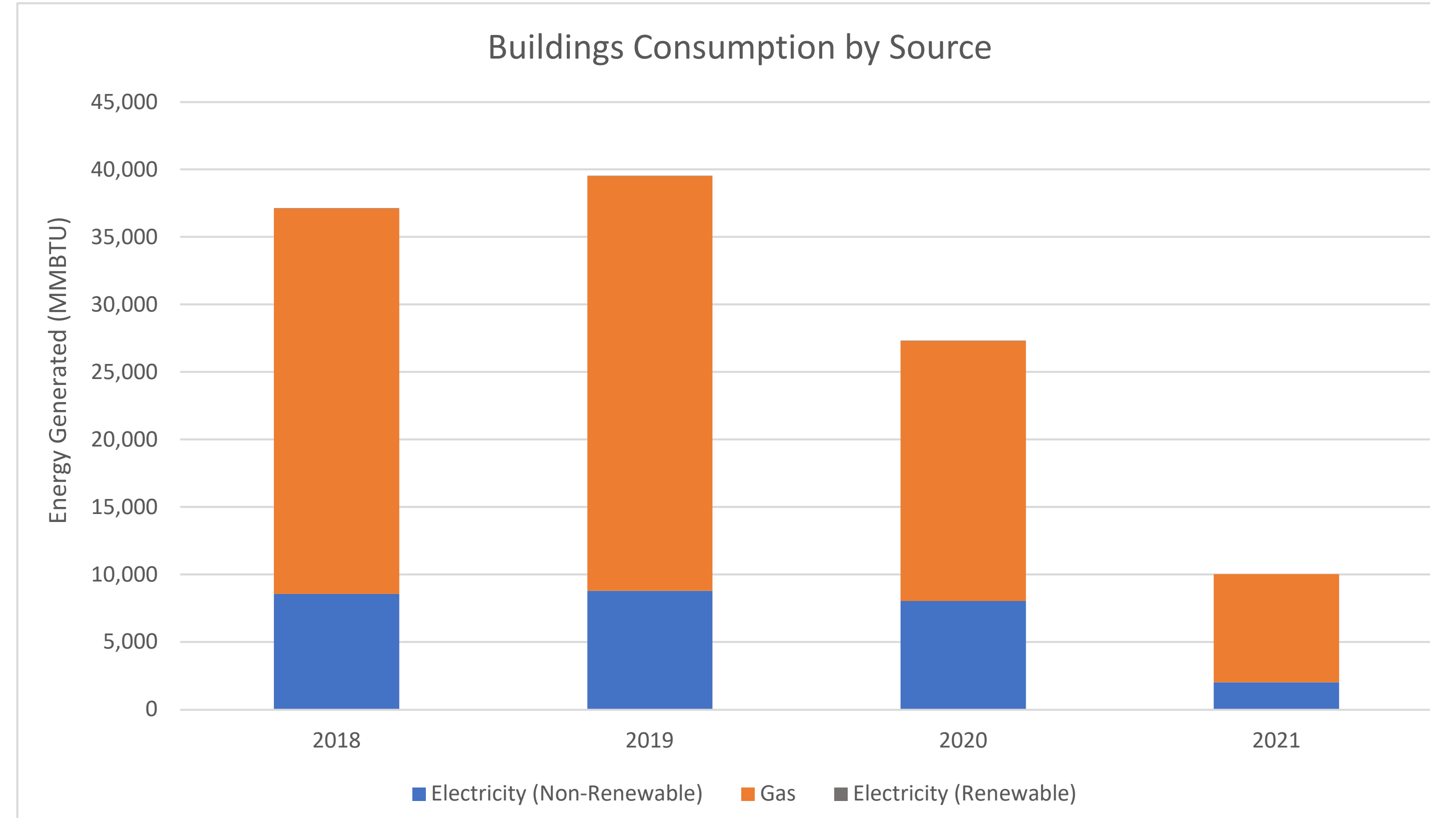
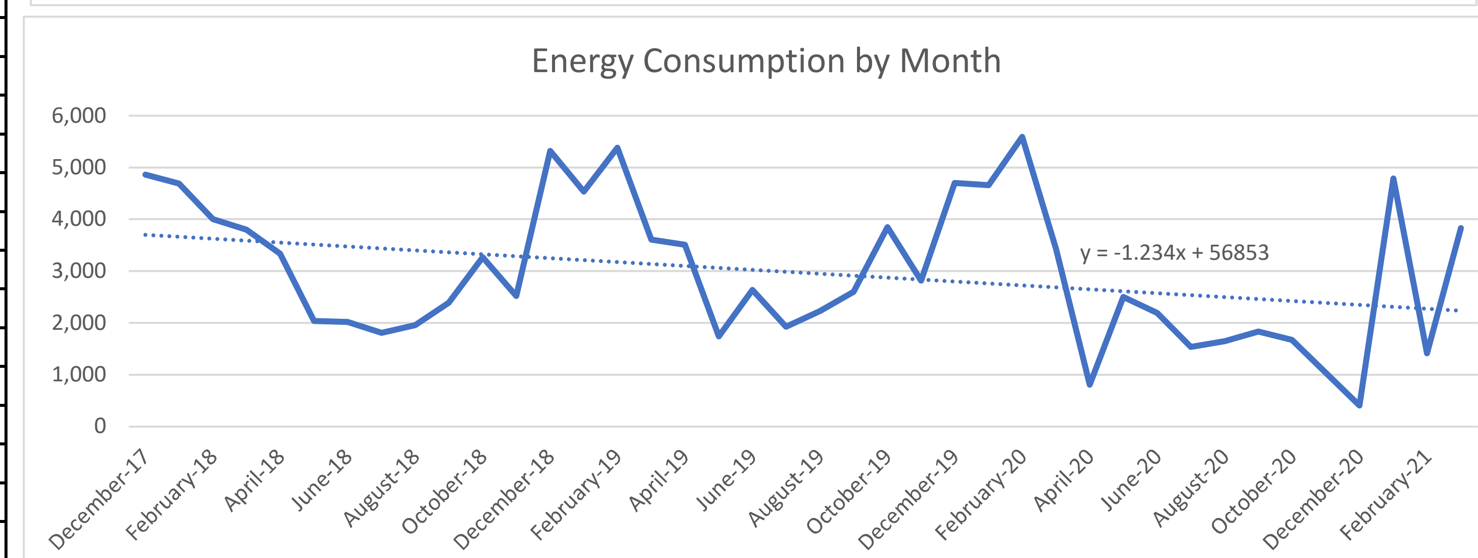
March-21

Buildings									
Month	Electricity						Gas		Total
	Renewable		Non-Renewable		Total		Total		
	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU	Therms	MMBTU	MMBTU
December-17	0	0	199,600	681	199,600	681	41,831	4182.1	4,863
January-18	128	0	163,231	557	163,359	557	41,327	4131.712	4,689
February-18	63	0	156,366	534	156,429	534	34,688	3467.971	4,002
March-18	0	0	175,419	599	175,419	599	32,011	3200.335	3,799
April-18	265	1	335,576	1,145	335,841	1,146	21,886	2188.077	3,333
May-18	1,069	4	216,554	739	217,623	743	12,972	1296.89	2,036
June-18	940	3	279,141	952	280,081	956	10,679	1067.645	2,020
July-18	1,149	4	258,659	883	259,808	887	9,251	924.8789	1,807
August-18	1,077	4	246,532	841	247,609	845	11,166	1116.333	1,958
September-18	859	3	190,659	651	191,518	653	17,366	1736.185	2,387
October-18	533	2	173,465	592	173,998	594	26,729	2672.261	3,264
November-18	459	2	22,720	78	23,179	79	24,385	2437.917	2,515
December-18	486	2	290,214	990	290,700	992	43,310	4329.965	5,320
January-19	192	1	22,560	77	22,752	78	44,594	4458.334	4,535
February-19	59	0	423,310	1,444	423,369	1,445	39,392	3938.259	5,383
March-19	0	0	220,640	753	220,640	753	28,568	2856.117	3,609
April-19	932	3	341,549	1,165	342,481	1,169	23,398	2339.241	3,505
May-19	1,389	5	24,800	85	26,189	89	16,552	1654.804	1,739
June-19	1,568	5	458,175	1,563	459,743	1,569	10,728	1072.544	2,636
July-19	1,448	5	234,754	801	236,202	806	11,216	1121.332	1,922
August-19	1,221	4	236,874	808	238,095	812	14,182	1417.861	2,226
September-19	1,066	4	182,780	624	183,846	627	19,728	1972.329	2,596
October-19	930	3	184,704	630	185,634	633	32,158	3215.031	3,845
November-19	484	2	20,160	69	20,644	70	27,466	2745.944	2,815
December-19	533	2	229,024	781	229,557	783	39,189	3917.963	4,699
January-20	440	2	200,422	684	200,862	685	39,760	3975.05	4,659
February-20	889	3	190,807	651	191,696	654	49,429	4941.719	5,593
March-20	1,078	4	179,684	613	180,762	617	28,094	2808.709	3,422
April-20	1,426	5	173,471	592	174,897	597	2,156	215.5485	807
May-20	1,658	6	201,818	689	203,476	694	18,120	1811.567	2,500
June-20	1,122	4	464,949	1,586	466,071	1,590	6,055	605.3553	2,192
July-20	0	0	261,363	892	261,363	892	6,441	643.9461	1,536
August-20	1,495	5	246,037	840	247,532	845	8,067	806.5072	1,646
September-20	1,060	4	191,694	654	192,754	658	11,790	1178.718	1,833
October-20	977	3	20,720	71	21,697	74	16,022	1601.817	1,673
November-20	837	3	207,061	707	207,898	709	3,304	330.321	1,037
December-20	431	1	22,240	76	22,671	77	3,304	330.321	406
January-21	0	0	220,112	751	220,112	751	40,357	4034.735	4,786
February-21	0	0	162,744	555	162,744	555	8,571	856.8952	1,412
March-21	0	0	207,251	707	207,251	707	31,234	3122.654	3,830

Summary of Consumption by Source, Per Year (MMBTU)				
Year	Electricity (Non-Renewable)	Electricity (Renewable)	Gas	% Renewable
2018	8,559	24	28,570	0.06%
2019	8,801	34	30,710	0.08%
2020	8,054	39	19,250	0.14%
2021	2,014	0	8,014	0.00%





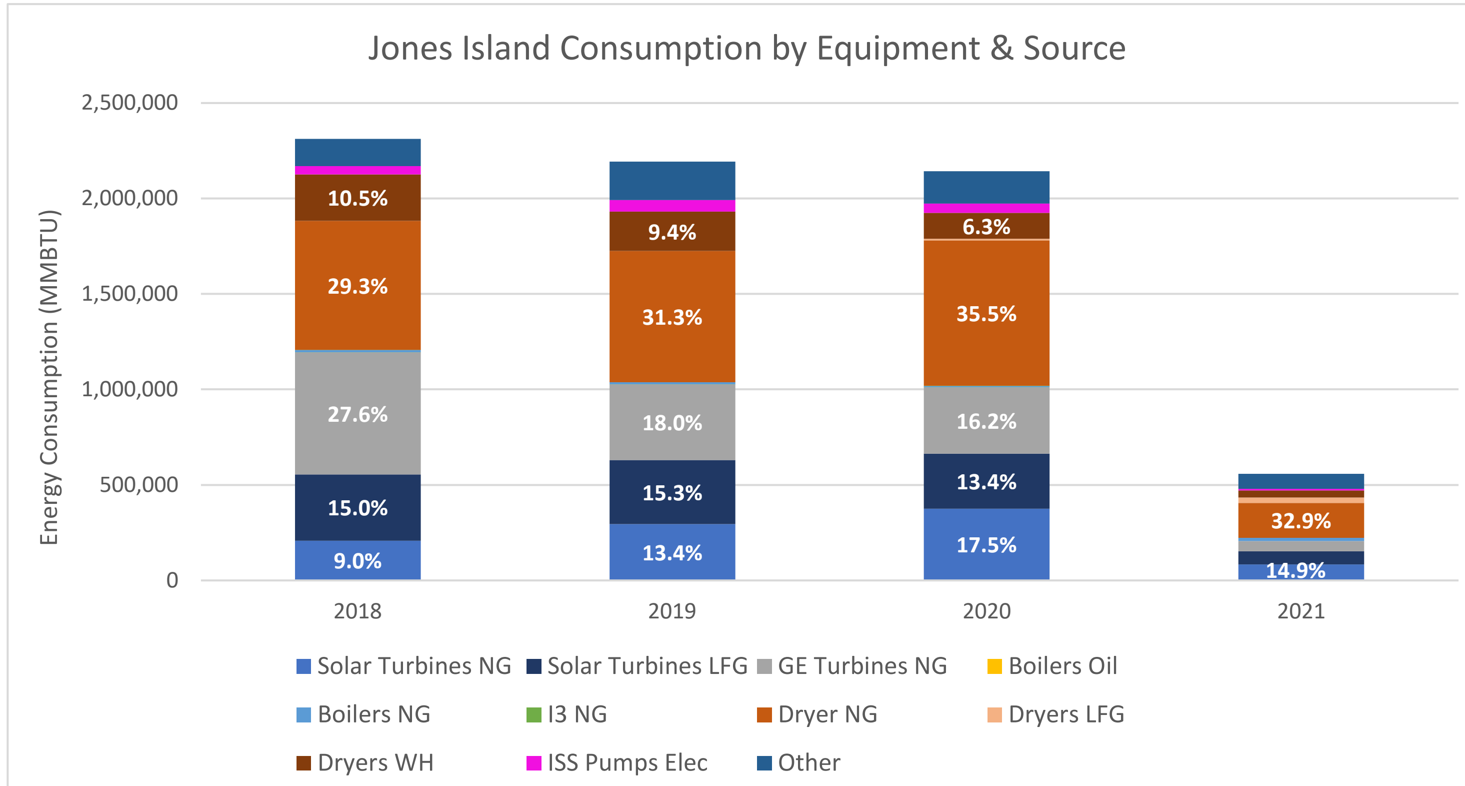
Jones Island Consumption by Equipment

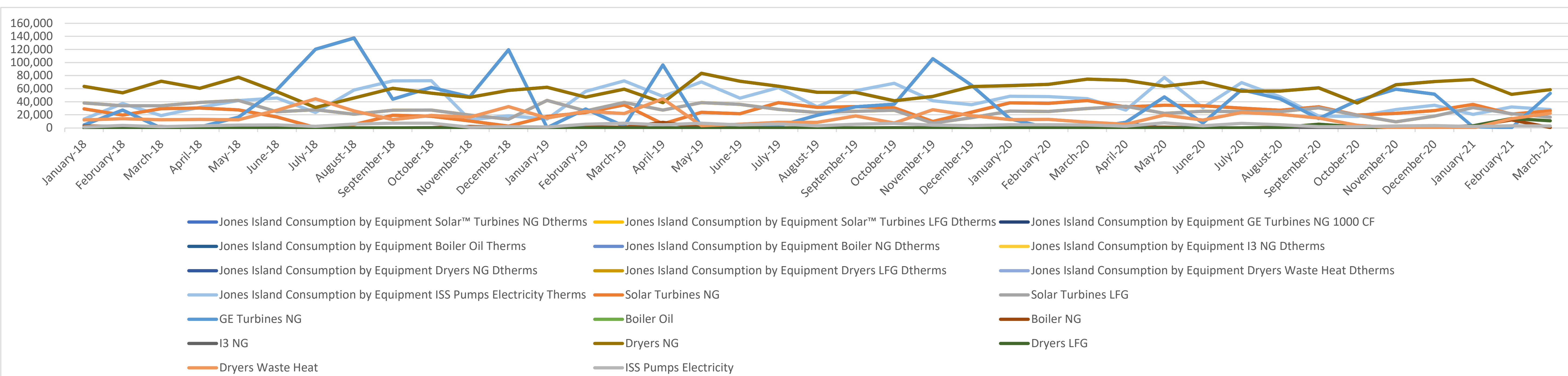
		Solar™ Turbines						GE Turbines			Boiler						I3		
	Total	NG			LFG			NG			Oil			NG			NG		
Month	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	1000 CF	Therms	MMBTU	Gal	Therms	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU
January-18	175,585	29,037	290,368	29,030	38,029	380,289	38,020	4,629	46,290	4,628	0	0	0	2,559	25,589	2,558	18	180	18
February-18	175,882	19,626	196,264	19,622	33,714	337,144	33,706	27,163	271,629	27,156	39	54	5	2,308	23,084	2,308	15	147	15
March-18	171,839	29,320	293,195	29,313	33,960	339,600	33,952	0	0	0	40	56	6	2,215	22,152	2,215	13	131	13
April-18	162,918	30,516	305,157	30,508	38,807	388,066	38,797	1,245	12,452	1,245	32	45	4	1,149	11,489	1,149	11	108	11
May-18	181,120	27,426	274,264	27,420	42,148	421,477	42,138	16,348	163,479	16,344	0	0	0	633	6,330	633	3	32	3
June-18	189,902	16,645	166,448	16,641	24,484	244,841	24,478	58,304	583,039	58,290	160	223	22	1,000	10,000	1,000	1	7	1
July-18	226,524	647	6,465	646	27,848	278,479	27,841	120,207	1,202,066	120,178	0	0	0	17	170	17	0	2	0
August-18	235,376	5,050	50,500	5,049	20,923	209,231	20,918	137,389	1,373,890	137,356	0	0	0	0	0	0	0	2	0
September-18	173,554	19,349	193,494	19,345	26,863	268,630	26,857	43,793	437,930	43,783	0	0	0	0	0	0	0	5	0
October-18	189,738	17,790	177,896	17,785	27,231	272,307	27,224	61,817	618,166	61,802	0	0	0	333	3,332	333	3	29	3
November-18	169,973	10,577	105,773	10,575	19,585	195,852	19,581	47,504	475,043	47,493	130	182	18	2,023	20,229	2,022	9	95	9
December-18	258,033	2,747	27,468	2,746	13,296	132,963	13,293	119,433	1,194,332	119,405	36	50	5	1,038	10,376	1,037	13	134	13
January-19	172,828	17,523	175,231	17,519	42,106	421,058	42,096	154	1,540	154	419	585	58	1,179	11,793	1,179	17	167	17
February-19	186,799	23,598	235,983	23,593	25,893	258,925	25,886	28,728	287,284	28,722	1,806	2,522	252	1,481	14,806	1,480	15	152	15
March-19	191,612	35,146	351,458	35,137	38,909	389,088	38,899	2,603	26,030	2,602	0	0	0	746	7,464	746	12	123	12
April-19	235,274	6,110	61,104	6,109	27,326	273,257	27,319	96,231	962,305	96,208	38	53	5	8,393	83,934	8,391	8	80	8
May-19	183,839	23,685	236,846	23,679	38,627	386,268	38,618	2,022	20,220	2,022	0	0	0	684	6,837	684	5	49	5
June-19	160,967	21,637	216,370	21,632	35,923	359,228	35,914	3,131	31,310	3,130	0	0	0	0	0	0	1	13	1
July-19	153,333	38,595	385,953	38,586	28,301	283,011	28,294	2,873	28,727	2,872	0	0	0	0	0	0	0	5	0
August-19	146,887	31,352	313,523	31,345	23,576	235,756	23,570	19,320	193,201	19,315	0	0	0	0	0	0	1	11	1
September-19	173,589	32,523	325,231	32,515	25,283	252,832	25,277	32,350	323,500	32,342	0	0	0	0	0	0	1	12	1
October-19	158,131	30,769	307,689	30,762	26,912	269,116	26,905	36,274	362,738	36,265	42	59	6	21	214	21	4	35	4
November-19	220,131	9,802	98,020	9,800	7,220	72,203	7,219	105,816	1,058,155	105,790	0	0	0	69	692	69	10	105	10
December-19	208,883	23,938	239,380	23,932	15,593	155,931	15,589	65,256	652,557	65,240	0	0	0	306	3,059	306	13	127	13
January-20	182,151	38,220	382,198	38,211	25,753	257,527	25,747	13,793	137,930	13,790	100	140	14	225	2,249	225	15	149	15
February-20	172,133	37,661	376,607	37,652	25,010	250,103	25,004	0	0	0	391	546	55	730	7,302	730	15	148	15
March-20	178,972	42,011	420,114	42,001	29,675	296,749	29,668	0	0	0	2	3	0	2,173	21,733	2,173	12	118	12
April-20	171,096	31,900	319,005	31,893	33,006	330,061	32,998	8,468	84,680	8,466	5,293	7,391	739	664	6,644	664	10	100	10
May-20	208,958	34,734	347,336	34,725	22,273	222,729	22,268	47,416	474,160	47,405	0	0	0	1,001	10,006	1,000	6	63	6
June-20	157,806	33,912	339,120	33,904	25,428	254,281	25,422	7,347	73,470	7,345	0	0	0	0	0	0	2	19	2
July-20	199,431	30,107	301,066	30,099	24,742	247,418	24,736	58,309	583,085	58,295	0	0	0	0	0	0	0	4	0
August-20	184,099	26,919	269,185	26,912	24,724	247,245	24,719	44,347	443,470	44,336	1	1	0	0	0	0	949	9,488	949
September-20	170,494	32,244	322,440	32,236	30,788	307,877	30,780	14,267	142,670	14,264	1	1	0	0	0	0	1	5	1
October-20	140,558	19,492	194,915	19,487	19,252	192,518	19,247	41,707	417,074	41,697	0	0	0	1,483	14,828	1,482	3	35	3
November-20	182,726	22,088	220,881	22,083	9,214	92,143	9,212	59,247	592,465	59,232	0	0	0	428	4,283	428	7	66	7
December-20	193,572	26,489	264,888	26,482	17,973	179,730	17,969	51,583	515,826	51,570	5	7	1	642	6,416	641	0	0	0
January-21	179,858	35,909	359,093	35,901	31,043	310,430	31,036	1,591	15,911	1,591	34	47	5	2,577	25,772	2,577	14	136	14
February-21	159,469	21,269	212,688	21,264	21,686	216,856	21,680	257	2,570	257	5,584	7,797	780	12,265	122,647	12,262	15	151	15
March-21	219,992	26,140	261,395	26,133	16,287	162,866	16,283	52,807	528,067	52,794	0	0	0	433	4,332	433	11	105	10

Dryers									ISS Pumps			Other
NG			LFG			Waste Heat			Electricity			-
Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	KWh	Therms	MMBTU	MMBTU
63,342	633,416	63,326	0	0	0	12,063	120,625	12,060	395,809	13508.84	1,351	24,595
53,742	537,418	53,729	0	0	0	14,108	141,081	14,105	1,095,339	37383.584	3,737	21,498
71,453	714,532	71,436	0	0	0	12,323	123,231	12,320	549,370	18749.829	1,875	20,710
60,413	604,129	60,398	0	0	0	13,069	130,690	13,066	924,070	31538.225	3,153	14,586
77,388	773,875	77,369	0	0	0	12,563	125,630	12,560	1,223,668	41763.413	4,175	478
55,235	552,346	55,221	0	0	0	26,842	268,421	26,836	1,339,318	45710.512	4,570	2,843
31,333	313,334	31,326	0	0	0	44,279	442,791	44,268	685,610	23399.659	2,339	-92
45,604	456,040	45,593	0	0	0	26,027	260,274	26,021	1,696,849	57912.935	5,790	-5,352
60,452	604,516	60,437	0	0	0	12,817	128,172	12,814	2,103,989	71808.498	7,179	3,139
53,090	530,897	53,077	0	0	0	19,051	190,514	19,047	2,110,886	72043.891	7,203	3,264
46,764	467,637	46,753	0	0	0	16,307	163,069	16,303	371,338	12673.652	1,267	25,952
57,293	572,927	57,279	0	0	0	32,423	324,229	32,415	542,629	18519.761	1,852	29,987
62,175	621,752	62,160	0	0	0	15,121	151,206	15,117	396,323	13526.382	1,352	33,176
46,980	469,804	46,969	0	0	0	25,264	252,643	25,258	1,636,399	55849.795	5,584	29,040
59,287	592,867	59,273	0	0	0	22,027	220,266	22,021	2,107,203	71918.191	7,190	25,730
38,498	384,977	38,489	0	0	0	44,462	444,617	44,451	1,411,396	48170.512	4,816	9,479
83,594	835,943	83,574	0	0	0	3,513	35,128	3,512	2,062,350	70387.372	7,037	24,709
71,459	714,592	71,442	0	0	0	5,601	56,012	5,600	1,329,375	45371.16	4,536	18,711
63,618	636,177	63,602	0	0	0	8,445	84,452	8,443	1,801,311	61478.191	6,146	5,388
54,518	545,182	54,505	0	0	0	8,480	84,805	8,478	943,797	32211.502	3,220	6,452
54,307	543,071	54,294	0	0	0	18,365	183,654	18,361	1,666,133	56864.608	5,685	5,112
41,460	414,604	41,450	0	0	0	7,534	75,344	7,533	1,994,494	68071.468	6,806	8,380
48,012	480,116	48,000	0	0	0	27,777	277,774	27,771	1,213,525	41417.235	4,141	17,331
63,070	630,698	63,055	0	0	0	18,900	189,004	18,896	1,035,753	35349.932	3,534	18,318
64,613	646,133	64,598	0	0	0	12,796	127,956	12,793	1,419,743	48455.392	4,844	21,916
66,480	664,802	66,464	0	0	0	13,090	130,896	13,086	1,403,358	47896.177	4,788	24,338
74,465	744,653	74,447	0	0	0	8,644	86,436	8,642	1,310,871	44739.625	4,473	17,556
72,649	726,487	72,631	0	0	0	5,491	54,909	5,490	799,145	27274.573	2,727	15,478
63,792	637,916	63,776	0	0	0	19,695	196,945	19,690	2,261,554	77186.143	7,717	12,370
69,992	699,919	69,975	0	0	0	11,791	117,912	11,788	905,521	30905.154	3,090	6,279
56,035	560,353	56,022	0	0	0	23,540	235,398	23,534	2,031,732	69342.389	6,933	-188
56,213	562,134	56,200	488	4,877	488	20,619	206,190	20,614	1,393,941	47574.778	4,756	5,125
61,176	611,762	61,162	5,600	56,004	5,599	15,022	150,225	15,019	526,978	17985.597	1,798	9,636
38,130	381,304	38,121	1,610	16,097	1,609	3,854	38,543	3,853	509,261	17380.922	1,738	13,318
65,932	659,319	65,916	915	9,155	915	0	0	0	823,516	28106.348	2,810	22,123
70,704	707,040	70,687	1,176	11,759	1,176	0	0	0	1,011,528	34523.14	3,451	21,594
73,949	739,488	73,931	3,279	32,791	3,278	0	0	0	604,542	20632.833	2,063	29,464
51,327	513,275	51,315	14,455	144,554	14,452	14,147	141,466	14,143	935,435	31926.109	3,192	20,109
58,541	585,408	58,527	10,776	107,755	10,773	22,434	224,342	22,429	821,825	28048.635	2,804	29,805

Summary of Consumption by Equipment and Source, Per Year (MMBTU)																	
	Solar Turbines NG	Solar Turbines LFG	GE Turbines NG	Boilers Oil	Boilers NG	I3 NG	Dryer NG	Dryers LFG	Dryers WH	ISS Pumps Elec	Other	total	Dryer NG	Dryer WH	GE NG	Solar NG	Solar LFG
2018	208,679	346,805	637,679	61	13,272	87	675,945	0	241,815	44,491	141,609	2,310,444	29.3%	10.5%	27.6%	9.0%	15.0%
2019	294,608	335,587	394,662	322	12,877	88	686,814	0	205,441	60,047	201,826	2,192,273	31.3%	9.4%	18.0%	13.4%	15.3%
2020	375,686	287,769	346,400	809	7,344	1,019	760,000	9,787	134,509	49,125	169,547	2,141,996	35.5%	6.3%	16.2%	17.5%	13.4%
2021	83,298	68,999	54,642	784	15,271	39	183,773	28,503	36,572	8,059	79,379	559,319	32.9%	6.5%	9.8%	14.9%	12.3%

*Fill in 2021 data when received

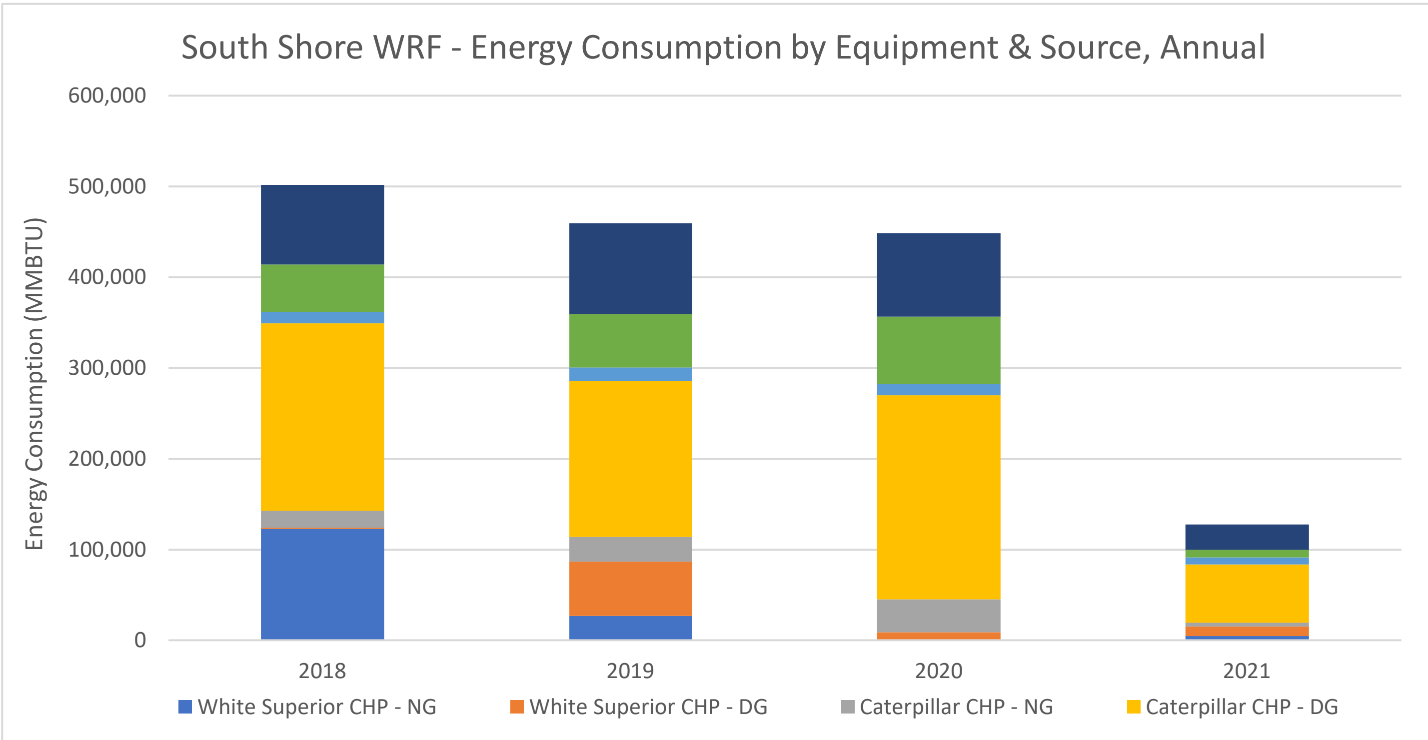


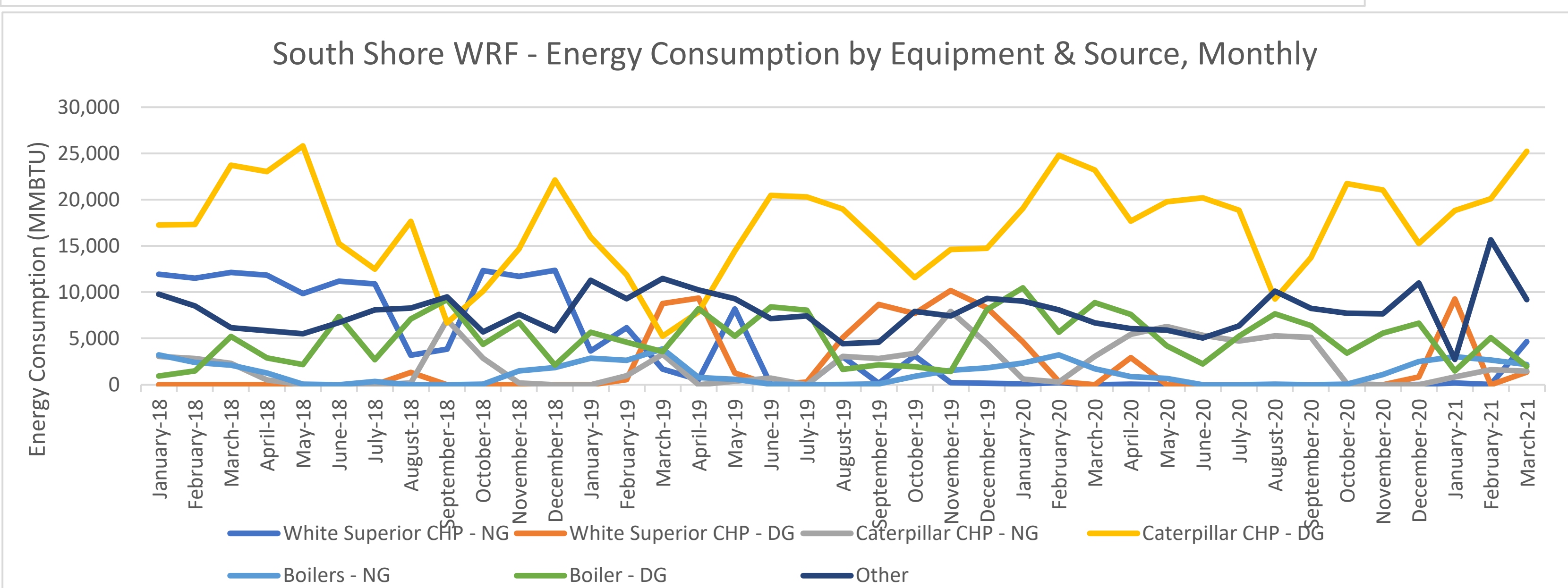


South Shore Consumption by Equipment																				
		White Superior CHP						Caterpillar CHP						Boilers						Other
	Total	NG			DG			NG			DG			NG			DG			-
Month	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	Dtherms	Therms	MMBTU	MMBTU
January-18	46,151	11,931	119,313	11,928	0	0	0	3,046	30,462	3,045	17,256	172,559	17,252	3,211	32,109	3,210	945	9,454	945	9,770
February-18	44,057	11,529	115,285	11,526	0	0	0	2,816	28,163	2,816	17,333	173,331	17,329	2,412	24,119	2,411	1,477	14,765	1,476	8,499
March-18	51,632	12,140	121,401	12,137	0	0	0	2,298	22,983	2,298	23,734	237,339	23,728	2,114	21,145	2,114	5,212	52,124	5,211	6,144
April-18	45,360	11,832	118,318	11,829	0	0	0	499	4,987	499	23,047	230,466	23,041	1,263	12,625	1,262	2,899	28,986	2,898	5,831
May-18	43,396	9,835	98,354	9,833	0	0	0	0	0	0	25,828	258,285	25,822	64	635	64	2,182	21,816	2,181	5,497
June-18	40,511	11,197	111,970	11,194	0	0	0	0	0	0	15,257	152,568	15,253	2	20	2	7,357	73,567	7,355	6,706
July-18	34,510	10,898	108,975	10,895	0	0	0	0	0	0	12,505	125,054	12,502	341	3,409	341	2,685	26,854	2,685	8,087
August-18	37,724	3,193	31,928	3,192	1,326	13,264	1,326	184	1,837	184	17,648	176,479	17,644	2	21	2	7,096	70,955	7,094	8,283
September-18	36,201	3,830	38,305	3,830	0	0	0	7,017	70,165	7,015	6,683	66,827	6,681	0	1	0	9,200	92,001	9,198	9,478
October-18	35,438	12,327	123,265	12,324	0	0	0	2,877	28,771	2,876	10,102	101,018	10,099	57	571	57	4,377	43,774	4,376	5,706
November-18	42,344	11,695	116,949	11,692	0	0	0	170	1,698	170	14,667	146,670	14,663	1,503	15,032	1,503	6,735	67,353	6,734	7,583
December-18	44,216	12,365	123,648	12,362	0	0	0	0	5	0	22,108	221,080	22,103	1,835	18,351	1,835	2,096	20,958	2,095	5,821
January-19	39,416	3,658	36,584	3,657	0	0	0	2	17	2	15,954	159,545	15,951	2,857	28,575	2,857	5,682	56,821	5,681	11,269
February-19	36,010	6,150	61,498	6,148	528	5,285	528	953	9,535	953	11,858	118,577	11,855	2,633	26,331	2,632	4,590	45,901	4,589	9,304
March-19	37,928	1,681	16,813	1,681	8,759	87,586	8,757	3,296	32,960	3,295	5,251	52,512	5,250	3,890	38,897	3,889	3,593	35,934	3,593	11,464
April-19	36,966	547	5,469	547	9,345	93,452	9,343	0	0	0	7,854	78,541	7,852	773	7,731	773	8,203	82,026	8,201	10,250
May-19	39,381	8,177	81,773	8,175	1,249	12,491	1,249	375	3,751	375	14,438	144,377	14,434	591	5,915	591	5,251	52,510	5,250	9,306
June-19	36,751	0	0	0	0	0	0	707	7,066	706	20,447	204,469	20,442	55	553	55	8,405	84,047	8,403	7,144
July-19	36,068	15	155	15	272	2,718	272	0	0	0	20,302	203,025	20,298	1	6	1	8,065	80,646	8,063	7,420
August-19	36,258	3,015	30,150	3,014	5,095	50,953	5,094	3,061	30,613	3,061	18,996	189,960	18,991	15	149	15	1,665	16,653	1,665	4,418
September-19	33,859	156	1,558	156	8,688	86,884	8,686	2,845	28,450	2,844	15,319	153,194	15,316	98	981	98	2,153	21,534	2,153	4,606
October-19	36,547	3,121	31,211	3,120	7,709	77,092	7,707	3,373	33,733	3,372	11,595	115,945	11,592	889	8,890	889	1,934	19,341	1,934	7,933
November-19	43,314	204	2,037	204	10,174	101,739	10,171	7,949	79,488	7,947	14,620	146,197	14,616	1,548	15,480	1,548	1,412	14,122	1,412	7,416
December-19	46,923	163	1,631	163	8,299	82,989	8,297	4,451	44,512	4,450	14,757	147,567	14,753	1,822	18,224	1,822	8,120	81,197	8,118	9,320
January-20	46,257	90	899	90	4,635	46,354	4,634	613	6,134	613	19,058	190,577	19,053	2,353	23,530	2,352	10,494	104,940	10,492	9,022
February-20	42,660	208	2,076	208	359	3,589	359	292	2,922	292	24,817	248,167	24,811	3,218	32,176	3,217	5,686	56,859	5,685	8,089
March-20	43,508	0	0	0	0	0	0	3,043	30,429	3,042	23,200	232,003	23,195	1,719	17,190	1,719	8,882	88,820	8,880	6,673
April-20	40,623	66	663	66	2,915	29,149	2,914	5,435	54,348	5,434	17,694	176,940	17,690	866	8,656	865	7,586	75,858	7,584	6,070
May-20	36,808	0	1	0	0	1	0	6,278	62,778	6,276	19,761	197,607	19,756	688	6,880	688	4,206	42,064	4,205	5,883
June-20	32,812	0	0	0	6	58	6	5,347	53,472	5,346	20,184	201,843	20,179	1	13	1	2,228	22,281	2,228	5,052
July-20	35,168	0	0	0	0	0	0	4,723	47,232	4,722	18,869	188,687	18,864	1	10	1	5,230	52,297	5,228	6,352
August-20	32,369	0	0	0	0	0	0	5,277	52,772	5,276	9,277	92,769	9,275	63	627	63	7,661	76,615	7,660	10,097
September-20	33,498	0	0	0	0	0	0	5,121	51,205	5,119	13,748	137,483	13,745	5	48	5	6,395	63,952	6,394	8,235
October-20	33,066	0	0	0	0	0	0	119	1,190	119	21,743	217,430	21,738	62	620	62	3,421	34,210	3,420	7,727
November-20	35,351	0	0	0	0	0	0	0	0	0	21,049	210,491	21,044	1,096	10,960	1,096	5,562	55,615	5,560	7,651
December-20	36,240	15	150	15	833	8,334	833	0	0	0	15,259	152,589	15,255	2,508	25,078	2,507	6,649	66,492	6,648	10,982
January-21	36,358	179	1,794	179	9,246	92,455	9,243	854	8,539	854	18,820	188,196	18,815	3,030	30,304	3,030	1,506	15,060	1,506	2,731
February-21	45,156	34	339	34	0	0	0	1,626	16,258	1,625	20,100	201,003	20,095	2,660	26,597	2,659	5,068	50,679	5,067	15,676
March-21	46,057	4,671	46,706	4,669	1,350	13,501	1,350	1,458	14,583	1,458	25,234	252,337	25,228	2,182	21,824	2,182	1,993	19,932	1,993	9,177

Summary of Consumption by Equipment and Source, Per Year (MMBTU)							
Year	White Superior CHP - NG	White Superior CHP - DG	Caterpillar CHP - NG	Caterpillar CHP - DG	Boilers - NG	Boilers - DG	Other
2018	122,742	1,326	18,903	206,118	12,801	52,248	87,404
2019	26,881	60,105	27,006	171,350	15,169	59,059	99,849
2020	379	8,746	36,240	224,605	12,576	73,983	91,834
2021	4,883	10,593	3,937	64,138	7,871	8,565	27,584

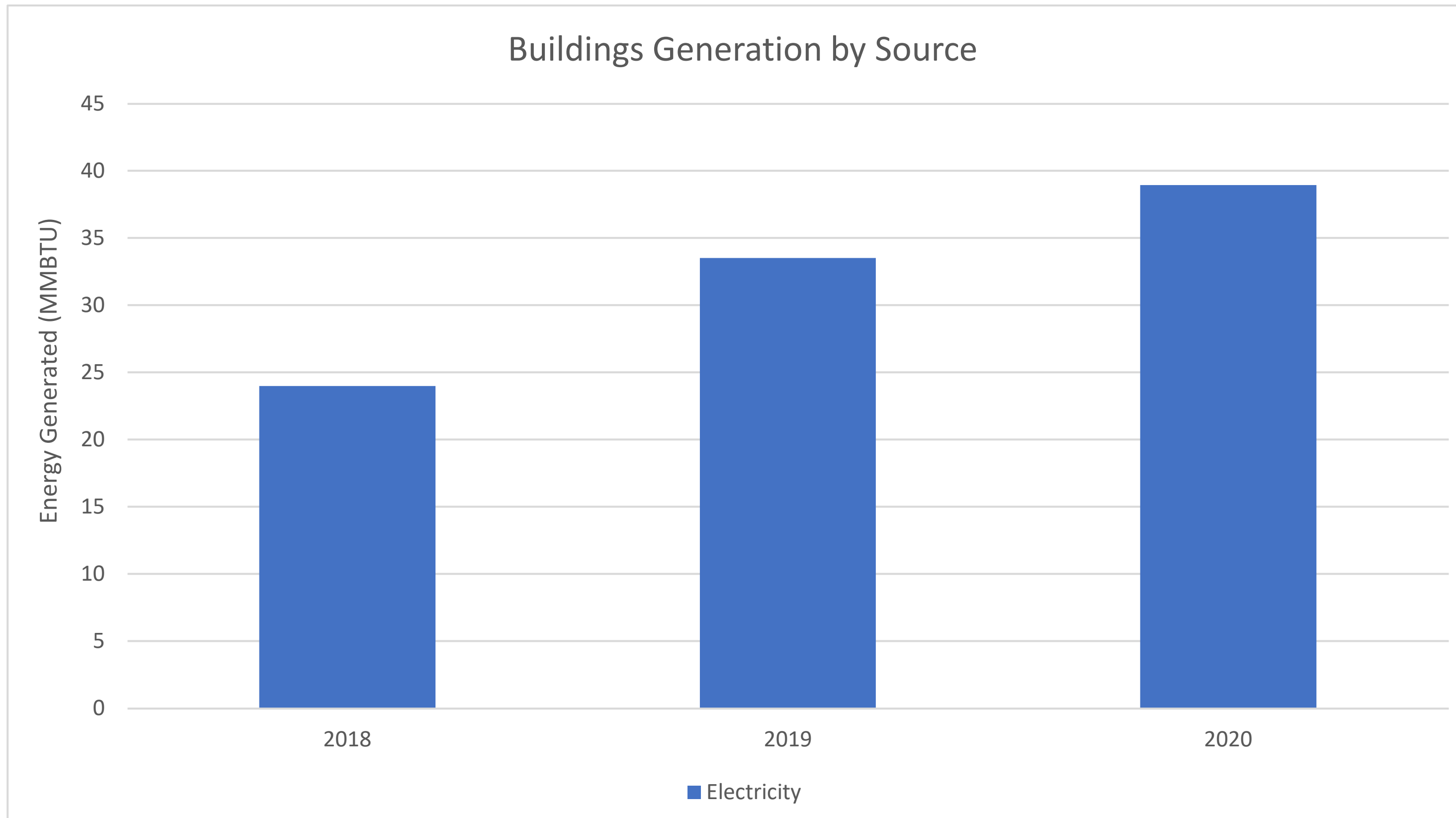
*Fill in 2021 data when received





Buildings		
Month	Electricity	
	Total	
	kWh	MMBTU
January-18	128	0
February-18	63	0
March-18	0	0
April-18	265	1
May-18	1,069	4
June-18	940	3
July-18	1,149	4
August-18	1,077	4
September-18	859	3
October-18	533	2
November-18	459	2
December-18	486	2
January-19	192	1
February-19	59	0
March-19	0	0
April-19	932	3
May-19	1,389	5
June-19	1,568	5
July-19	1,448	5
August-19	1,221	4
September-19	1,066	4
October-19	930	3
November-19	484	2
December-19	533	2
January-20	440	2
February-20	889	3
March-20	1,078	4
April-20	1,426	5
May-20	1,658	6
June-20	1,122	4
July-20	0	0
August-20	1,495	5
September-20	1,060	4
October-20	977	3
November-20	837	3
December-20	431	1
January-21	0	0
February-21	0	0
March-21	0	0

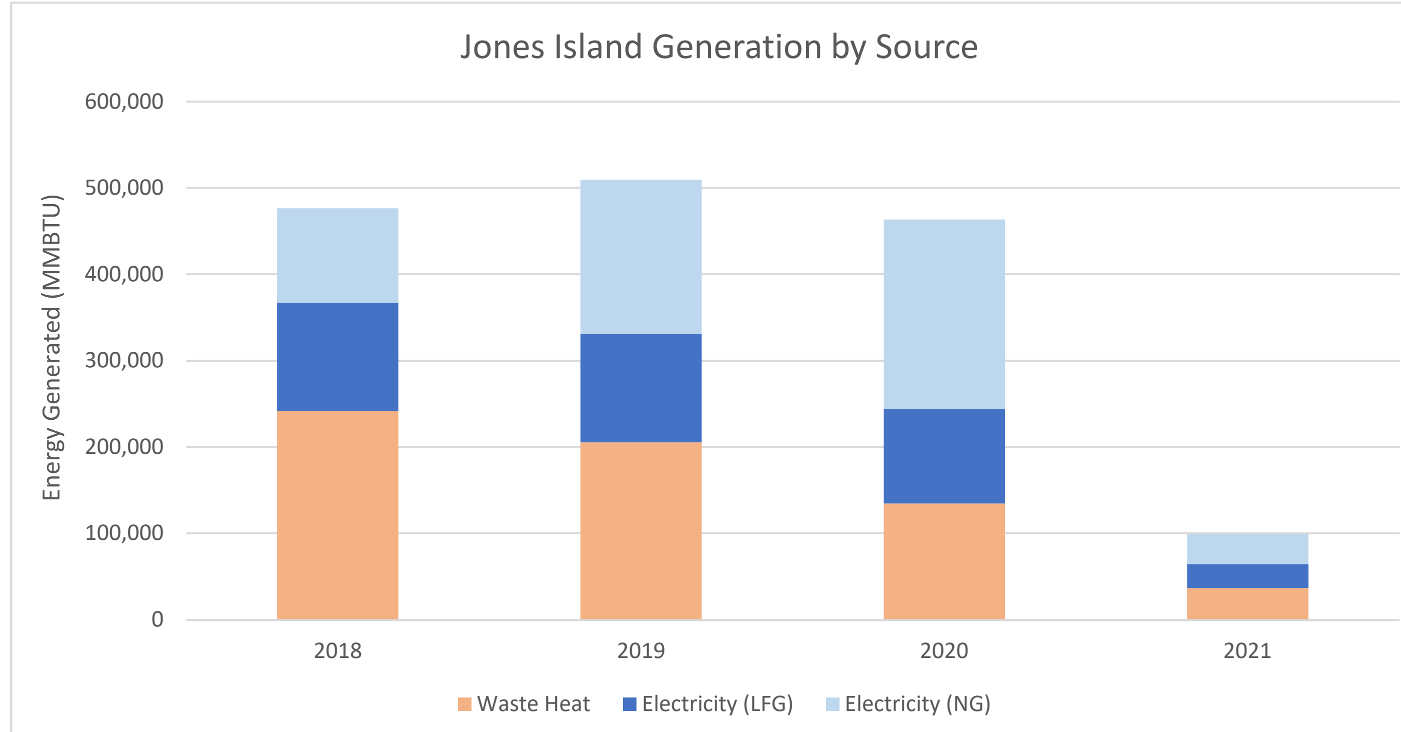
Summary of Generation by Source, Per Year (MMBTU)	
Year	Electricity
2018	24
2019	34
2020	39
2021	0

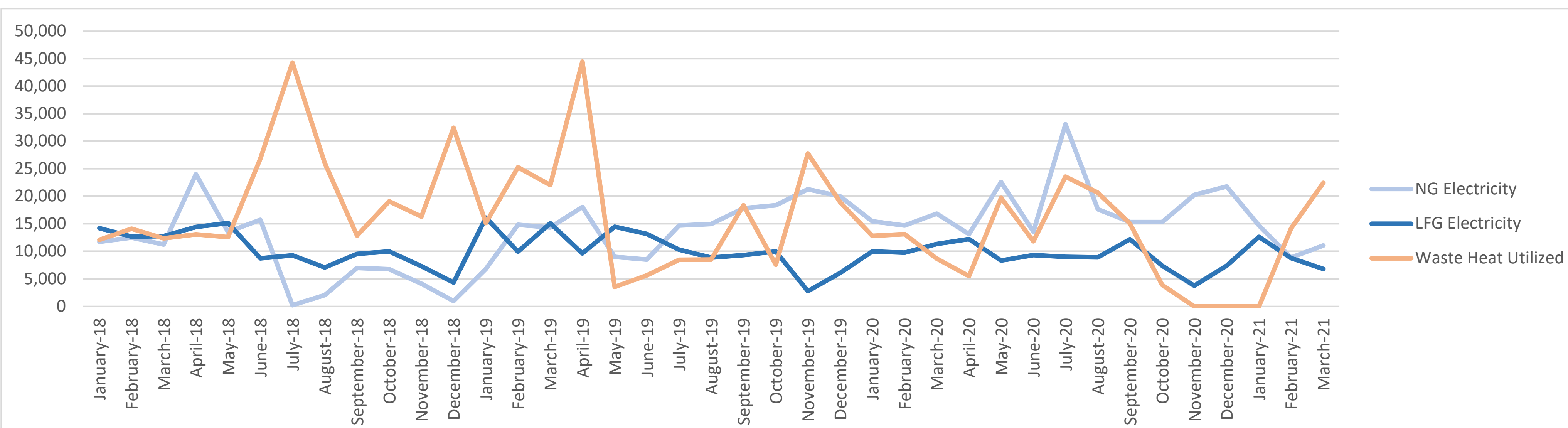


Jones Island Generation by Source													
	NG Electricity					LFG Electricity		Waste Heat Utilized					
	Solars	GE		Total		Total		Renewable		Non-Renewable		Total	
Month	MWh	kWh	MWh	MWh	MMBTU	MWh	MMBTU	Therms	MMBTU	Therms	MMBTU	Dtherms	MMBTU
January-18	3,198	236,000	236	3,434	11,718	4,154	14,175	52,226	5,221	68,399	6,838	12,063	12,060
February-18	2,174	1,478,027	1,478	3,652	12,460	3,712	12,667	51,910	5,190	89,171	8,915	14,108	14,105
March-18	3,288	0	0	3,288	11,218	3,736	12,746	57,097	5,708	66,134	6,612	12,323	12,320
April-18	3,384	3,648,000	3,648	7,032	23,996	4,225	14,416	57,530	5,752	73,160	7,314	13,069	13,066
May-18	2,914	1,044,818	1,045	3,959	13,510	4,434	15,128	49,524	4,951	76,106	7,609	12,563	12,560
June-18	1,788	2,818,371	2,818	4,607	15,718	2,553	8,711	108,629	10,860	159,792	15,975	26,842	26,836
July-18	65	0	0	65	220	2,709	9,244	10,046	1,004	432,744	43,264	44,279	44,268
August-18	587	0	0	587	2,003	2,070	7,062	50,606	5,059	209,668	20,962	26,027	26,021
September-18	2,033	0	0	2,033	6,935	2,792	9,525	53,666	5,365	74,506	7,449	12,817	12,814
October-18	1,971	0	0	1,971	6,727	2,923	9,974	75,281	7,526	115,233	11,521	19,051	19,047
November-18	1,192	0	0	1,192	4,068	2,134	7,283	57,184	5,717	105,884	10,586	16,307	16,303
December-18	273	0	0	273	932	1,267	4,323	55,512	5,550	268,717	26,865	32,423	32,415
January-19	1,981	0	0	1,981	6,759	4,723	16,114	44,435	4,442	106,771	10,675	15,121	15,117
February-19	2,793	1,544,066	1,544	4,337	14,799	2,905	9,911	120,466	12,044	132,177	13,215	25,264	25,258
March-19	4,045	152,000	152	4,197	14,320	4,423	15,091	104,537	10,451	115,729	11,570	22,027	22,021
April-19	656	4,633,200	4,633	5,289	18,047	2,820	9,622	81,254	8,123	363,363	36,328	44,462	44,451
May-19	2,624	0	0	2,624	8,953	4,234	14,447	13,352	1,335	21,776	2,177	3,513	3,512
June-19	2,340	146,000	146	2,486	8,481	3,851	13,140	21,055	2,105	34,957	3,495	5,601	5,600
July-19	4,125	171,000	171	4,296	14,660	3,011	10,273	48,724	4,871	35,728	3,572	8,445	8,443
August-19	3,451	927,000	927	4,378	14,937	2,594	8,851	48,406	4,839	36,399	3,639	8,480	8,478
September-19	3,540	1,676,300	1,676	5,216	17,797	2,724	9,296	103,328	10,330	80,326	8,031	18,365	18,361
October-19	3,377	2,001,997	2,002	5,379	18,354	2,924	9,976	40,191	4,018	35,153	3,514	7,534	7,533
November-19	1,109	5,117,877	5,118	6,227	21,248	814	2,777	159,952	15,991	117,822	11,779	27,777	27,771
December-19	2,736	3,117,344	3,117	5,853	19,972	1,781	6,076	114,451	11,442	74,553	7,454	18,900	18,896
January-20	4,343	181,000	181	4,524	15,437	2,925	9,979	76,446	7,643	51,510	5,150	12,796	12,793
February-20	4,303	0	0	4,303	14,682	2,848	9,717	78,659	7,864	52,237	5,222	13,090	13,086
March-20	4,693	237,682	238	4,931	16,825	3,314	11,309	50,655	5,064	35,780	3,577	8,644	8,642
April-20	3,490	347,119	347	3,837	13,092	3,579	12,211	26,987	2,698	27,922	2,792	5,491	5,490
May-20	3,880	2,737,480	2,737	6,618	22,581	2,427	8,281	119,997	11,997	76,948	7,693	19,695	19,690
June-20	3,648	320,034	320	3,968	13,540	2,726	9,300	67,385	6,737	50,527	5,051	11,791	11,788
July-20	3,204	6,490,191	6,490	9,694	33,076	2,632	8,980	129,212	12,918	106,187	10,616	23,540	23,534
August-20	2,896	2,270,124	2,270	5,166	17,628	2,606	8,891	107,475	10,745	98,715	9,869	20,619	20,614
September-20	3,739	742,000	742	4,481	15,291	3,569	12,176	76,848	7,683	73,377	7,336	15,022	15,019
October-20	2,328	2,153,056	2,153	4,481	15,289	2,154	7,349	19,391	1,939	19,152	1,915	3,854	3,853
November-20	2,840	3,094,143	3,094	5,934	20,248	1,097	3,744	0	0	0	0	0	0
December-20	3,229	3,145,861	3,146	6,374	21,751	2,162	7,379	0	0	0	0	0	0
January-21	4,300	0	0	4,300	14,671	3,689	12,588	0	0	0	0	0	0
February-21	2,589	0	0	2,589	8,833	2,570	8,769	70,047	7,003	71,420	7,140	14,147	14,143
March-21	3,241	0	0	3,241	11,057	1,984	6,769	138,222	13,819	86,121	8,610	22,434	22,429

Summary of Generation by Source, Per Year (MMBTU)			
	Electricity (NG)	Electricity (LFG)	Waste Heat
2018	109,505	125,254	241,815
2019	178,326	125,574	205,441
2020	219,441	109,318	134,509
2021	34,562	28,126	36,572

Summary of Generation by Source, Per Year (MMBTU)			
	Non-Renewable	Renewable	% Renewable
2018	283,415	193,159	40.53%
2019	293,774	215,567	42.32%
2020	278,663	184,606	39.85%
2021	50,312	48,948	49.31%

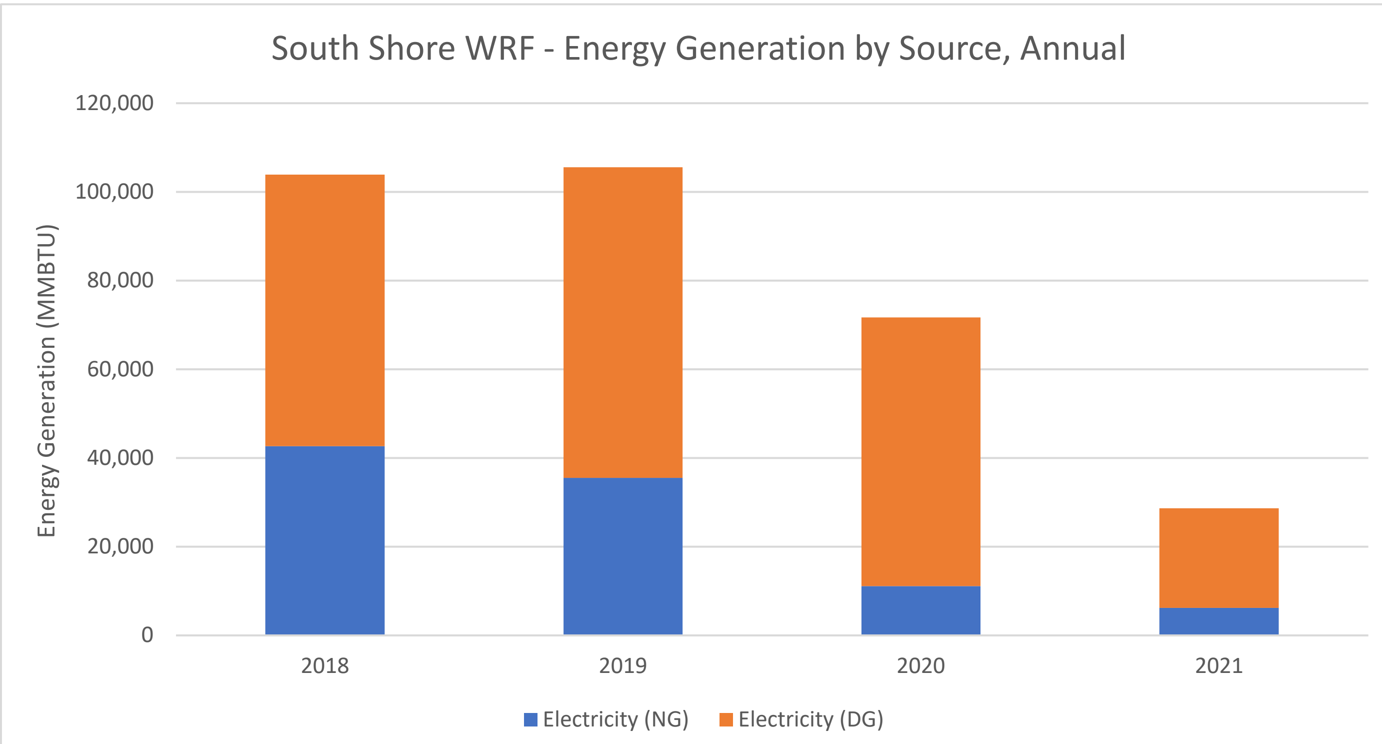


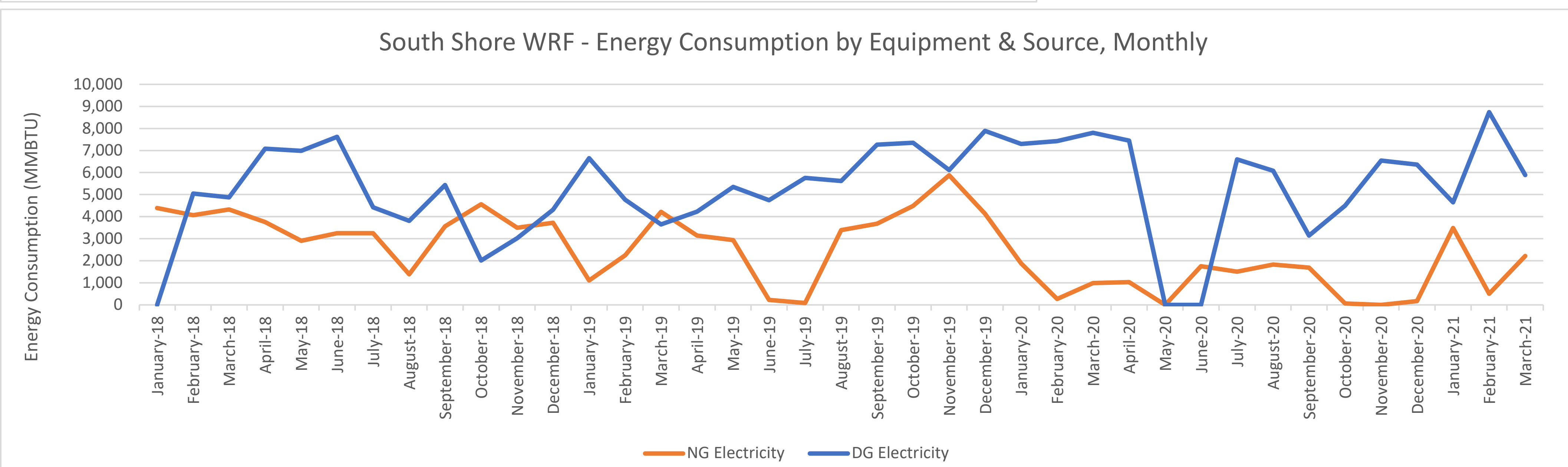


South Shore Generation by Source												
	NG Electricity						DG Electricity					
	White Superior CHP (Gen 5)		Caterpillar CHP (Gen 1-4)		Total		White Superior CHP (Gen 5)		Caterpillar CHP (Gen 1-4)		Total	
Month	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU
January-18	1,023,458	3,492	264,247	902	1,287,704	4,394	0	0	1,479,407	5,048	1,479,407	5,048
February-18	940,349	3,209	250,126	853	1,190,476	4,062	0	0	1,429,577	4,878	1,429,577	4,878
March-18	1,031,806	3,521	234,091	799	1,265,897	4,319	0	0	2,074,368	7,078	2,074,368	7,078
April-18	1,013,239	3,457	85,312	291	1,098,552	3,748	0	0	2,047,567	6,987	2,047,567	6,987
May-18	855,498	2,919	-4,451	-15	851,047	2,904	0	0	2,232,651	7,618	2,232,651	7,618
June-18	965,897	3,296	-14,659	-50	951,238	3,246	0	0	1,295,316	4,420	1,295,316	4,420
July-18	981,733	3,350	-30,873	-105	950,860	3,244	0	0	1,115,533	3,806	1,115,533	3,806
August-18	270,990	1,309	22,145	76	293,135	1,384	112,582	384	1,479,002	5,047	1,591,584	5,431
September-18	334,000	1,140	710,294	2,424	1,044,295	3,563	0	0	588,118	2,007	588,118	2,007
October-18	1,078,338	3,679	258,900	883	1,337,238	4,563	0	0	884,728	3,019	884,728	3,019
November-18	1,007,759	3,439	15,738	54	1,023,497	3,492	0	0	1,264,032	4,313	1,264,032	4,313
December-18	1,065,678	3,636	23,978	82	1,089,656	3,718	0	0	1,948,247	6,648	1,948,247	6,648
January-19	313,007	1,068	11,150	38	324,157	1,106	0	0	1,396,409	4,765	1,396,409	4,765
February-19	518,650	1,922	95,838	327	614,488	2,249	44,568	152	1,024,083	3,494	1,068,651	3,646
March-19	149,547	3,168	307,262	1,048	456,809	4,217	779,044	2,658	458,894	1,566	1,237,938	4,224
April-19	51,080	3,152	-3,168	-11	47,913	3,142	872,788	2,978	694,080	2,368	1,566,867	5,346
May-19	708,538	2,787	42,340	144	750,878	2,931	108,230	369	1,282,247	4,375	1,390,477	4,745
June-19	0	0	64,010	218	64,010	218	0	0	1,687,022	5,756	1,687,022	5,756
July-19	1,312	83	-12	0	1,300	83	23,019	79	1,623,050	5,538	1,646,069	5,617
August-19	269,625	2,475	268,786	917	538,411	3,392	455,662	1,555	1,673,248	5,709	2,128,910	7,264
September-19	14,318	2,773	266,280	909	280,598	3,682	798,509	2,725	1,355,326	4,625	2,153,835	7,349
October-19	291,214	3,448	304,995	1,041	596,209	4,489	719,312	2,454	1,072,886	3,661	1,792,198	6,115
November-19	19,297	3,354	739,777	2,524	759,074	5,879	963,796	3,289	1,347,375	4,597	2,311,171	7,886
December-19	15,399	2,727	410,690	1,401	426,089	4,128	783,700	2,674	1,354,590	4,622	2,138,291	7,296
January-20	9,398	1,685	56,187	192	65,584	1,877	484,366	1,653	1,691,041	5,770	2,175,407	7,423
February-20	18,884	176	24,552	84	43,436	260	32,648	111	2,252,664	7,686	2,285,312	7,798
March-20	0	0	288,022	983	288,022	983	0	0	2,183,931	7,452	2,183,931	7,452
April-20	6,828	1,047	-6,828	-23	0	1,024	299,966	1,024	-299,966	-1,024	0	0
May-20	0	0	0	0	0	0	0	0	0	0	0	0
June-20	1	0	512,140	1,747	512,141	1,748	108	0	1,931,632	6,591	1,931,740	6,591
July-20	0	0	439,672	1,500	439,672	1,500	0	0	1,780,579	6,076	1,780,579	6,076
August-20	0	0	535,150	1,826	535,150	1,826	0	0	919,893	3,139	919,893	3,139
September-20	0	0	492,974	1,682	492,974	1,682	0	0	1,318,321	4,498	1,318,321	4,498
October-20	0	0	16,927	58	16,927	58	0	0	1,917,174	6,542	1,917,174	6,542
November-20	0	0	0	0	0	0	0	0	1,864,162	6,361	1,864,162	6,361
December-20	872	169	308	1	1,180	170	48,596	166	1,314,803	4,486	1,363,399	4,652
January-21	17,825	3,195	85,920	293	103,745	3,488	918,556	3,134	1,643,615	5,608	2,562,171	8,742
February-21	2,534	9	143,924	491	146,458	500	0	0	1,724,648	5,885	1,724,648	5,885
March-21	389,500	1,713	145,534	497	535,034	2,210	112,591	384	2,189,323	7,470	2,301,913	7,854

Summary of Generation by Source, Per Year (MMBTU)		
Year	Electricity (NG)	Electricity (DG)
2018	42,639	61,252
2019	35,515	70,010
2020	11,126	60,531
2021	6,198	22,482

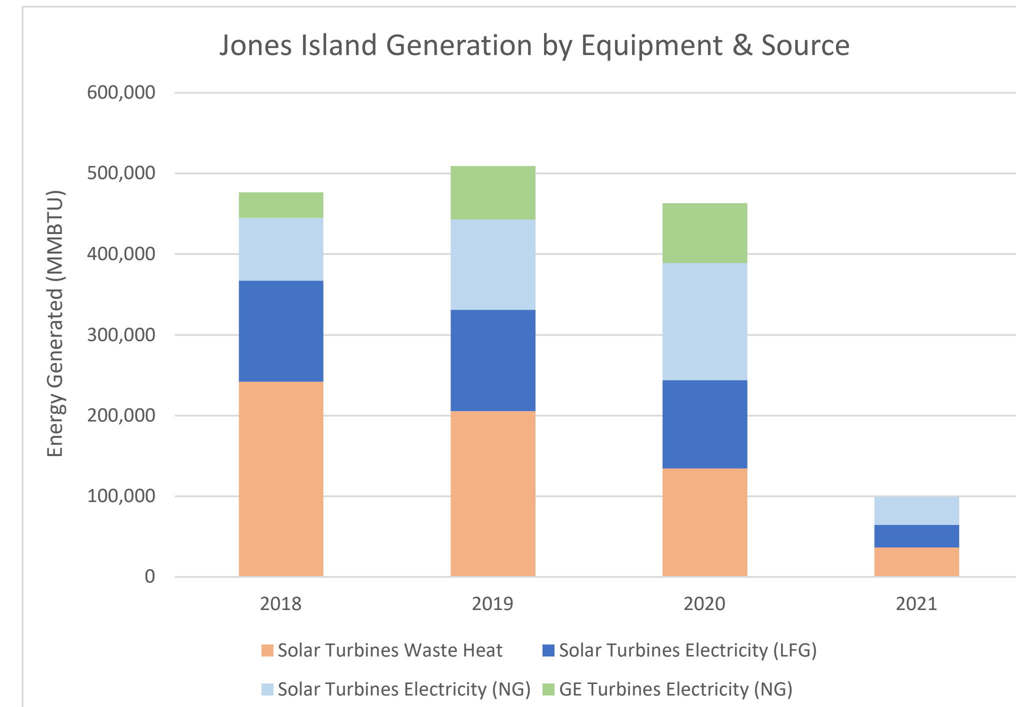
Summary of Generation, Per Year (MMBTU)			
Year	Non-Renewable	Renewable	% Renewable
2018	42,639	61,252	58.96%
2019	35,515	70,010	66.34%
2020	11,126	60,531	84.47%
2021	6,198	22,482	78.39%





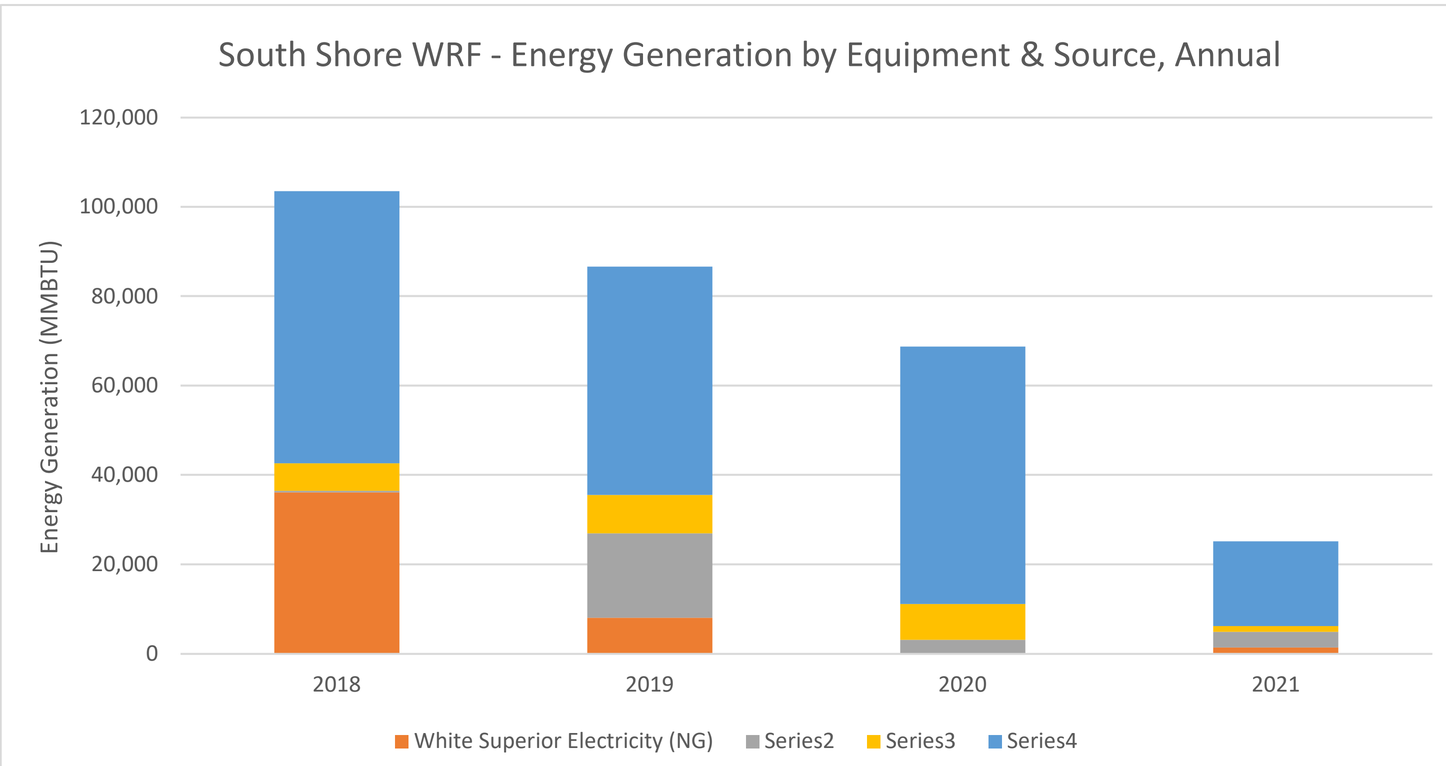
Jones Island Generation by Equipment									
	Solar™ Turbines						GE Turbines		
	NG Electricity		LFG Electricity		Waste Heat Utilized		NG Electricity		
Month	MWh	MMBTU	MWh	MMBTU	Dtherms	MMBTU	kWh	MWh	MMBTU
January-18	3,198	10,913	4,154	14,175	12,063	12,060	236,000	236	805
February-18	2,174	7,417	3,712	12,667	14,108	14,105	1,478,027	1,478	5,043
March-18	3,288	11,218	3,736	12,746	12,323	12,320	0	0	0
April-18	3,384	11,548	4,225	14,416	13,069	13,066	3,648,000	3,648	12,447
May-18	2,914	9,945	4,434	15,128	12,563	12,560	1,044,818	1,045	3,565
June-18	1,788	6,102	2,553	8,711	26,842	26,836	2,818,371	2,818	9,617
July-18	65	220	2,709	9,244	44,279	44,268	0	0	0
August-18	587	2,003	2,070	7,062	26,027	26,021	0	0	0
September-18	2,033	6,935	2,792	9,525	12,817	12,814	0	0	0
October-18	1,971	6,727	2,923	9,974	19,051	19,047	0	0	0
November-18	1,192	4,068	2,134	7,283	16,307	16,303	0	0	0
December-18	273	932	1,267	4,323	32,423	32,415	0	0	0
January-19	1,981	6,759	4,723	16,114	15,121	15,117	0	0	0
February-19	2,793	9,530	2,905	9,911	25,264	25,258	1,544,066	1,544	5,269
March-19	4,045	13,802	4,423	15,091	22,027	22,021	152,000	152	519
April-19	656	2,237	2,820	9,622	44,462	44,451	4,633,200	4,633	15,809
May-19	2,624	8,953	4,234	14,447	3,513	3,512	0	0	0
June-19	2,340	7,983	3,851	13,140	5,601	5,600	146,000	146	498
July-19	4,125	14,077	3,011	10,273	8,445	8,443	171,000	171	583
August-19	3,451	11,774	2,594	8,851	8,480	8,478	927,000	927	3,163
September-19	3,540	12,077	2,724	9,296	18,365	18,361	1,676,300	1,676	5,720
October-19	3,377	11,523	2,924	9,976	7,534	7,533	2,001,997	2,002	6,831
November-19	1,109	3,785	814	2,777	27,777	27,771	5,117,877	5,118	17,463
December-19	2,736	9,335	1,781	6,076	18,900	18,896	3,117,344	3,117	10,637
January-20	4,343	14,819	2,925	9,979	12,796	12,793	181,000	181	618
February-20	4,303	14,682	2,848	9,717	13,090	13,086	0	0	0
March-20	4,693	16,014	3,314	11,309	8,644	8,642	237,682	238	811
April-20	3,490	11,907	3,579	12,211	5,491	5,490	347,119	347	1,184
May-20	3,880	13,241	2,427	8,281	19,695	19,690	2,737,480	2,737	9,341
June-20	3,648	12,448	2,726	9,300	11,791	11,788	320,034	320	1,092
July-20	3,204	10,931	2,632	8,980	23,540	23,534	6,490,191	6,490	22,145
August-20	2,896	9,882	2,606	8,891	20,619	20,614	2,270,124	2,270	7,746
September-20	3,739	12,759	3,569	12,176	15,022	15,019	742,000	742	2,532
October-20	2,328	7,943	2,154	7,349	3,854	3,853	2,153,056	2,153	7,347
November-20	2,840	9,690	1,097	3,744	0	0	3,094,143	3,094	10,558
December-20	3,229	11,017	2,162	7,379	0	0	3,145,861	3,146	10,734
January-21	4,300	14,671	3,689	12,588	0	0	0	0	0
February-21	2,589	8,833	2,570	8,769	14,147	14,143	0	0	0
March-21	3,241	11,057	1,984	6,769	22,434	22,429	0	0	0

Summary of Generation by Equipment and Source, Per Year (MMBTU)				
	Solar Turbines Electricity (NG)	Solar Turbines Electricity (LFG)	Solar Turbines Waste Heat	GE Turbines Electricity (NG)
2018	78,027	125,254	241,815	31,478
2019	111,835	125,574	205,441	66,492
2020	145,334	109,318	134,509	74,107
2021	34,562	28,126	36,572	0



South Shore Generation by Equipment														
	Total Electricity				White Superior (Gen 5)						Caterpillar CHP (Gen 1-4)			
	NG		DG		Total Electricity		NG Electricity		DG Electricity		NG Electricity		DG Electricity	
Month	MWh	MMBTU	MWh	MMBTU	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU	kWh	MMBTU
January-18	1,288	4,394	1,479	5,048	1,023,458	3,492	1,023,458	3,492	0	0	264,247	902	1,479,407	5,048
February-18	1,190	4,062	1,430	4,878	940,349	3,209	940,349	3,209	0	0	250,126	853	1,429,577	4,878
March-18	1,266	4,319	2,074	7,078	1,031,806	3,521	1,031,806	3,521	0	0	234,091	799	2,074,368	7,078
April-18	1,099	3,748	2,048	6,987	1,013,239	3,457	1,013,239	3,457	0	0	85,312	291	2,047,567	6,987
May-18	851	2,904	2,233	7,618	855,498	2,919	855,498	2,919	0	0	-4,451	-15	2,232,651	7,618
June-18	951	3,246	1,295	4,420	965,897	3,296	965,897	3,296	0	0	-14,659	-50	1,295,316	4,420
July-18	951	3,244	1,116	3,806	981,733	3,350	981,733	3,350	0	0	-30,873	-105	1,115,533	3,806
August-18	293	1,000	1,592	5,431	383,573	1,309	270,990	925	112,582	384	22,145	76	1,479,002	5,047
September-18	1,044	3,563	588	2,007	334,000	1,140	334,000	1,140	0	0	710,294	2,424	588,118	2,007
October-18	1,337	4,563	885	3,019	1,078,338	3,679	1,078,338	3,679	0	0	258,900	883	884,728	3,019
November-18	1,023	3,492	1,264	4,313	1,007,759	3,439	1,007,759	3,439	0	0	15,738	54	1,264,032	4,313
December-18	1,090	3,718	1,948	6,648	1,065,678	3,636	1,065,678	3,636	0	0	23,978	82	1,948,247	6,648
January-19	324	1,106	1,396	4,765	313,007	1,068	313,007	1,068	0	0	11,150	38	1,396,409	4,765
February-19	614	2,097	1,069	3,646	563,217	1,922	518,650	1,770	44,568	152	95,838	327	1,024,083	3,494
March-19	457	1,559	1,238	4,224	928,591	3,168	149,547	510	779,044	2,658	307,262	1,048	458,894	1,566
April-19	48	163	1,567	5,346	923,868	3,152	51,080	174	872,788	2,978	-3,168	-11	694,080	2,368
May-19	751	2,562	1,390	4,745	816,768	2,787	708,538	2,418	108,230	369	42,340	144	1,282,247	4,375
June-19	64	218	1,687	5,756	0	0	0	0	0	0	64,010	218	1,687,022	5,756
July-19	1	4	1,646	5,617	24,331	83	1,312	4	23,019	79	-12	0	1,623,050	5,538
August-19	538	1,837	2,129	7,264	725,287	2,475	269,625	920	455,662	1,555	268,786	917	1,673,248	5,709
September-19	281	957	2,154	7,349	812,827	2,773	14,318	49	798,509	2,725	266,280	909	1,355,326	4,625
October-19	596	2,034	1,792	6,115	1,010,526	3,448	291,214	994	719,312	2,454	304,995	1,041	1,072,886	3,661
November-19	759	2,590	2,311	7,886	983,093	3,354	19,297	66	963,796	3,289	739,777	2,524	1,347,375	4,597
December-19	426	1,454	2,138	7,296	799,100	2,727	15,399	53	783,700	2,674	410,690	1,401	1,354,590	4,622
January-20	66	224	2,175	7,423	493,763	1,685	9,398	32	484,366	1,653	56,187	192	1,691,041	5,770
February-20	43	148	2,285	7,798	51,532	176	18,884	64	32,648	111	24,552	84	2,252,664	7,686
March-20	288	983	2,184	7,452	0	0	0	0	0	0	288,022	983	2,183,931	7,452
April-20	0	0	0	0	306,794	1,047	6,828	23	299,966	1,024	-6,828	-23	-299,966	-1,024
May-20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June-20	512	1,747	1,932	6,591	109	0	1	0	108	0	512,140	1,747	1,931,632	6,591
July-20	440	1,500	1,781	6,076	0	0	0	0	0	0	439,672	1,500	1,780,579	6,076
August-20	535	1,826	920	3,139	0	0	0	0	0	0	535,150	1,826	919,893	3,139
September-20	493	1,682	1,318	4,498	0	0	0	0	0	0	492,974	1,682	1,318,321	4,498
October-20	17	58	1,917	6,542	0	0	0	0	0	0	16,927	58	1,917,174	6,542
November-20	0	0	1,864	6,361	0	0	0	0	0	0	0	0	1,864,162	6,361
December-20	1	4	1,363	4,652	49,469	169	872	3	48,596	166	308	1	1,314,803	4,486
January-21	104	354	2,562	8,742	936,382	3,195	17,825	61	918,556	3,134	85,920	293	1,643,615	5,608
February-21	146	500	1,725	5,885	2,534	9	2,534	9	0	0	143,924	491	1,724,648	5,885
March-21	535	1,826	2,302	7,854	502,091	1,713	389,500	1,329	112,591	384	145,534	497	2,189,323	7,470

Summary of Generation by Equipment and Source, Per Year (MMBTU)				
	White Superior Electricity (NG)	White Superior Electricity (DG)	Caterpillar Electricity (NG)	Caterpillar Electricity (DG)
2018	36,062	384	6,193	60,868
2019	8,025	18,933	8,557	51,077
2020	123	2,954	8,050	57,577
2021	1,398	3,518	1,281	18,963



Appendix D: PVWatts Summary Sheet

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Caution: Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Both NREL and private companies provide more sophisticated PV modeling tools (such as the System Advisor Model at https://sam.nrel.gov) that allow for more precise and complex modeling of PV systems.

The expected range is based on 30 years of actual weather data at the given location and is intended to provide an indication of the variation you might see. For more information, please refer to this NREL report: The Error Report.

The energy output range is based on analysis of 30 years of historical weather data for nearby , and is intended to provide an indication of the possible interannual variability in generation for a Fixed (open rack) PV system at this location.

RESULTS

17,758,556 kWh/Year*

System output may range from 16,756,973 to 18,596,760 kWh per year near this location.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.64	966,459	110,756
February	3.71	1,210,954	138,775
March	4.50	1,552,431	177,909
April	5.19	1,677,371	192,227
May	5.80	1,899,715	217,707
June	6.49	1,996,005	228,742
July	6.65	2,069,199	237,130
August	5.84	1,803,190	206,646
September	5.22	1,602,352	183,630
October	3.90	1,293,185	148,199
November	2.72	924,664	105,966
December	2.14	763,031	87,443
Annual	**4.57**	**17,758,556**	**$ 2,035,130**

Location and Station Identification

Requested Location	700 E Jones St, milwaukee WI
Weather Data Source	Lat, Lon: 43.01, -87.9 0.6 mi
Latitude	43.01° N
Longitude	87.9° W

PV System Specifications *(Commercial)*

DC System Size	13360 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Economics

Average Retail Electricity Rate	0.115 $/kWh

Performance Metrics

Capacity Factor	15.2%

Greeley and Hansen LLC
100 South Wacker Drive, Suite 1400
Chicago, Illinois 60606
1-800-837-9779
www.greeley-hansen.com

GREELEY AND HANSEN

Appendix B

Administration Buildings and Conveyance System (TM-2)

Energy Plan for MMSD Facilities

Technical Memorandum 2: Administration Buildings, Conveyance System

Milwaukee Metropolitan Sewerage District
Contract M03109P01

Final – September 2022

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Executive Summary

Background and Purpose

The primary Administrative Buildings are the MMSD Headquarters, Central Lab Building, and South 13th Street Facility. The Administration Buildings in this technical memorandum (TM-2) refers to the facility at Seeboth located at 250 W Seeboth, 260 w Seeboth, as well as the utility bills at 6060 S 13th Street. The Conveyance System facilities include all the pump and metering stations throughout the Conveyance System prior to the Inline Sewer System pump station. The Administration Buildings and Conveyance System facilities account for 1.5% of the entire MMSD average energy consumption from 2018 to 2020 as shown in Table ES-1. Average energy consumption during the 2018 to 2020 timeframe was agreed upon for analysis as part of this memorandum. The MMSD's total energy consumption for the Conveyance System, Administration Facilities, SSWRF, and JIWRF has decreased by approximately 200,000 MMBTU or 8% from 2018 to 2020. This may be due to efficiency gains, decreased occupancies, and flow variances throughout the Administration Buildings and Conveyance System. While offsetting energy at these locations will not have a significant impact on MMSD's overall energy consumption, there are opportunities to improve the energy consumption of the Administration Buildings and the Conveyance System themselves.

Table ES-1: MMSD Energy Consumption by Facility

	Conveyance		Administration		SSWRF		JIWRF		Total
	MMBTU	%	MMBTU	%	MMBTU	%	MMBTU	%	MMBTU
2018	5,574	0.20%	37,130	1.3%	501,541	17.6%	2,310,444	80.9%	2,854,689
2019	5,477	0.20%	39,511	1.5%	459,420	17.0%	2,192,273	81.3%	2,696,680
2020	3,921	0.15%	27,303	1.0%	448,362	17.1%	2,141,996	81.7%	2,621,583
AVG	4,991	0.18%	34,648	1.3%	469,774	17.2%	2,214,904	81.3%	2,724,317

Electricity use accounts for 58%, or 2,907 MMBTU, of the Conveyance System energy consumption, while natural gas accounts for the remaining 46%, 2,084 MMBTU. For the Administration Buildings, electricity use accounts for 25%, or 8,471 MMBTU, while natural gas accounts for 75%, 26,177 MMBTU.

TM-2 evaluates energy reduction or generation alternatives quantitatively and qualitatively for their contribution to reaching MMSD's energy goals in the Administration Buildings and Conveyance System. The alternative numbering was established during the 2015 Energy Plan and maintained in this technical memorandum and evaluation for consistency. The alternatives are limited to those that are a part of and affect the Administration Buildings and Conveyance System facilities at MMSD. All alternatives included in this memo were previously included in the 2015 Energy Plan.

Introduction

The alternative evaluations recommended for evaluation in TM-2 were initially provided in the 2015 Energy Plan and further refined and agreed upon during this project's Technical Memorandum 1. These alternative summaries in this executive summary describe the alternative, provides supporting summaries of the evaluation, and provides a recommendation for moving forward.

Alternative 32: Thermal Energy Generation in Collection System

Description - Heat can be recovered from the Conveyance System sewers utilizing a heat exchanger and heat pump. Electricity cannot be generated thermally from the sewers since the water temperature is not high enough to generate the large thermal temperature differential required to drive a turbine, run a thermoelectric generator, or even heat a space from water temperature alone. Therefore, it must be used as a medium to extract or reject heat using a heat exchanger in conjunction with a heat pump and cannot be used to directly produce energy or heat in other ways.

Recommendation - Installing heat exchangers to recover thermal energy from the Conveyance System sewers is a low priority due to the low flow system rates, process intrusion, large capital cost, and lengthy payback which exceeds the equipment's expected life cycle. Low quality heat energy is not economical to generate electricity or to transport energy. In addition, the non-centralized location of multiple heat recovery systems spread throughout the Conveyance System could pose operational and maintenance difficulties. Thermal energy generation/recovery will be evaluated at Jones Island and South Shore WRFs in tasks 1.4 and 1.5 where this alternative is anticipated to be more feasible than it is for the Conveyance System. It is recommended to transition the natural gas heated facilities to utilize air source heat pumps for their heating loads.

Air Source Heat Pumps

Air source heat pumps, in conjunction with electric resistance coils, can replace natural gas fired or hot water coil air handlers. This would require all existing air handlers to be replaced and heat pumps be installed outdoors. Transitioning natural gas fired equipment and appliances to electric is important to meet MMSD' energy goals. Natural gas is a finite resource with limited renewable alternatives whereas renewable electricity is more readily available through the utility grid.

Alternative 63: Install More Efficient Pump Station Pumps

Description - MMSD has eight pump stations throughout its Conveyance System with operations of some being only used during some wet weather events and the others used continuously. These pump stations are assumed to have been constructed 30 to 40 years ago and since then, improvements in pump and motor technologies have been achieved. This alternative analyzes the potential energy savings possible from upgrading these pump station pumps.

Recommendation - Replacing the pump station pumps with more efficient models is recommended to be completed when the existing equipment reaches the end of its life. A targeted replacement based on energy reductions on its own does not result in a positive return on investment. Replacing the pumps and motors with premium-efficient models is recommended when the equipment's scheduled for replacement. In general, if the pump motor was installed prior to 1998, the motor is recommended to be replaced with a premium efficiency motor. Additionally, it is recommended for process engineers to evaluate most efficient operating point and select most efficient pump type to achieve that curve, as well as evaluate opportunity to install a VFD to achieve optimal turndown and efficiency gains associated with that.

Alternative 68: HVAC Control at Major Remote Sites (Conveyance System)
Description - This alternative addresses the heating and ventilation equipment and controls at the Conveyance System pump stations and support facilities. Reducing heating and ventilation when spaces are not occupied can significantly reduce the amount of energy for HVAC purposes. Demand controlled ventilation automatically adjusts room ventilation rate in response to space occupancy or indoor air pollutant concentration. Smart devices such as occupancy sensors, CO2 monitors, economizers interlocked with HVAC equipment and other smart technologies have been shown to reduce space ventilation energy requirements up to 60%. Building management systems (BMS) can incorporate smart HVAC controls into a buildings heating and ventilation systems.

Recommendation - Installing smart building controls to reduce energy consumption is a low priority at Conveyance System facilities due to the buildings small footprints and NFPA 820 ventilation requirements. Smart building management systems have significantly better return on investment when applied to larger buildings (>50,000 SF) and are recommended during planned facility system replacements. However, typical Conveyance System facilities are small pump stations with one or two air handling units that serve process spaces. Implementation of facility smart HVAC controls is recommended for the larger administration buildings when the buildings' HVAC systems reach the end of their useful life, and the building systems as a whole are upgraded.

Alternative 71: Solar Power at Flow Monitoring Sites or Lighting at Other Low Wattage Facilities (Conveyance System)
Description - This investigation provides a high-level overview for the potential to add Photovoltaics (PV) to existing Conveyance facilities. According to the Conveyance Spreadsheet that we received, there are approximately 250 Conveyance facilities that have a WE Energy electric utility account. However, only 65 of these facilities each consume more than 500kWh per month and are considered for PV installation in this analysis.

Recommendation - Solar power at Flow Measuring Stations or Lighting at Other Low Wattage Facilities within the Conveyance System is recommended for consideration. The evaluated PV installations could offset 72% of the total non-renewable electricity consumed by the Conveyance System facilities which accounts for 42% of all energy consumed by the Conveyance System facilities. However, the electrical demand at each Conveyance facility may not allow for the use of all electricity generated by the PV system. Battery storage would be required which may increase the payback period.

Alternative 72: General Energy/Water Conservation Measures

Description - This analysis addresses basic energy savings techniques for the Administration Buildings and Conveyance System facilities. Opportunities exist to improve energy monitoring, reduce energy demand, include more energy efficient controls. The general measures evaluated include improving the building's thermal envelope, install high efficiency faucets and shower heads, replace equipment with high efficiency models, install LED's, install premium efficiency motors, upgrade HVAC and lighting controls, monitor receptacle loads to have the ability to quantify equipment plugged into receptacles energy consumption, install adjustable frequency drives on motors, monitor energy consumption data, install photovoltaic cells, and store excess renewable energy. Further investigation of the various energy savings techniques is recommended on a case-by-case basis.

Recommendation - Incorporating general energy and water conservation measures are recommended when the asset is due for maintenance or end of life replacement. These energy savings techniques are considered good design practices to include when the assets are due for maintenance or end of life replacement.

Alternative 73: Increase Natural Light in Buildings

Description - This alternative considers the increase of natural light in applicable buildings across MMSD's network of Administrative Buildings and Conveyance System facilities. Taking advantage of natural light or daylighting can significantly reduce the energy load from artificial lighting, reduce the cooling loads needed to offset the heat produced from lighting fixtures, and increase the well-being and productivity of building occupants. Cooling costs associated with lighting are considered to be minimal. Cooling costs associated with the increased natural light is likely comparable or more than the lighting heat gain to the space.

Recommendation - The considerations for daylighting are vastly different between occupied and unoccupied buildings. Since Conveyance System pump stations and buildings are not regularly occupied, the benefits of daylighting will be diminished given that no lighting is typically needed.

In the Administrative Buildings, increased daylight should be sought after with any rehabilitation project effecting regularly occupied spaces. Existing windows and skylights at the end of their life should be replaced with high efficiency alternatives that minimize solar heat gain. Additional skylights or larger window assemblies should be considered for heavily used spaces. Interior space should be renovated to relocate task areas closer to daylit sources, incorporate light color finishes, and increase the amount of glass and translucent wall partition materials.

Overall, the increasing of natural light is not a practical standalone strategy to achieve energy reduction goals. This alternative is a low priority and should be considered only in coordination with larger renovation projects planned or proposed for the Administrative Buildings and Conveyance System facilities.

Alternative 74: Alternative Fuel Fleet Vehicles
Description - MMSD owns and operates a vehicle fleet to assist operations and other staff with traveling and maintaining various assets throughout MMSD's facilities. Currently, this fleet is fueled by gasoline or diesel-powered engines that contribute to MMSD's overall energy consumption and a direct contributor to its CO_2 carbon footprint. Alternative fuels such as compressed natural gas (CNG) or electric have shown the potential to reduce fleet energy consumption and emissions. MMSD's vehicle fleet consists of cars and light trucks primarily fueled by gasoline, and various class 9 and heavy trucks primarily fueled by diesel. Large class 9 trucks are limited to CNG due to current technologies and their large torque requirements. The smaller cars and light trucks are the primary targets of this analysis.

Recommendation - Retrofitting the existing diesel-duty fleet to be CNG is a low priority due to the costly up-front capital costs and limited renewable energy potential. Replacing smaller gasoline fueled vehicles with electric vehicles is recommended when vehicle replacement is needed. Purchasing new electrical vehicles are recommended as they are shown to reduce lifetime CO_2 emissions by 30%. Utilizing digester gas and cleaning to renewable natural gas was not considered or recommended as MMSD already beneficially utilizes the fuel and its carbon offset internally in its power generation equipment and using it in vehicle fueling would necessitate costly fuel cleaning, compression, and storage.

Installing electric vehicle charging stations at locations where the gasoline fueled vehicles are parked is recommended to be completed up front, so electric vehicle infrastructure is available when vehicles are purchased.

Alternative 77: Consolidate or Downsize Non-Process Administrative Buildings
Description - This alternative considers the downsizing or consolidating of workspace in MMSD's Administrative Building. Assuming that current employees are allocated an average amount of space, downsizing or consolidating working space would only have a discernable effect on energy consumption if thresholds were met that eliminate portions of MMSD's floorspace or real estate.

Recommendation - The decision to downsize or consolidate staff involves many positional and productivity related variables that should be the primary and initial consideration. If a spatial analysis identifies a large percentage of unused or inefficient space, then the potential reduction in energy load due to consolidation may also be a considerable factor. Otherwise, the reduction in energy used due to the decrease or optimization of the working footprint is a secondary benefit and not a long-term strategy for energy reduction. Overall, the downsizing or consolidating of workspace is not a prioritized practical standalone strategy to achieve energy reduction goals. This alternative is considered low priority on its own, however should be considered in coordination with larger renovation projects planned or proposed for the Administrative Buildings.

Alternative 82: Use Smaller Pumps for Dewatering ISS Between Rain Events and Diversions
Description - JIWRF ISS pump station lifts water from the MMSD's ISS system approximately 300 ft. to two head tanks. Each head tank has standpipes inside which are designed at an elevation such that the water can flow by gravity to the SSWRF or the JIWRF depending on which head tank the ISS pumps discharge to.

The ISS pump station is also used to dewater the tunnel from ground water which enters the tunnel via infiltration. The water level in tunnel builds up to the point where it needs to be pumped on a daily or weekly basis. This pumping could also be accomplished with a single small pump in order to avoid using one of the three 5,500 HP driven ISS pumps.

The ISS pumps energy consumption is included as part of JIWRF's energy consumption and not the Conveyance System's because the pumps are metered and powered from there, however the asset is considered part of the Conveyance System.

Recommendation – Due to the large head requirements, pumps of this size have limited turndown and capacity capabilities. Additionally, if a smaller pump were capable of being installed with a higher efficiency, the pump would have to operate longer to dewater the wet well, thus diminishing any energy savings.

After much consultation with pump manufacturers, it does not appear that this alternative will result in any significant energy savings.

Installing smaller dewatering pumps is not recommended as it is not apparent that there will be significant energy savings.

Conclusions
In order to achieve the goals of the 2035 Vision, MMSD needs to prioritize energy efficiency upgrades across all administrative buildings and conveyance system sites. Although these two areas only account for 1.5% of MMSD's total energy consumption, they offer quick wins for reducing energy consumption. As a matter of practice, all projects that are replacing energy consuming assets should seek out replacements that offer reductions in energy use. Overtime, this practice will show progress towards and commitment to the 2035 Vision across all District facilities. Cost alone should not be a limiting factor, ease of change or retrofit, timing, and energy savings by system should be considered. Alternatives 63 and 71 are expected to have the largest impact on reducing MMSD's energy consumption. Alternatives 63 and 71 combined, would account for 80% of the Conveyance System's electricity consumption, or 45% of the Conveyance System's energy consumption which includes both electricity and natural gas.

Section 1 Administration Buildings and Conveyance System

1.1 Background and Purpose

The purpose of this technical memorandum is to provide a high-level evaluation and recommendation of whether the alternatives summarized should be evaluated further as potential energy saving or generation opportunities to further MMSD's progress towards the 2035 Vision goals. The overall goals will be achieved through reducing non-renewable energy consumption and reducing overall carbon emissions. The alternative numbering was established during the 2015 Energy Plan and maintained in this plan and evaluation for consistency. The alternatives are limited to those that are a part of and affect the administration buildings and Conveyance System facilities at MMSD.

1.2 Baseline Energy Consumption

Table 1-1 shows MMSD's energy consumption by facility using data from 2018-2020. The energy included in the numbers includes renewable and non-renewable energy, and assets are included at the location where the asset's utility meter is located. Note that JIWRF includes the ISS pump energy consumption in this table.

Table 1-1: MMSD Energy Consumption by Facility

	Conveyance		Administration		SSWRF		JIWRF		Total
	MMBTU	%	MMBTU	%	MMBTU	%	MMBTU	%	MMBTU
2018	5,574	0.20%	37,130	1.3%	501,541	17.6%	2,310,444	80.9%	2,854,689
2019	5,477	0.20%	39,511	1.5%	459,420	17.0%	2,192,273	81.3%	2,696,680
2020	3,921	0.15%	27,303	1.0%	448,362	17.1%	2,141,996	81.7%	2,621,583
AVG	4,991	0.18%	34,648	1.3%	469,774	17.2%	2,214,904	81.3%	2,724,317

This table shows us that the administration buildings and Conveyance System facilities account for approximately 1.5% of MMSD's total energy consumption.

Electricity use accounts for 58%, or 2,907 MMBTU, of the Conveyance System energy consumption, while natural gas accounts for the remaining 46%, 2,084 MMBTU. For the Administration Buildings, electricity use accounts for 25%, or 8,471 MMBTU, while natural gas accounts for 75%, 26,177 MMBTU. Figure 1-1 and Figure 1-2 show the energy consumption by source for the Conveyance System and Administration Buildings.

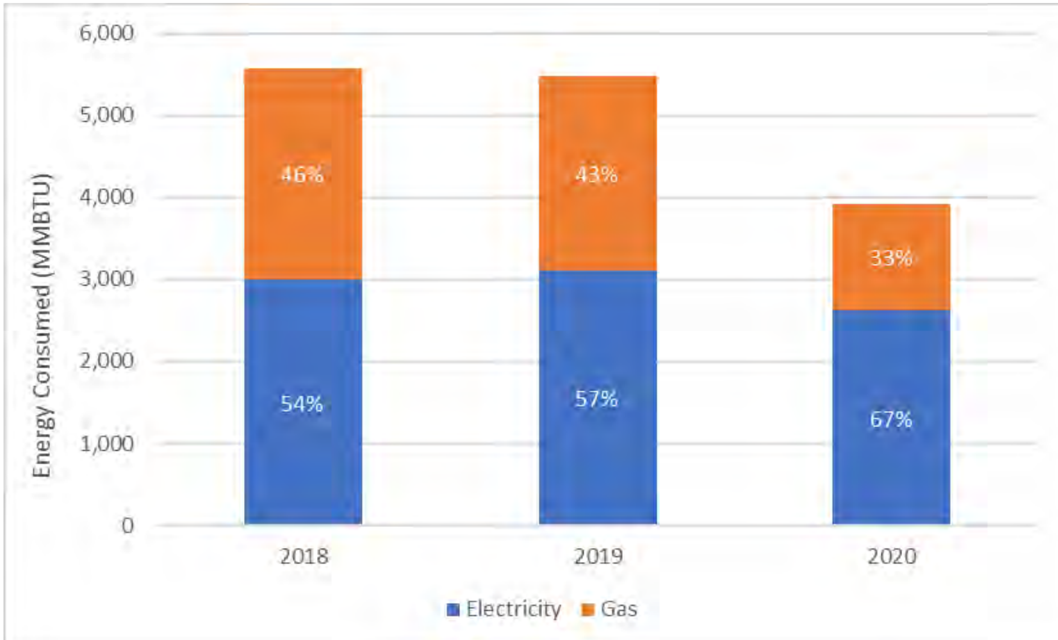

Figure 1-1:Conveyance System Energy Consumption by Source

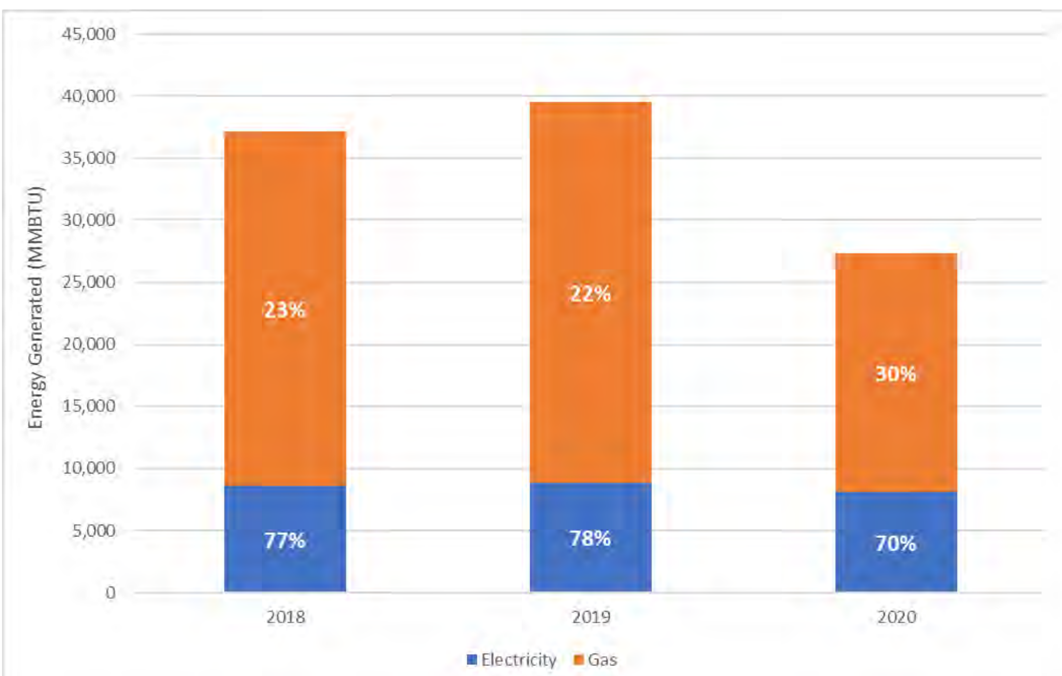

Figure 1-2:Administration Buildings Energy Consumption by Source

1.2.1 Conveyance System Energy Consumers

The top 11 energy users in the Conveyance System were identified as top targets for the energy alternatives evaluated. 11 were chosen because there is a significant drop off in energy consumption between the 11^{th} and 12^{th} largest energy consumers (4,000 MMBTU down to 500 MMBTU). These are summarized in Table 1-2 below. The 10 largest electricity users account for 70% of the Conveyance Systems energy consumption, which the 10 largest natural gas users account for 99.7% of the Conveyance Systems natural gas consumption. It is also clear that natural gas demand is mostly limited to winter months, indicating that the primary use is for heating purposes.

Table 1-2: Conveyance System Top Energy Consumers

Facility	Address	Energy Consumption (Therms)	Energy Source	Rank
Port Washington Road PS	5022 N Port Washington Rd - Glendale	75,643	Electric	1
32nd and Hampton - Large Bypass PS: BS0502	4830 N 32nd St - Milwaukee	63,596	Both	2
Underwood Creek PS	12308 W Underwood Pkwy - Wauwatosa	55,438	Electric	3
CT1 Drop Shaft	8950 W Watertown Plank Rd - Milwaukee	22,995	Electric	4
Greentree Road PS	1300 W Green Tree Rd - River Hills	21,305	Both	5
59th and State - Large Bypass PS: BS0405	5901 W State St - Milwaukee	15,308	Electric	6
Greenfield Park PS	1500 S 124th St - West Allis	13,027	Electric	7
Beach Road PS	7509 N Beach Dr - Fox Point	10,034	Both	8
Construction Trailer - No longer exists	162 N 44th St - Milwaukee	8,464	Gas	9
CT7 Drop Shaft	1610 W Canal St - Milwaukee	4,769	Electric	10
CT34 Drop Shaft	4298 W Monarch Pl - Milwaukee	4,374	Electric	11

As the largest energy consumer, Port Washington Road PS was used as a representative sample to compare the electricity consumption to the monthly average influent flow at JIWRF. JIWRF was used because Port Washington Road PS is part of the JIWRF tributary area. Figure 1-3 shows the monthly Port Washington Electricity consumption plotted over the JIWRF average monthly influent flow.

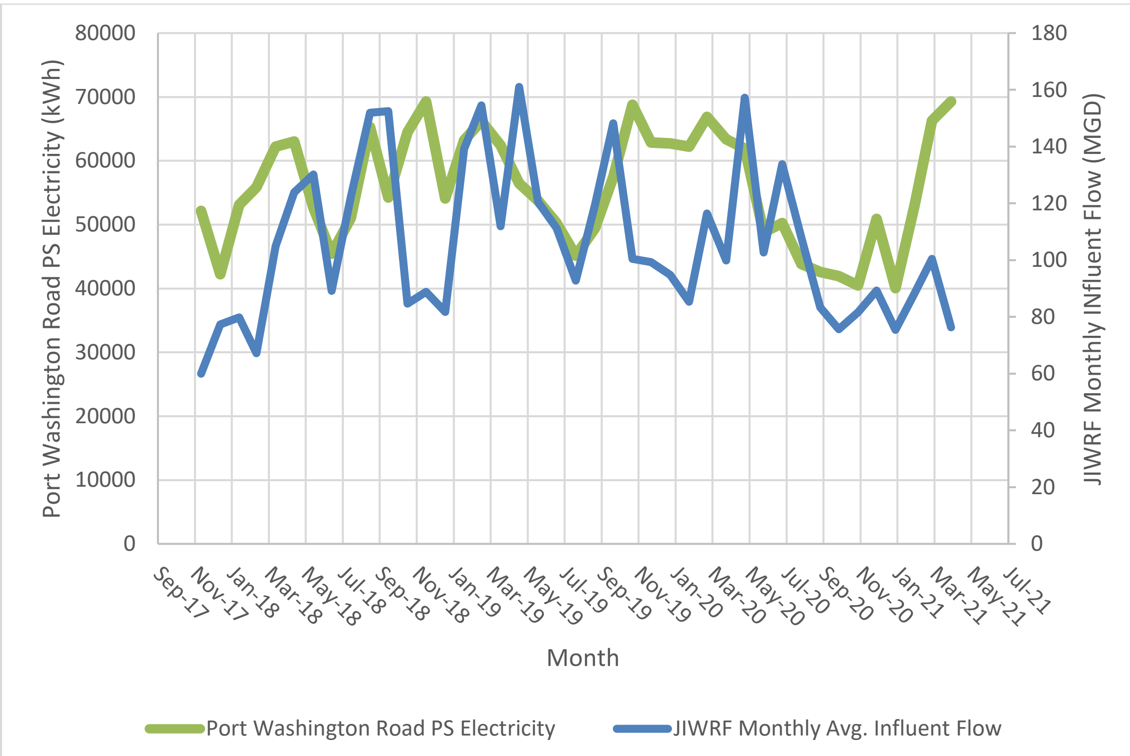

Figure 1-3:Port Washington Road PS Energy Profile

The figure shows a trend of electricity consumption being higher during months with higher wet weather influent flows. The highest monthly electricity consumption is about 70,000 kWh per month, generally corresponding to JIWRF average influent flows of about 160 MGD. The lowest monthly electricity consumption is about 40,000 kWh, corresponding to JIWRF average influent flows of about 80 MGD. Dividing both electricity demands by the hours in a month result in an average kW demand. The resulting average highest and lowest demands are 97 kW and 55 kW respectively.

1.3 Introduction

This section is split into subsections which summarize the alternatives previously recommended for further evaluation. These recommendations for evaluation were initially provided in the 2015 Energy Plan and further refined and agreed upon during this projects Technical Memorandum 1. These alternative summaries describe the alternative, evaluates its benefits, summarizes its impact, provides a basis of the evaluation, includes a high-level cost analysis, and provides a recommendation for moving forward. All alternatives included in this memo were previously included in the 2015 Energy Plan.

Utility energy costs presented in this Memorandum were sourced from the 2015 Energy Plan and discussed and agreed upon with MMSD. Cost paybacks are simple paybacks assuming a fixed energy rate.

1.4 Alternative 32: Thermal Energy Generation in Collection System

Description
Heat can be recovered from the Conveyance System sewers utilizing a heat exchanger and heat pump. Electricity cannot be generated thermally from the sewers since heat that can be recovered is low quality heat. This means the water temperature is not high enough to generate a large thermal temperature differential to drive a turbine, run a thermoelectric generator, or even heat a space from water temperature alone. Therefore, it must be used as a medium to extract or reject heat using a heat exchanger in conjunction with a heat pump.

In 2013, Pirnie/ARCADIS created the *Assessment of Sewage Heat Recovery Technology and Applicability to the Milwaukee Metropolitan Sewerage District* Memorandum. This memo detailed the available technologies, associated costs, and potential benefits of installing heat pumps serving locations throughout MMSD's facilities.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:
- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Reduce facility natural gas consumption. • Reduce facility energy consumption from HVAC loads.	• Increased maintenance and complicates process. • Invasive construction with large associated capital costs. • Simple payback exceeds expected system life cycle.

Facility Impacts from Modifications
Modifications to the existing infrastructure are required and summarized below:

- Heat exchangers must be installed at the Conveyance System facilities in the sewers.
- Screens must be installed to protect the heat exchangers and prevent debris accumulation on the heat exchanger.
- Maintenance to clean and support the systems is required.

Basis of Design
This alternative consists of installing heat exchangers in conjunction with heat pumps and HVAC equipment for Conveyance System facilities that have heating loads. Assumptions are listed below.

- Facilities do not require cooling.
- Heating loads are only required for 6 months of the year.
- 200,000 BTU/hr system offsets 876 MMBTU/yr of natural gas
- Cost of electricity for the Conveyance System assumed to be $0.13/kWh[4]
- Cost of natural gas for the Conveyance System assumed to be $0.54/100,000 BTU[4]

The entirety of the gas consumption equipment is not known. HVAC and heating equipment are assumed to be the consumers. If 200,000 BTU/hr systems were installed at 8 of the Conveyance System pump stations, approximately 7,000 MMBTU/yr of energy would be reduced. The installations were limited to feasible locations where the flow and pipe sizes are sufficient to support such a system. This 7,000 MMBTU/yr of energy is also more than the facilities consume for heating purposes. As this is low quality heat, this energy can only be beneficially utilized at the generation source and cannot be transported to other locations where it would be needed. Assuming a 2" pipe with 1" insulation and 150F water, the heat loss is 13 btu/h/ft. The maximum pipe length to limit losses to 10% of the 200,000 BTU/hr system is approximately 1,500 ft.

Therefore, the energy offset is equal to the total of the 876 MMBTU/yr of natural gas consumption, however additional electricity is required to operate the heat pump and fan these systems operate with.

Cost Analysis

The cost of installing a heat exchanger and heat pump varies by the size of the system. Smaller sized systems, similar to what would be installed at the Conveyance System facilities, range from about $200,000-$400,000. This does not include the cost of new or retrofitted HVAC equipment required to utilize the heat pump's energy. The Arcadis report quantifies the MBTU/hr recovery from the system and compares that to the natural gas heat this system offsets. This calculation does not include any cooling loads and assumes all heat can be utilized for 6 months out of the year. Typically, heat pumps only have a net positive payback when both heating and cooling is required. Net annual savings from offsetting natural gas consumption is approximately $3,000-$4,000. The resulting simple payback equates to about 80 years, which exceeds the equipment's estimated life cycle of approximately 20 years.

Recommendations

Installing heat exchangers to recover thermal energy from the Conveyance System sewers is a low priority due to the low flow system rates, process intrusion, large capital cost, and lengthy payback which exceeds the equipment's expected life cycle. Low quality energy is not economical to produce electricity or to transport energy. In addition, the non-centralized location of multiple heat recovery systems spread throughout the Conveyance System could pose operational and maintenance difficulties. Thermal energy generation/recovery will be evaluated for the at Jones Island and South Shore WRFs in tasks 1.4 and 1.5.

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[4] From 2013 Pirnie/ARCADIS report. Conveyance system utility costs are higher than at the water recovery facilities

It is anticipated to be more feasible at the WRFs than it is for the Conveyance System. It is recommended to transition the natural gas heated facilities to utilize air source heat pumps for their heating loads. This recommendation will be discussed further in the following section.

1.4.1 Air Source Heat Pumps

Air source heat pumps, in conjunction with electric resistance coils, can replace natural gas fired or hot water coil air handlers. This would require all existing air handlers to be replaced and heat pumps be installed outdoors. Transitioning natural gas fired equipment and appliances to electric is important to meet MMSD' energy goals. Natural gas is a finite resource with limited renewable alternatives whereas renewable electricity is more readily available through the utility grid.

Air source heat pumps generally have a positive return on investment when there are both heating and cooling load requirements for buildings. It is recommended they be incorporated when equipment is at the end of its useful life and up for replacement. It is estimated that heat pumps can reduce the heating and cooling energy consumption by about 20%. This number is conservative when considering the U.S. Department of Energy references that heat pumps can reduce energy consumption up to 50%.[5] 20% was used because Milwaukee is a colder climate that would require auxiliary heating backup for very cold days, and it will also generally have a lower coefficient of performance, which dictates how much efficiency the unit will gain versus standard electric resistive heating.

The largest natural gas consumers in the Conveyance System are the locations identified below. These were identified by having monthly gas demands greater than 100 therms. There were identified as locations that would benefit the most from HVAC improvements projects.

- 4830 N 32nd Street – Milwaukee
- 7007 N River Rd – River Hills
- 162 N 44th Street – Milwaukee
- 7509 N Beach Dr – Fox Point
- 8000 W Wisconsin Ave – Wauwatosa

[5] https://www.energy.gov/energysaver/heat-pump-systems

1.5 Alternative 63: Install More Efficient Pump Station Pumps

Description
MMSD has 8 pump stations throughout its Conveyance System with operations of each being relief or continuous. These pump stations are assumed to have been constructed 30 to 40 years ago and since then, improvements in pump and motor technologies have been achieved. This alternative analyzes the potential energy savings possible from upgrading these pump station pumps.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:
- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Pumps and motors can be swapped out relatively easily • Additional cost is easily justifiable based on energy savings when equipment is up for replacement	

Facility Impacts from Modifications
Modifications to the existing infrastructure are required and summarized below:

- Replace existing pump and motors with newer, more efficient models.
- Verify electrical supply is appropriately sized for the motors and equipment.

Basis of Design
The pump stations have a base flow rate and head that they operate at most of the time. This operation point brake horsepower (BHP) is set with the pump curve, and newer pumps are not expected to improve this BHP significantly. New premium-efficiency motors, however, are expected to provide quantifiable efficiency improvements. The efficiencies for high efficiency motors are defined by tables in NEMA standard MG-1-1998. The motor efficiencies are assumed to have improved by approximately ~10% since the original motors have been installed. Intermittent, wet weather pumping efficiency improvements are not expected to have any energy reduction benefits.

It is assumed that the pump stations account for most of the Conveyance System electrical energy consumption excluding the ISS pump consumption. The Conveyance System averaged 852,000 kwh per year from 2018-2020. Assuming 90% of this was for pump station pumping results in 766,800 kwh. If the existing pump motors were replaced with premium-efficiency motors which are 10% more efficient, the resulting energy consumption is 690,120 kwh/year or a savings of 76,680 kwh/year. This equates to a 9% decrease in Conveyance System facilities electricity consumption, or a 5% decrease in Conveyance System energy consumption which includes both electricity and natural gas.

Cost Analysis
Utilizing $0.14/kwh, the energy savings results in $10,735/year. Over a 20-year life cycle, the total savings is $214,700. It is estimated replacing 8 pumps could cost upwards of $400,000, and therefore the upgrades would not have a positive return on investment from energy savings alone. The cost savings here are representative of replacing in kind. We recommend as alternatives from the energy plan are incorporated, evaluating the type of pump, need, and sizing for pump replacement.

Recommendations
Replacing the pump station pumps with more efficient models is recommended to be completed when the existing equipment reaches the end of its life. Replacing the pumps and motors with premium-efficient models is recommended when the equipment's scheduled for replacement. In general, if the pump motor was installed prior to 1998, the motor is recommended to be replaced with a premium efficiency motor. A targeted replacement based on energy reductions on its own does not result in a positive return on investment, however it is easily justifiable based on energy savings for when the asset is due for replacement.

Future project considerations:

- Incorporate high efficiency pump motors in specifications
- Process engineers to evaluate most efficient operating point and select most efficient pump type to achieve that curve. Evaluate opportunity to install a variable frequency drive (VFD) to achieve optimal turndown and efficiency gains associated with that.

1.6 Alternative 68: HVAC Control at Major Remote Sites (Conveyance System)

Description

This alternative addresses the heating and ventilation equipment and controls at the Conveyance System pump stations and support facilities. Reducing heating and ventilation when spaces are not occupied can significantly reduce the amount of energy for HVAC purposes. Demand controlled ventilation automatically adjusts room ventilation rate in response to space occupancy or indoor air pollutant concentration. Smart devices such as occupancy sensors, CO2 monitors, economizers interlocked with HVAC equipment and other smart technologies have been shown to reduce space ventilative energy requirements up to 60% according to the American Council for an Energy-Efficient Economy.[6] Building management systems (BMS) can incorporate smart HVAC controls into a buildings heating and ventilation systems.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:

- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Reduce facility natural gas consumption. • Reduce facility energy consumption from HVAC loads.	• Dependent upon existing ventilation design and requirements.

Facility Impacts from Modifications

Modifications to the existing infrastructure are required and summarized below:

- Install new HVAC controls including thermostats, occupancy sensors, and additional monitoring
- Install new HVAC equipment with outside air economizers, higher efficiencies, and variable speed motors.

Basis of Design

Heating and ventilation loads are established by energy calculations and codes and regulations. According to NFPA 820, wastewater pumping station wet wells and dry wells are classified dependent on the amount of ventilation air provided. A summary table of the classifications is provided below.

[6] https://www.aceee.org/sites/default/files/publications/researchreports/a1701.pdf

Table 1-3: NFPA 820 Classification Table

Location and Function	Class I Division 1	Class I Division II	Unclassified
Wastewater Pumping Station Wet Well	No Ventilation or <12Air Changes per Hour (ACH)	Continuously at 12ACH	N/A
Below Grade Wastewater Pumping Station Dry Well	N/A	No Ventilation or <6ACH	Continuously at 6ACH
Above Grade Wastewater Pumping Station Dry	N/A	N/A	No Ventilation Required

Locations with large outside air requirements that also have the ability to reduce their outside air during unoccupied periods are the targets for optimized HVAC controls. NFPA 820 does not allow reduction of ventilation rates, and therefore pump stations have limited opportunities for smart controls with demand reduction. If these pump stations were constructed prior to the NFPA standard, any improvements would have to bring the facility up to the standard's requirements and may result in increased ventilation requirements, ultimately increasing the energy consumption of the building. NFPA-820 became a standard in 1995. There is some leniency to compliance for facilities built prior to the date, however it is up to the Authority Having Jurisdiction (AHJ) to allow deviation.

The largest natural gas consumers in the Conveyance System are the locations identified below. These were identified by having monthly gas demands greater than 100 therms.

- 4830 N 32nd Street – Milwaukee
- 7007 N River Rd – River Hills
- 162 N 44th Street – Milwaukee
- 7509 N Beach Dr – Fox Point
- 8000 W Wisconsin Ave – Wauwatosa

The HVAC systems at the Conveyance System facilities account for about half of the Conveyance Systems energy consumption. Therefore, if the HVAC demand were reduced by 20%, this equates to a 10% reduction of the Conveyance System's overall energy consumption.

Similar analysis can be done for the administration buildings. HVAC loads are estimated to account for approximately 75% of the administration building's energy demand. Therefore, a 20% reduction would reduce the Administration Building's energy consumption by approximately 15%.

Cost Analysis

The cost of installing building management systems vary by space and function. It is estimated retrofitting an existing HVAC system with one that has demand-controlled ventilation and monitoring will cost approximately $50,000. This is installed costs and includes control panels, wiring, and equipment. This cost is the engineers estimate for smaller buildings similar to the pump stations, based off experience and familiarity with similar systems. Larger facilities such as the administration buildings would cost more and could be upwards of $250,000.

Recommendations

Installing smart building controls to reduce energy is a low priority at Conveyance System facilities due to the buildings small footprints and NFPA 820 ventilation requirements. Smart building management systems have a better return on investment in larger buildings (>50,000 SF). Figure 1-4 shows the percentage of buildings with energy management control systems (EMCS), similar to BMS's, by square footage. Note that the data below is for commercial buildings.

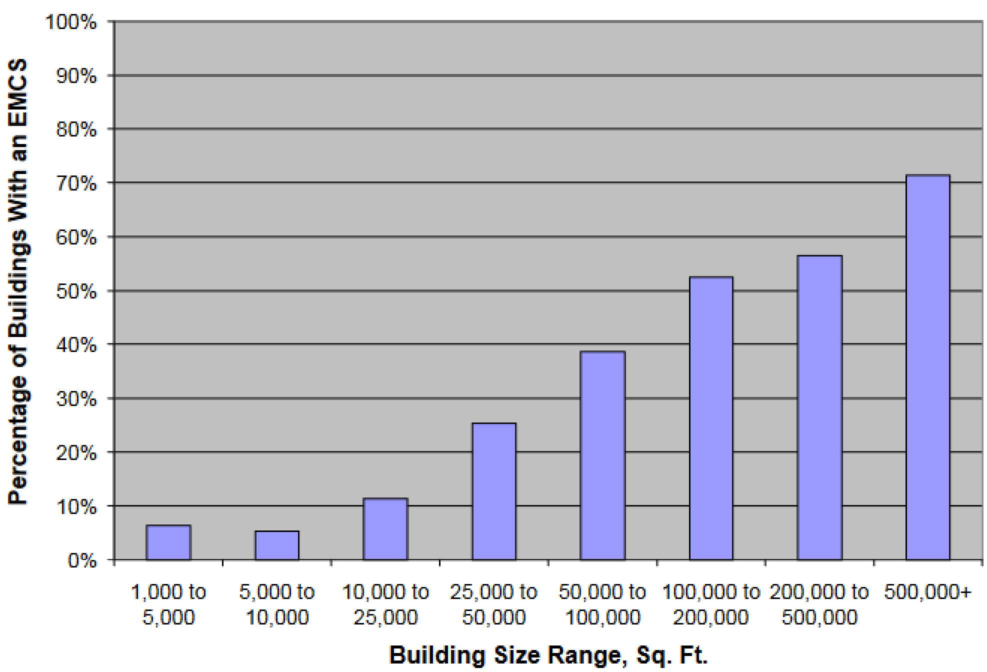

Figure 1-4: Percentage of Buildings with an EMCS, by Building Size[7]

Typical Conveyance System facilities are small pump stations with one or two air handling units and are service process spaces. In some cases, the systems may be required to operate constantly, eliminating the

[7] CBECS. 1999. "Commercial Buildings Energy Consumption Survey (CBECS)," U.S. Department of Energy, Energy Information Administration. http://www.eia.doe.gov/emeu/cbecs/contents.html

need of a smart BMS. Since many Conveyance facilities are considered classified spaces by NFPA 820, any upgrades would have to comply with the ventilation requirements.

Implementation of facility smart HVAC controls is recommended for the larger administration buildings when the building's HVAC systems reach the end of their useful life and the building systems as a whole can be upgraded.

Future project considerations:

- Upgraded HVAC controls to be considered if possible in conveyance system facilities such as the major consumers identified in this section.
- Smart building controls to be incorporated into administration building systems upgrades and updates. The additional costs for incorporating smart controls when systems are due to be replaced is justified by the energy and savings.

1.7 Alternative 71: Solar Power at Flow Monitoring Sites or Lighting at Other Low Wattage Facilities (Conveyance System)

Description
This investigation provides a high-level overview for the potential to add Photovoltaics (PV) to existing Conveyance System facilities. According to the Conveyance System Spreadsheet that was provided, there are approximately 250 Conveyance System facilities that have a WE Energy electric utility account. However, only 65 of these facilities each consume more than 500kWh per month and will be considered for PV installation in this analysis.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:

- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Internal, renewable energy source • Reduces carbon footprint • Reduces electricity bills	• Capital cost required for PV system • Operation and maintenance of PV system

Facility Impacts from Modifications
Modifications to the existing infrastructure are required and summarized below:

- Installation of new photovoltaic system at existing Conveyance facilities.
- The existing WE Energy feed would be maintained for power consumption when PV energy is not available.

Basis of Design
According to the National Renewable Energy Laboratory (NREL) U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020, the average residential PV system benchmark is 7.0 kW (DC). This analysis assumes the 65 identified Conveyance facilities have the necessary land space to accommodate the average residential system size.

The estimated PV array power density for a ground based, south facing, 10-degree tilt configuration is 118 WDC/land m^2. A 7kW system would require approximately 60 m^2 (646 ft^2). This is equal to a 25 ft by 25 ft area. PVWatts is an online tool that aids in the design and evaluation of solar PV systems. Using PVWatts which accounts for solar resource data in Milwaukee, WI, a 7kW DC system size is estimated to output 9,500 kWh per year per installation.

9,500 kWh at each of the 65 identified facilities extrapolates to 617,500 kWh. The amount of energy generated from renewable solar energy is approximately 72% of the total electricity used and 42% of the total energy consumed by the Conveyance System. The total land area these installations requires is 3900 m^2 (41990 ft^2) or about 1 acre.

This analysis is assuming all electricity generated can be utilized. Flow measuring and pump stations vary their electricity demand based on when pumping energy is required. Batteries would be required to store energy for times when generation exceeds demand. Generally, batteries will always be required for installations were net-metering or exporting to the utility grid are not viable.

Cost Analysis

Per the U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020, the average residential PV system cost $2.71 per watt (DC). The cost of a 7kW system would be approximately $19,000.

The yearly O&M cost for a PV system is estimated to be $20/kW according to an NREL report "PV O&M Cost Model and Cost Reduction"[8]. This results in a yearly O&M cost of $140.

Assuming an output of 9,500 kWh per year and an electricity cost of $0.14/kWh, the annual electricity cost savings per year is $1,190. This calculates to a payback period of 15.6 years.

Recommendations

Solar power at Flow Measuring Stations or Lighting at Other Low Wattage Facilities (Conveyance System) is recommended. The evaluated PV installation could offset for 72% of the total non-renewable electricity consumed by the Conveyance System facilities which accounts for 42% of all energy consumed by the Conveyance System facilities. However, the electrical demand at each Conveyance facility may not allow for the use of all electricity generated by the PV system. Battery storage would be required which may increase the payback period.

[8] https://www.nrel.gov/docs/fy17osti/68023.pdf

1.8 Alternative 72: General Energy/Water Conservation Measures

Description
This analysis addresses basic energy savings techniques for the Administration Buildings and Conveyance System facilities. Opportunities exist to improve energy monitoring, reduce energy demand, include more energy efficient controls. Resources available include energy codes and standards, including the International Energy Conservation Code (IECC) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1 "Energy Standard for Buildings except Low-Rise Residential Buildings".

The IECC promotes sustainability and energy efficiency based on fundamentals of using new energy efficient materials and new energy efficient designs. The code is updated regularly and defines the minimum energy conservation requirements for new buildings in both commercial and low-rise buildings by focusing on new construction designs of heating and ventilation, lighting, and power usage appliances. ASHRAE Standard 90.1 "Energy Standard for Buildings except Low-Rise Residential Buildings" Standard 90.1 defines, in detail, minimum energy requirements of new buildings, new portions of an existing building, and new electrical and mechanical systems associated with the building. Although these documents are mainly applicable to new construction, the presented techniques can be applied to existing facilities in an effort to improve energy savings.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:

- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Reduced facility energy consumption. • Improved energy monitoring. • Production of renewable energy.	• Impact on existing operations.

Facility Impacts from Modifications
Modifications to the existing infrastructure are required and summarized below:

- Improve thermal envelope by decreasing the U-Factor (thermal transmittance).
- Replace faucets and shower heads with energy efficient compatible products.
- Continue to replace equipment including lights, HVAC equipment, motors, and transformer with more efficient equivalents.
- Improve lighting, receptacle, and HVAC control systems to increase energy efficiency.

- Improved energy monitoring.
- Installation of photovoltaic system with energy storage capability.

Basis of Design
Addressing the building's thermal envelope is a good first measure towards reducing energy demand. The thermal envelope is quantified by the use of the U-Factor also known as the thermal transmittance value. The thermal transmittance is influenced by the building's insulation and fenestration ratings. Increasing the R-value of the building thermal envelope insulation and decreasing the U-factor for fenestrations will reduce the amount of energy the HVAC system requires to maintain the dry, heated or cooled indoor environment. The IECC sets the minimum thermal envelope requirements for new construction. Testing can be performed to determine existing thermal envelope to check for air leakages and recommend corrective actions.

General water conservation measures include using high efficiency faucets and shower heads which are available in the US marketplace and can save up to 30-50% overall consumption of water. Apart from conserving water, electronic sensor faucets also improve hygiene in public areas. It is recommended to choose models with 'WaterSense' labels that limit the flow rates to 1.5 gallons per minute. This can reduce a sink's water flow by 30 percent or more from the standard flow of 2.2 gallons per minute. This water use reduction will also reduce demand for the energy used for water heaters.

Energy reductions may be achieved through the replacement of existing equipment with newer, more efficient models. Replacement of HVAC equipment provides the greatest opportunity for energy savings because it composes a substantial portion of overall facility load and improvements in motor technology may offer significant margin for efficiency improvements. Replacement of transformers and lighting also provide some energy savings through increased product efficiencies.

The Light Emitting Diode (LED) is the most energy efficient lighting source. Replacing incandescent lights with LEDs, like MMSD is currently doing, can lower the energy use for lighting by about 75%. Replacing fluorescent with LEDs can reduce energy costs by 30%,-50% but the largest benefit LEDs have over fluorescent is their long life span, whereas fluorescent have to be replaced often. In addition, the life cycle of an average LED is 25 times greater than an incandescent light. LEDs also emit light in a specific direction which reduces the need for lamp shades, diffusers, and reflectors which in itself trap and waste light. LEDs also emit very little heat compared to an incandescent lamp which released 90% of its energy as heat.

Another general energy conservation measure is to install premium efficiency motors. In industrial and commercial sectors, electrical motors including motors powering pumps, fans, and other processes, account for about 40% of energy consumption. With the rise in awareness about energy conservation National Electrical manufacturers Association (NEMA) introduced the concept of Premium Efficiency standard for motor. The goal of using Premium Efficiency motors is to reduce power loss by increasing efficiency of motors, and usually as the horsepower of the motors increase, the efficiency also improves.

Motor efficiency gains are usually small when seen as percentages, but the benefits and power savings are huge when translated to kilowatts and power bill savings.

HVAC control systems are responsible for control of operations of heating, ventilation, and air conditioning equipment. The goal of a modern control system is to reduce installation, maintenance, and energy consumption costs. A 'smart' HVAC control system usually has a central user interface like a head-on computer and software that allows the operators to monitor and send control functions. Controllers are devices that provide means for controlling the end devices. The end devices have sensors that measure the value of HVAC variables like temperature or humidity. Instead of having just one-set value in a building for temperature or humidity, a control system ensures continuous comfort and safety while operating as efficiently as possible from an energy consumption standpoint. Manual thermostat adjustment can reduce heating and cooling energy consumption and would not require additional HVAC controls upgrades.

Lighting control systems sense the lighting requirements and provides right amount of light, the right color, at the right place, at the right time. The daylight response will reduce energy consumption by dimming lights when there is adequate light outside. The time-switch control can automatically adjust the light including shutting off at night or when space is no longer needed. Occupancy sensors, like MMSD is already installing in office spaces and conference rooms, similarly vary lighting intensity based on the number of occupants or the kind of tasks to be performed. Using lighting control reduce the energy consumption by 10-30% annually.

Per ASRARE standard 90.1, at least 50% of all receptacles in office space must be controlled. The receptacle control has occupancy sensors that shut down the receptacles within 30 minutes of all occupants leaving the space or having a scheduled basis that turn off the receptacles at specific times of the day. Almost 30% of building loads are plug loads like computer monitors, personal heaters and coolers and installing receptacle controls help minimize the energy consumption by these loads.

Adjustable Frequency Drives (AFD), another name for VFDs, can save energy by enabling motors to operate at less than full speed. By reducing motor speed by 25% decreases energy consumption by about 60%, while reducing motor speed by 50% decreases energy consumption by 90%. In many HVAC and process applications, pumps and motors are oversized to account for many uncertainties, and this in turn results in energy wastage. Installing AFD in such applications can significantly reduce the energy bills. AFDs also start motors by gradually ramping up the voltages rather than applying full voltage at once. This reduces the wear and overheating of motors and increases the life of the motor.

Improved energy consumption data can be used to target energy efficiency measures more effectively. Simple energy monitors help consumers to monitor their energy use by providing real-time feedback. These devices can display cost of energy used at different times. This can in turn help consumers to make informed decisions about their energy use and habits about energy consumption. With the use of energy monitors, it is estimated that energy usage by an average customer drop by 7%.

Photovoltaic (PV) cells, commonly known as solar cells are semiconductor devices that convert sunlight into usable electrical energy. Solar energy is one of the most advancing and popular forms of renewable energy in the market. The initial cost for installing solar panels is high, but the payback is quick. Usually, there are financial incentives provided by the government and the energy suppliers. Energy suppliers will set a rate for each kWh of electricity that you produce. The energy supplier will pay further for each kWh of energy that you export back to the electricity grid. This means you can sell energy that you generate and don't end up using. Apart from the financial benefits solar energy is also renewable and helps reduce carbon footprint by 80% in one year. Solar panels usually are very easy on maintenance and once installed have very little upkeep.

Electric energy can be stored at one time to be used at later time to reduce imbalance between energy demand and production. Usually, the electric production over a certain period of time is fixed while the demand can significantly vary. In times like these, energy storage devices like batteries can supply energy and reduce the amount of energy needed from the grid. PV systems usually produce more energy than needed and this excess energy can be saved in energy storage systems like batteries and this energy can be used at peak load times when the energy rates are high. Using battery stored energy at peak load times can significantly reduce electricity bills.

Recommendations

Incorporating general energy/water conservation measures are recommended when the asset is due for maintenance or end of life replacement. These energy savings techniques are considered good design practices to include when the assets are due for maintenance or end of life replacement. All of the measures included in this section have become standard practice for energy efficient designs and would help the District advance progress towards their goals.

The largest energy consumers these improvements would have the biggest impact at are listed below. These were selected based on reviewing utility bills for facilities with electric demands above 7,500 kWh per month and gas demands greater than 100 therms per month. These values were chosen as they represented significantly larger demands than the majority of conveyance system assets.

- 4830 N 32nd Street – Milwaukee
- 7007 N River Rd – River Hills
- 162 N 44th Street – Milwaukee
- 7509 N Beach Dr – Fox Point
- 8000 W Wisconsin Ave – Wauwatosa
- 12308 W Underwood Parkway – Wauwatosa
- 1610 W Canal St – Milwaukee
- 5901 W State St – Milwaukee

- 5022 N Port Washington Rd – Glendale
- 8950 W Watertown Plank Rd – Milwaukee
- 1300 W Green Tree Rd - River Hills
- 1500 S 124th St - West Allis

1.9 Alternative 73: Increase Natural Light in Buildings

Description
This alternative considers the increase of natural light in applicable buildings across MMSD's network of Conveyance System facilities and Administrative Buildings. Taking advantage of natural light or daylighting can significantly reduce the energy load from artificial lighting, reduce the cooling loads needed to offset the heat produced from lighting fixtures, and increase the well-being and productivity of building occupants. The Department of Energy estimates that artificial lighting fixtures account for approximately 11% of the energy consumption of buildings in addition to the additional energy needed to offset heat loads[9]. Side and top daylighting on buildings is typically achieved with the placement of windows and skylights. Optimal windows and skylights provide a balance of high visible light transmittance and low solar heat gain; and should be effective parts of building climate control and lighting systems.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:
- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Reduce electricity consumption due to artificial lighting • Increase productivity and health of occupants • Reduce building energy consumption due to cooling	• Not applicable to all locations. • Dependent upon existing space layout, building orientation, and occupancy areas • Up-front renovation costs

Facility Impacts from Modifications
Modifications to the existing building are required and summarized below:

- Install new lighting controls, occupancy sensors, and additional monitoring
- Replace existing fenestrations with high efficiency windows and skylights with optimal light transmittance and low emissivity coating
- Add new windows and skylights to under-daylit occupied buildings and areas
- Install light color finishes on walls and ceilings to bounce light further into the room

[9] QUADRENNIAL TECHNOLOGY REVIEW. September 2015. "An Assessment of Energy Technologies and Research Opportunities," U.S. Department of Energy. https://www.energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf

- Perform commissioning to ultimately reduce the size of cooling systems

Basis of Design

Daylighting design considers a space's light level requirements, heat gain and loss, glare control, and daylight availability. These factors are influenced by the fenestration size and location, orientation of the building, occupancy of task areas, shading techniques, surface reflectance, and daylighting controls.

The International Energy Conservation and ASHRAE 90.1 Codes requires high efficiency glazing by regulating the solar heat gain coefficient and U-Factor requirements for vertical fenestrations and skylights. The solar heat gain coefficient (SHGC) is a measure of the fraction of total sunlight energy that can pass through the fenestration. The lower the SHGC the less solar heat the window or skylight transmits. The U-Factor is the rate at which a window transmits non-solar heat flow. The lower the U-factor, the more energy efficient the window or skylight.

There are no specific code requirements for daylighting with MMSD's building types but utilizing daylighting with daylight responsive controls can permit vertical fenestrations and skylights with higher SHGC and U-factor values. Daylighting is often designed in coordination with lighting controls that adjust the amount of the artificial light needed based on the intensity and penetration of daylight into the space.

Cost Analysis

The benefit of increased daylighting is dependent on the renovation costs of a variety of existing building elements including the wall construction, roof construction, and HVAC systems, as well as the size, material, placement, and performance of new fenestrations. The cost to replace an existing window and skylight with a high efficiency alternative is approximately $75 and $125 per square foot of the opening, respectively. The cost to add and support a new opening in an existing wall and roof is approximately $150 and $250 per square foot respectively. This cost is the engineers estimate, based off RS Means and experience and familiarity with similar products.

Recommendations

The considerations for daylighting are vastly different between occupied and unoccupied buildings. Since Conveyance System pump stations and buildings are not regularly occupied, the benefits of daylighting will be diminished given that no lighting is typically needed. The lighting in these building is typically high efficiency and the percentage of energy load due to lighting is already lower than other buildings. Existing windows and skylights at the end of their life should be replaced with high efficiency alternatives that minimize solar heat gain. In Conveyance buildings that are more regularly occupied, additional glass block windows could be utilized as a cost-effective way to increase more daylight while maintaining the needed security and privacy of a remote facility. Light colored finishes on the walls and ceilings should also be considered to bounce as much available daylight as possible.

In the Administrative Buildings, increased daylight should be sought after with any rehabilitation project effecting regularly occupied spaces. Existing windows and skylights at the end of their life should be replaced with high efficiency alternatives that minimize solar heat gain. Additional skylights or larger window assemblies should be considered for heavily used spaces. Interior space should be renovated to relocate task areas closer to daylit sources, incorporate light color finishes, and increase the amount of glass and translucent wall partition materials.

Overall, the increasing of natural light is not a practical standalone strategy to achieve energy reduction goals. This alternative is a low priority and should be considered only in coordination with larger renovation projects planned or proposed for the Conveyance Facilities and Administrative Buildings.

1.10 Alternative 74: Alternative Fuel Fleet Vehicles

Description

MMSD owns and operates a vehicle fleet to assist operations and other staff with traveling and maintaining various assets throughout MMSD's facilities. Currently, this fleet is fueled by gasoline or diesel-powered engines that contribute to MMSD's overall energy consumption and a direct contributor to its CO_2 carbon footprint. Alternative fuels such as compressed natural gas (CNG) or electric have shown the potential to reduce fleet energy consumption and emissions. MMSD's vehicle fleet consists of cars and light trucks primarily fueled by gasoline, and various class 9 and heavy trucks primarily fueled by diesel. Large class 9 trucks are limited to CNG due to current technologies and their large torque requirements. The smaller cars and light trucks are the primary targets of this analysis.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:

- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Overall vehicle energy consumption and CO_2 emissions reductions. • Electric vehicles can accept energy generated from multiple renewable sources.	• High capital cost associated with vehicle retrofitting • Fueling time requirements • Vehicle range flexibility • There are no local, reliable CNG fueling stations and MMSD would likely have to add their own.

Facility Impacts from Modifications

Modifications to the existing infrastructure are required and summarized below:

- Retrofit existing vehicle fleet with compressed natural gas engine or electric motor and batteries.
- Install electric or CNG vehicle fueling stations where fleet can be refueled overnight or conveniently to minimize workflow disruptions.

Basis of Design

MMSD does not monitor its fleets fuel consumption. This report utilizes the U.S. Department of Energy's Greenhouse Gas Emissions from Electric and Plug-In Hybrid Vehicles calculator to compare the total GHG emissions the vehicle will contribute during its lifetime. An all-electric pick-up truck such as the Rivian R1T was selected as a comparable electric vehicle for the district. The resulting vehicle would generate approximately 130 grams CO_2/mi fewer than a similar gasoline powered vehicle[10]. This equates to about a 30% reduction in total lifetime CO_2 emitted.

CNG vehicles emit approximately 6% to 11% lower levels of greenhouse gases when compared to gasoline fueled vehicles[11]. Large diesel-duty fleet vehicles are limited to a CNG retrofit due to the large torque and fuel consumption of the large trucks. Electrical vehicles are not yet at the point where retrofitting these large trucks are feasible.

Cost Analysis

The costs associated with this alternative include up front new vehicle costs, retrofitting costs, and lifetime vehicle costs. A vehicle retrofit for either CNG or electric is estimated to cost approximately $30,000 to $50,000 when done by a professional. Future new vehicle costs are expected to be comparable for electric, CNG, and gas fueled vehicles. AAA estimates an electric vehicle fuel cost for a year driving 15,000 miles is on average $546 ($0.036/mi), while a gas fueled vehicle would cost $1,255 more ($0.12/mi). Additional savings are incurred considering electric vehicles maintenance costs are on average $330 less than a gas-powered car.[12]

Additional costs are incurred if the district prioritizes using internal, landfill gas to fuel their fleet, however the costs associated with cleaning, compressing, storing, and fueling the vehicles are not a part of this evaluation.

Costs for electric vehicle charging stations vary depending on the voltage of the installation desired. Costs can range anywhere from $10,000 to $50,000 per station.

Recommendations

Retrofitting the existing large diesel-duty fleet to be CNG is a low priority due to the costly up-front capital costs and limited renewable energy potential. Replacing smaller gasoline fueled vehicles with electric vehicles is recommended when vehicle replacement is needed. Purchasing new electrical vehicles are recommended as they are shown to reduce lifetime CO_2 emissions by 30%. Utilizing digester gas and cleaning to renewable natural gas was not considered or recommended as MMSD already beneficially utilizes the fuel and its carbon offset internally in its power generation equipment and using it in vehicle fueling would necessitate costly fuel cleaning, compression, and storage.

Installing electric vehicle charging stations at locations where the gasoline fueled vehicles are parked is recommended to be completed up front, so electric vehicle infrastructure is available when vehicles are purchased.

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10 https://www.fueleconomy.gov/feg/Find.do?year=2022andvehicleId=44462andzipCode=53207andaction=bt3
11 https://afdc.energy.gov/vehicles/natural_gas_emissions.html
12 https://www.aaa.com/autorepair/articles/true-cost-of-ev

1.11 Alternative 77: Consolidate or Downsize Non-Process Administrative Facilities

Description

This alternative considers the downsizing or consolidating of workspace in MMSD's Administrative Buildings. The primary Administrative Buildings are the MMSD Headquarters, Central Lab Building, and South 13th Street Facility. Assuming that current employees are allocated an average amount of space, downsizing or consolidating working space would only have a discernable effect on energy consumption if thresholds were met that eliminate portions of MMSD's floorspace or real estate.

The largest energy consumers in office buildings are the lighting and HVAC systems. The U.S. Energy Information Administration calculates that lighting, space heating, cooling, and water heating are the four greatest end uses in buildings and are consumed in 90% of the total floor space[13]. However, a reduction in spatial working area is not directly proportional to a reduction in energy use because a base amount of energy is needed to run most building systems.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:

- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Reduce energy consumption by eliminating unused space • Reduce energy consumption by reducing occupied working area • Taking advantage of work from home opportunities	• May not be applicable to all locations or departments • Less workspace for future growth • Renovation costs needed to consolidate staff

Facility Impacts from Modifications

Analysis and modifications to the existing buildings and staff are required and summarized below:

- Determine unused space allocation in each facility
- Determine remote working opportunities and the effect on space needs
- Determine consolidation opportunities on a departmental level
- Renovate facilities as needed to accommodate new occupant loads

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[13] CBECS. 2018. "Commercial Buildings Energy Consumption Survey (CBECS)," U.S. Department of Energy, Energy Information Administration. https://www.eia.gov/consumption/commercial/data/2018/pdf/CBECS_2018_Building_Characteristics_Flipbook.pdf

- Reduce spatial footprint if possible

Basis of Design

In determining the design occupant load for business spaces, the International Building Code delineates a rate of one occupant per 150 square feet. This ratio can be used in a spatial analysis of the amount of used vs unused space, to determine a high-level estimate of spatial availability and potential optimization.

The energy use intensity (EUI) is a calculation of the energy consumed by a building in one year divided by the total gross floor area of the building. It is expressed in thousands of British thermal units used per square foot per year (kBtu/sq. ft./year) and can be an indicator of the energy efficiency of a buildings design and operations. The EUI value can be calculated as a benchmark for current conditions and then compared to the EUI of theoretical or modeled downsized conditions to determine potential energy use reduction.

One consideration can be to consolidate non-process administrative facilities as JIWRF or SSWRF to minimize the number of buildings and facilities MMSD needs to power and condition. Base power demand may not be significantly reduced, however there are more opportunities for renewable energy generation and consumption available at the WRFs, and therefore may be helpful to consolidate the energy consumers there. Further space availability and feasibility assessments would be required to further vet this as a potential option.

Cost Analysis

The cost associated with downsizing or consolidating space are related to renovation and construction costs necessary to accommodate the new smaller footprint. The cost to construct new office buildings in Midwest urban areas can range from $150-200 per square foot. The cost to renovate office space in Midwest urban areas can range from $100-150 per square foot. These costs are the engineers estimate for common construction based off RS Means and experience, and will vary with the existing conditions, material costs, and construction methods.

Recommendations

The decision to downsize or consolidate staff involves many positional and productivity related variables that should be the primary and initial consideration. If a spatial analysis identifies a large percentage of unused or inefficient space, then the potential reduction in energy load due to consolidation may also be a considerable factor. Otherwise, the reduction in energy used due to the decrease or optimization of the working footprint is a secondary benefit and not a long-term strategy for energy reduction. Given the current environment and the concern over the proximity of workers, the trend is to increase the amount of space designated to each employee, which works in contrast to the energy related benefits of downsizing. Overall, the downsizing or consolidating of workspace is not a high priority practical standalone strategy to achieve energy reduction goals. This alternative is considered low priority on its own, however should be considered in coordination with larger renovation projects planned or proposed for the Administrative Building.

1.12 Alternative 82: Use Smaller Pumps for Dewatering ISS Between Rain Events and Diversions

Description

The JIWRF ISS pump station lifts water from the MMSD tunnel system approximately 300 ft. to two head tanks. Each head tank has stand pipes inside which are designed at an elevation such that the water can flow by gravity to the SSWRF or the JIWRF depending on which head tank the ISS pumps discharge to.

The ISS pump station is also used to dewater the tunnel from ground water which enters the tunnel via infiltration. The water level in tunnel builds up to the point where it needs to be pumped on a daily or weekly basis. This pumping could also be accomplished with a single small pump in order to avoid using one of the three 5,500 HP driven ISS pumps. A small pump would have the following energy advantages:

1) The dewater pumping would be more efficient.
2) The large pumps could be deenergized for most time avoiding the plant parasite load from the ISS pumps isolation transformers and VFDs.

The ISS pumps energy consumption is included as part of JIWRF's energy consumption and not the Conveyance System's because the pumps are metered and powered from there, however the asset is considered part of the Conveyance System.

Energy Efficiency and Climate Mitigation and Adaptation Goals met by alternative:

- ✓ Meet a net 100% of MMSD's energy needs with renewable energy sources.
- ✓ Meet 80% of MMSD's energy needs with internal, renewable sources.
- ✓ Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

Alternative Benefit Comparison

Advantages	Disadvantages
• Energy savings of using smaller influent pump.	• Capital cost of adding ISS Pump Chamber Dewatering Pump. • Cost of adding pump between ISS Pump Chamber and discharge of influent screw pumps or to ISS pump station JI head tank.

Facility Impacts from Modifications

Modifications to the existing infrastructure is required to facilitate this alternative therefore a capital cost expenditure is required to implement. Adverse effects to utilities and buildings are not anticipated. The following equipment additions to JI are required.

- Pump installed in the ISS pump chamber.

- Force main installed between ISS pump chamber and screening building or ISS pump station JI head tank.

Basis of Design
The existing ISS pumps operate most efficiently between 70%-90% corresponding to flows between 30 and 60MGD. This alternative evaluates if increased efficiencies could be realized if a smaller pump were installed to operate when tank levels are low and flows are below 30 MGD.

Pump manufacturers were contacted, and the existing pump curves were reviewed. The ISS wet well water elevations correspond to pump minimum and maximum heads between 210 ft H2O and 330 ft H2O. The existing Ebara split-case centrifugal pumps utilize VFDs to operate down to 70% of their rated capacity to operate more efficiently and use less energy.

Due to the large head requirements, pumps of this size have limited turndown and capacity capabilities. Additionally, if a smaller pump were capable of being installed with a higher efficiency, the pump would have to operate longer to dewater the wet well, thus diminishing any energy savings.

After consultation with pump manufacturers, it does not appear that this alternative will result in any significant energy savings.

Recommendations
Installing smaller dewatering pumps is not recommended as it is not apparent that there will be significant energy savings.

Section 2 Conclusion

This memo evaluated nine alternatives that are initiatives to reduce energy consumption and bring MMSD closer to achieving its 2035 vision goals. The alternatives evaluated are summarized in Table 2-1 below.

Table 2-1: Alternatives Summary

Alternative Number	Description	Cost	Energy Savings	System Reduction
32	Thermal Energy Generation in Collection System	$200,000-$400,000	~20% of heating and cooling loads	~20% of heating and cooling loads
63	Install More Efficient Pump Station Pumps	$400,000	262 MMBTU/yr	10%
68	HVAC Control at Major Remote Sites (Conveyance System)	Varies by building	~20% reduction	20%
71	Solar Power at Flow Monitoring Sites	$19,000 per 7kW system	32 MMBTU/yr per 7kW system	N/A
72	General Energy/Water Conservation Measures	-	-	-
73	Increase Natural Light in Buildings	-	-	-
74	Alternative Fuel Fleet Vehicles	-	-	-
77	Consolidate or Downsize Non-Process Administrative Facilities	-	-	-
82	Use Smaller Pumps for Dewatering ISS Between Rain Events and Diversions	-	0	0

In order to achieve the goals of the 2035 Vision, MMSD needs to prioritize energy efficiency upgrades across all administrative buildings and conveyance system sites. Although these two areas only account for 1.5% of MMSD's total energy consumption, they offer quick wins for reducing energy consumption. As a matter of practice, all projects that are replacing energy consuming assets should seek out replacements that offer reductions in energy use. Overtime, this practice will show progress towards and commitment to the 2035 Vision across all District facilities. Cost alone should not be a limiting factor, ease of change or retrofit, timing, and energy savings by system should be considered. Alternatives 63 and 71 are expected to have the largest impact on reducing MMSD's energy consumption. Alternatives 63 and 71 combined, would account for 80% of the Conveyance System's electricity consumption, or 45% of the Conveyance System's energy consumption which includes both electricity and natural gas.

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Appendix C

JIWRF Energy Plan (TM-3)

Energy Plan for MMSD Facilities

Technical Memorandum 3: JIWRF Energy Plan

Milwaukee Metropolitan Sewerage District
Contract M03109P01

Final – October 2022

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Executive Summary

Background and Purpose

The Milwaukee Metropolitan Sewerage District (MMSD) adopted the 2035 Vision in 2010 that charts the path for where MMSD wants to be in the next 25 years. The 2035 Vision focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency, including the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

This *Technical Memorandum 3* (*TM-3*) focuses on energy planning for the Jones Island Water Reclamation Facility (JIWRF). The baseline energy demand is described, alternatives identified to be implemented to meet MMSD's energy goals are evaluated, and a strategy to achieve those goals is developed. The following reports are a part of this project:

- *TM-1: Energy Review and Renewables*
- *TM-2: Administration Buildings and Conveyance System*
- ***TM-3: JIWRF Energy Plan***
- *TM-4: SSWRF Energy Plan*
- *Planning Report*
- *TM-5: Carbon Free Needs Assessment*

Existing Conditions

JIWRF began operation in 1925 and was expanded and upgraded multiple times since. It has a current treatment capacity of 330 Million Gallons per Day (MGD) and a blending capacity of 390 MGD. JIWRF was at the forefront of developing the activated sludge wastewater treatment process, recognizing the value of wastewater treatment residuals and incorporating sludge drying to produce Milorganite® fertilizer.

For this project, MMSD provided total energy consumption data for 2018 – 2020 and Q1 of 2021 that provides the baseline energy usage for JIWRF. The energy consumption presented is from 2018-2020 and is a snapshot of what the demands were at this time. Future planning reports will consider anticipated demands and future projects.

The energy data provided includes a combination of external and internal energy types, including electricity, natural gas (NG), landfill gas (LFG), and renewable energy sources.

Internal energy consists of LFG, while external consists of NG, utility purchased electricity, and the remaining energy sources. Renewable energy consists of LFG, while all other sources are non-renewable, other than a portion of purchased electricity.

All energy was converted to million British Thermal Units (MMBTU). The facility's average total energy consumption from 2018-2020 is approximately 2,021,000 MMBTU/yr. **Figure ES-1** shows the total approximate energy consumption by major energy using equipment at JIWRF.

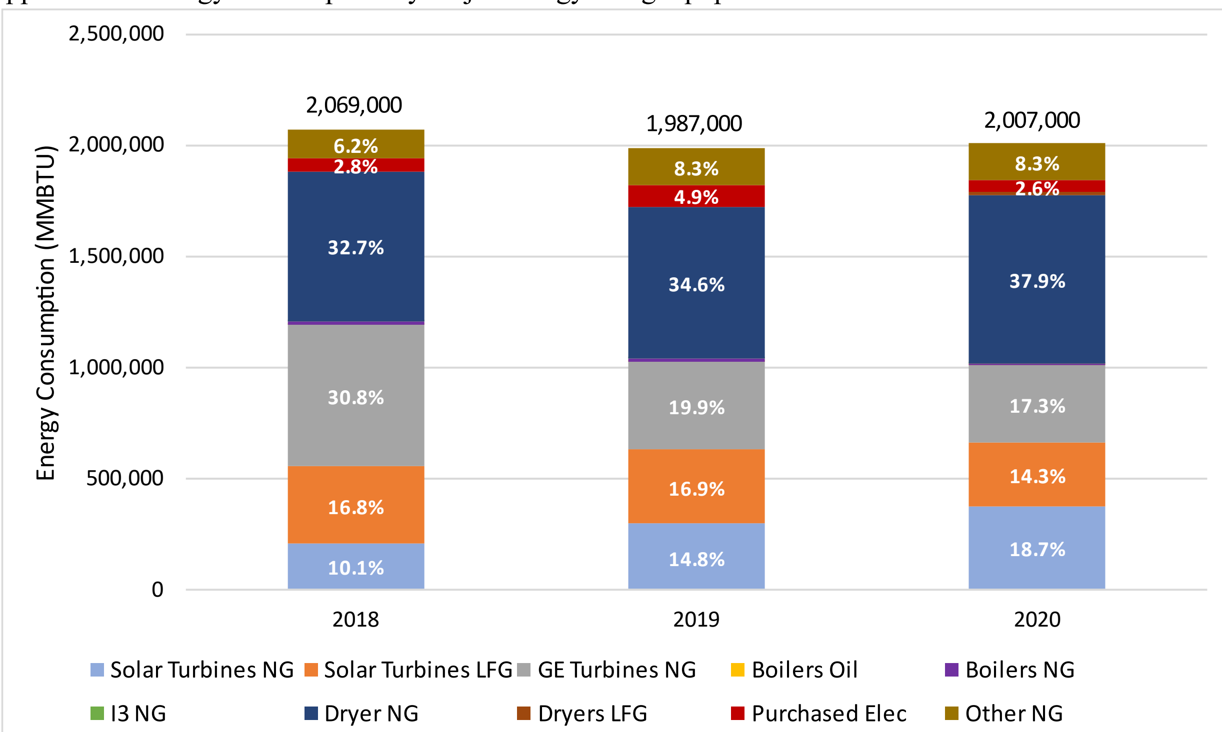

Figure ES-1: JIWRF Energy Consumption

NG is the primary energy source consumed at JIWRF and is primarily used in the drum dryers for Milorganite® production, turbines for electricity and waste heat generation, facility heating, and boilers.

LFG is used in the drum dryers for Milorganite® production and in the Solar Turbines for electricity and waste heat generation.

JIWRF does not have electrical meters for each building or broken down by wastewater process. The electrical consumption was estimated for each major wastewater process equipment using data provided and Operation and Maintenance (O&M) Manuals and run time data. The electrical consumption was averaged from 2018-2020 and consists of 85,000,000 kWh (290,000 MMTBU) produced by the turbines, and 20,500,000 kWh (70,000 MMBTU) of purchased electricity annually. **Table ES-1** and **Figure ES-2** shows the estimated baseline electrical consumption in MMBTU per year and kilowatt hour (kWh) per year for major equipment and processes.

Table ES-1: Estimated JIWRF Baseline Electricity Consumption

Equipment/Process	MMBTU/yr	kWh/yr	%
Aeration System	107,500	31,500,000	30%
Other (Misc. Facility Processes)	53,000	15,500,000	15%
ISS Pumps	52,000	15,240,000	14%
Effluent Pumps	30,000	8,800,000	8%
D&D Facility HVAC Fans	30,000	8,800,000	8%
Facility Lighting	29,000	8,500,000	8%
RAS Pumps	26,000	7,600,000	7%
Influent Pumps	14,000	4,100,000	4%
D&D Facility Dust System Fans	7,700	2,250,000	2%
WAS Pumps	4,400	1,300,000	1%
IPS Pumps	4,400	1,300,000	1%
Primary Sludge Pumps	2,000	586,000	1%
Total	**360,000**	**105,500,000**	**100%**

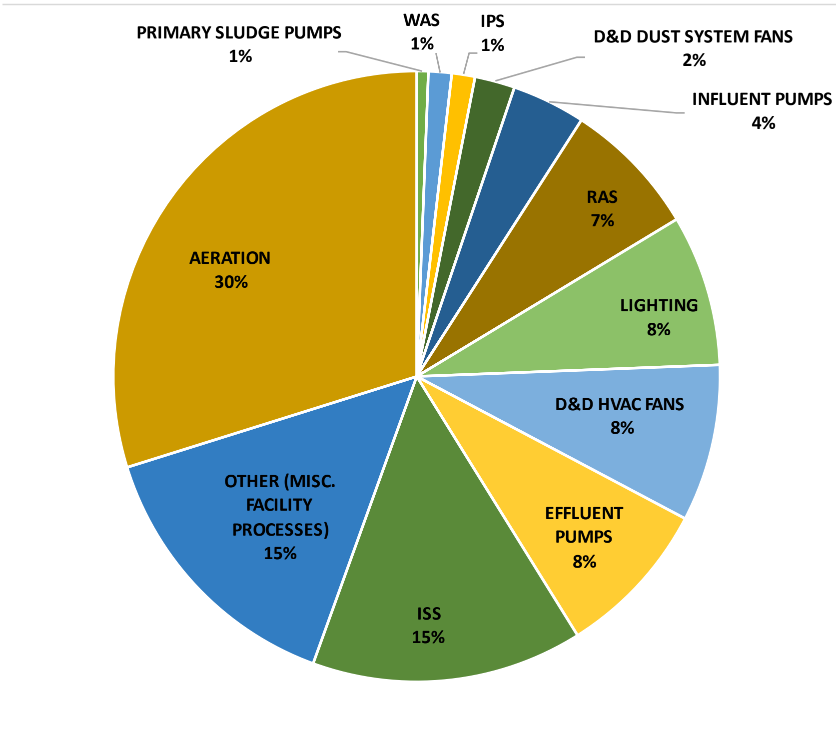

Figure ES-2: JIWRF Electrical Consumption

JIWRF Energy Plan

The plan for MMSD to meet their energy goals at JIWRF is broken up into three parts: optimization of energy operating strategy, energy generation, and energy efficiency. Energy generation is additionally discussed as renewable energy and non-renewable energy. Renewable energy is energy generated from renewable sources such as photovoltaics, wind, and landfill gas (LFG). Non-renewable energy consists of energy generated from non-renewable sources such as natural gas (NG). JIWRF is MMSD's largest energy user, mainly due to the Dewatering and Drying (D&D) Facility, where all MMSD digested biosolids are heat dried using waste heat, NG and LFG to produce Milorganite®, a fertilizer product.

Optimization of Energy Operating Strategy

<u>LFG</u>

MMSD uses LFG at the JIWRF received via pipeline from the EPL. The gas is used primarily by the Solar turbines to generate electricity and waste heat, and four drum dryers, which are dual fuel gas fired and dry the solids in the production of Milorganite®. The drum dryers have a gas demand exceeding the LFG available. To maximize the renewable energy utilized, it is recommended to burn all LFG available at the drum dryers.

Turbines

JIWRF has three Solar turbines which can run off landfill gas or natural gas, and two GE turbines that are fueled by natural gas or No. 2 Fuel Oil. MMSD prioritizes operating the solar turbines as they are more efficient at generating electricity.

Electricity and waste heat generated by the turbines when fueled from LFG is considered renewable, while the electricity and waste heat generated by NG is considered non-renewable.

It is recommended that the turbines not be run on natural gas to minimize the non-renewable energy consumption and resulting greenhouse gas (GHG) emissions at JIWRF. This is recommended when MMSD has other renewable electricity sources that can offset the non-renewable electricity consumption.

Prior to these renewable electricity sources or agreements, it is recommended to run the turbines to minimize the facility electrical utility demand and consumption charges.

Facility Electrification

Transitioning natural gas fired equipment and appliances to electric is important to meet MMSD' energy goals. Natural gas is a finite resource with limited renewable alternatives whereas renewable electricity is more readily available through the utility grid.

Air source heat pumps, in conjunction with electric resistance coils, can replace natural gas fired or hot water coil air handlers. This would require all existing air handlers to be replaced and heat pumps be installed outdoors. It is recommended they be incorporated when equipment is at the end of its useful life and up for replacement.

Energy Generation Summary

Alternatives for potential energy generation utilizing renewable processes like photovoltaic, wind, pyrolysis, algae bioreactor, and LFG were evaluated. The potential energy generation listed in **Table ES-2** below is all the renewable energy that can be generated internally at JIWRF based on this memorandum's analysis. This table summarizes that a total of 630,700 MMBTUs of renewable energy can be generated internally for consumption on site. Pyrolysis and an algae system that grows sufficient algae to produce biofuel can be net energy positive, however this memorandums analysis did not show a positive energy generation.

Table ES-2: JIWRF Renewable Energy Generation Summary (MMBTU)

Source	Electricity	Gas	Total
Photovoltaic	51,000	0	51,000
Wind	121,700	0	121,700
Pyrolysis of Chaff	0	0	0
Algae Bioreactor	0	0	0
LFG	0	475,000	475,000
Total	**186,700**	**475,000**	**661,700**

Energy Efficiency Alternatives Summary

Improvements to reduce energy usage at JIWRF by improving energy efficiencies for equipment and processes were evaluated. The baseline energy values from **Table ES-1** were used and approximate energy efficiency savings were calculated. The energy efficiency alternatives are summarized below.

- D&D Facility Dryers:
  - Based on the recommendations from the Biosolids Advanced Facility Plan (BAFP) that was completed by others, the process of heat drying biosolids will continue to produce Milorganite®.
  - For the purposes of this evaluation, it was assumed that the existing dryers would consume the same amount of energy.
- Secondary Treatment Aeration and Blowers
  - Installation of higher efficiency blowers, such as turbo blowers
  - Higher efficiency diffusers
  - Dissolved oxygen (DO) controls
  - Conventional activated sludge process modifications
- Process Pumps:
  - High-efficiency motor replacements
- Lighting:
  - Replacement of high-pressure sodium (HPS) lighting with light emitting diode (LED)
    - Completed

- Boilers:
    - Electrification and air or water source heat pump incorporation[1]
- Inline Storage System (ISS) Pumps:
    - Dewater with smaller pumps

The energy efficiency improvements are summarized by equipment type in **Table ES-3** below.

Table ES-3: Energy Efficiency Improvements Summary

Equipment/Process	Baseline Energy Usage (MMBTU)	Reduction in Energy Usage (MMBTU)	Reduced Energy Usage (MMBTU)
Dryers	861,000	0	861,000
Aeration and Blowers	107,500	31,700	75,800
Process Pumps	80,800	2,400	78,400
Lighting	29,000	15,500	13,500
Boiler	61,000	12,200	48,800
ISS Pumps	52,000	0	52,000
D&D Dust System and HVAC	37,700	1,100	36,600
Other Electric Loads	53,000	0	53,000
Other Natural Gas Loads	153,000	0	153,000
Total	**1,435,000**	**62,900**	**1,372,100**

Other electric loads refer to various electrical consumers throughout JIWRF, including air conditioning, D&D Facility dewatering, conveyors and other processes, and various other process motors and equipment not identified in **Table ES-3**. Other natural gas loads refer to various natural gas consumers throughout JIWRF including other boilers, water heaters, and natural gas fired HVAC units.

[1] https://www.energy.gov/energysaver/heat-pump-systems

Conclusions
Table ES-4 shows the new total energy consumption by equipment after the recommendations are incorporated.

Table ES-4: JIWRF Energy Source by Consumer with Recommended Improvements

Consumer	LFG (MMBTU)	NG (MMBTU)	Electricity (MMBTU)	Total (MMBTU)
Dryers	475,000	386,000	--	861,000
Aeration and Blowers	--	--	75,800	75,800
Process Pumps	--	--	78,400	78,400
Lighting	--	--	13,500	13,500
Boiler	--	--	48,800	48,800
ISS Pumps	--	--	52,000	52,000
D&D Dust System and HVAC	--	--	36,600	36,600
Other Electric Loads	--	--	53,000	53,000
Other Natural Gas Loads	--	--	153,000	153,000
Total	**475,000**	**386,000**	**511,100**	**1,372,100**

The purpose of **Table ES-4** is to show what the energy profile of the end using consumption equipment would look like after the energy recommendations and improvements are incorporated. The other natural gas loads column has the energy demand allocated under electricity because the recommendation is to transition those loads to electric fuel sources. The end goal would be to have renewable electricity fuel the electricity loads at JIWRF. It is recommended that non-renewable natural gas consumption be phased out to achieve MMSDs goals.

The potential total energy consumption with the energy efficiency alternatives incorporated is 1,372,100 MMBTU. This is lower than the baseline of 2,021,000 MMBTU due to inefficiencies in the generation of electricity through the turbines. Waste heat is produced through the turbines with some waste heat utilized for various processes at JIWRF while other waste heat is not utilized. This non-utilized waste heat is approximately 586,000 MMBTU. The energy consumption after incorporating the alternatives also includes the efficiencies realized by incorporating the alternatives evaluated in **Section 3** (62,900 MMBTU).[2]

329,600 MMBTU of natural gas would have to be offset with renewable energy. 511,100 MMBTU, or 150,000,000 kWh, of renewable electricity would have to be offset with renewable energy.

By executing the recommendations in this memo, the resultant renewable energy portfolio at JIWRF would be 48%, with 48% being produced internally. Reducing non-renewable energy consumption including grid purchased electricity, natural gas, and electricity generated from natural gas on-site directly reduces overall GHG emissions. Therefore a 4% reduction in non-renewable energy consumption is a 4% reduction in GHG emissions. As MMSD's renewable energy generation increases and non-renewable energy consumption decreases, MMSD's GHG emissions will consequently also be reduced. GHG emissions will be further quantified, with an established baseline in the Carbon Free portion of this project's scope.

Renewable energy comprises 48% of the total energy consumption shown in **Figure ES-3**. The remaining 52% would have to be offset with renewable energy generated at other MMSD facilities, such as the South Shore Water Reclamation Facility (SSWRF), or other offsite facilities.

[2] 2,021,000 – 586,000 – 62,900 = 1,372,100 MMBTU

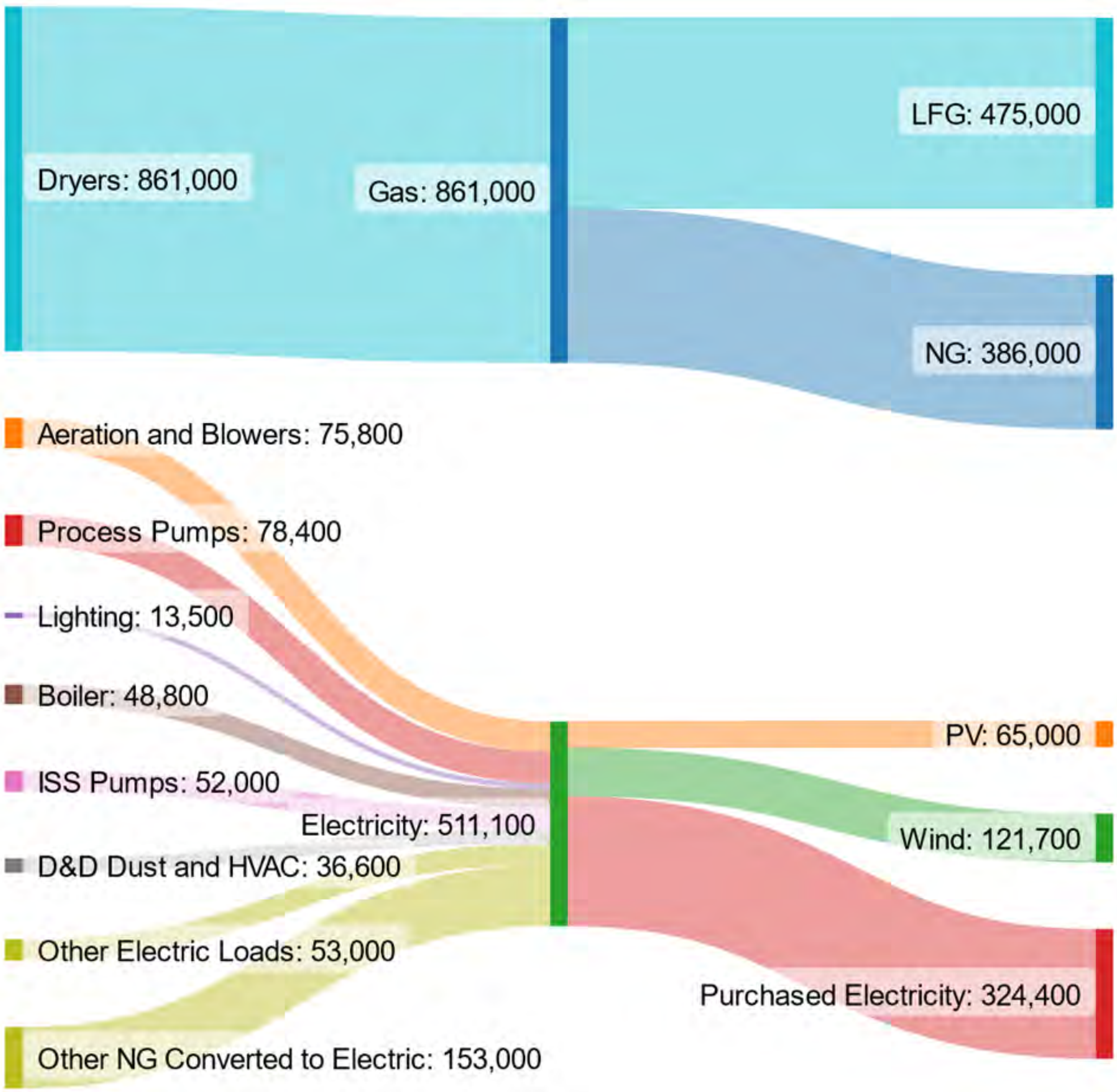

Figure ES-3: JIWRF Sourced Energy by Consumer (MMBTU)

The purpose of this diagram is to show the future optimized energy consumption at JIWRF. The turbines generate electricity and waste heat for other processes at the facility, so they can still be utilized to generate that heat and electricity demand until renewable energy fuels are available.

The production of Milorganite® is a major energy consumer at JIWRF. However, Milorganite® is a sustainable product that offsets the use of non-renewable fertilizers. Milorganite® uses less energy to produce when compared to non-renewable fertilizers, especially in its primary application for lawn fertilization. Approximately 466,000 MMBTU of energy is offset, when compared to alternative, non-renewable fertilizers, by the production and utilization of Milorganite®. While this energy does not actively push the needle towards MMSD's stated goals in the 2035 vision, it may be considered offsetting non-renewable energy outside of MMSD.

As part of this project, additional technical memorandums are being prepared and will be submitted at a later date.

- *Technical Memorandum 4 – SSWRF Energy Plan* will detail the energy plan at SSWRF.
- *The Planning Report* will be a MMSD-wide document to meet the MMSD energy goals. *The Planning Report* will include a plan to offset all non-renewable energy consumption. Non-renewable energy consumption at JIWRF may be offset through excess renewable energy generation at SSWRF, energy generation at other MMSD properties, or a combination of them.
- *Technical Memorandum 5 – Carbon Free Needs Assessment*

Section 1 Introduction

1.1 Purpose

The Milwaukee Metropolitan Sewerage District (MMSD) is a leading regional government agency that provides water reclamation and flood management services for approximately 1.1 million people in 28 communities in the Greater Milwaukee area. The wastewater collected within the MMSD's service area through the conveyance and storage asset system is sent to two water reclamation facilities: Jones Island Water Reclamation Facility (JIWRF) and the South Shore Water Reclamation Facility (SSWRF).

MMSD is a leader in the water industry in protecting the environment and sustainability. MMSD adopted the 2035 Vision in 2010, that focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency and includes the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal, renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

This Technical Memorandum (TM-3) defines JIWRF's energy baseline demand, identifies alternatives to be implemented to improve energy efficiency and generate energy through renewable sources, and develops a strategy to achieve MMSD's goals at JIWRF. The following reports are a part of this project:

- *TM-1: Energy Review and Renewables*
- *TM-2: Administration Buildings and Conveyance System*
- ***TM-3: JIWRF Energy Plan***
- *TM-4: SSWRF Energy Plan*
- *Planning Report*
- *TM-5: Carbon Free Needs Assessment*

1.2 JIWRF Background

JIWRF began operation in 1925 and was expanded and upgraded multiple times since. It has a full treatment capacity of 330 Million Gallons per Day (MGD) and 390 MGD with blending. JIWRF was at the forefront of developing the activated sludge wastewater treatment process, recognizing the value of wastewater treatment residuals, and incorporating sludge drying to produce Milorganite® fertilizer. An aerial photo showing JIWRF is included as **Figure 1-1**.

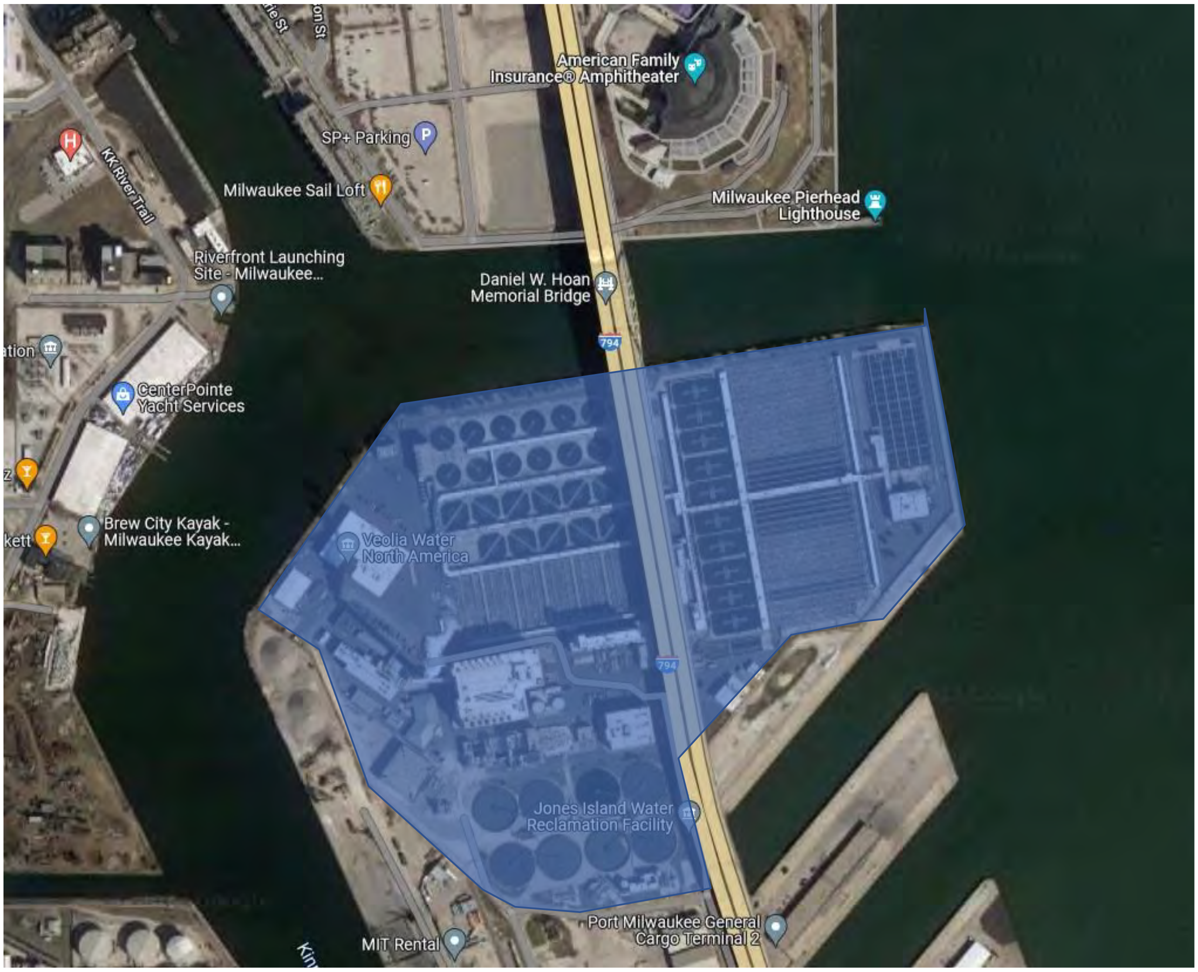

Figure 1-1: JIWRF Aerial Photo

The JIWRF Process Flow Diagram is shown in **Figure 1-2** and includes both the liquid and solids treatment systems.

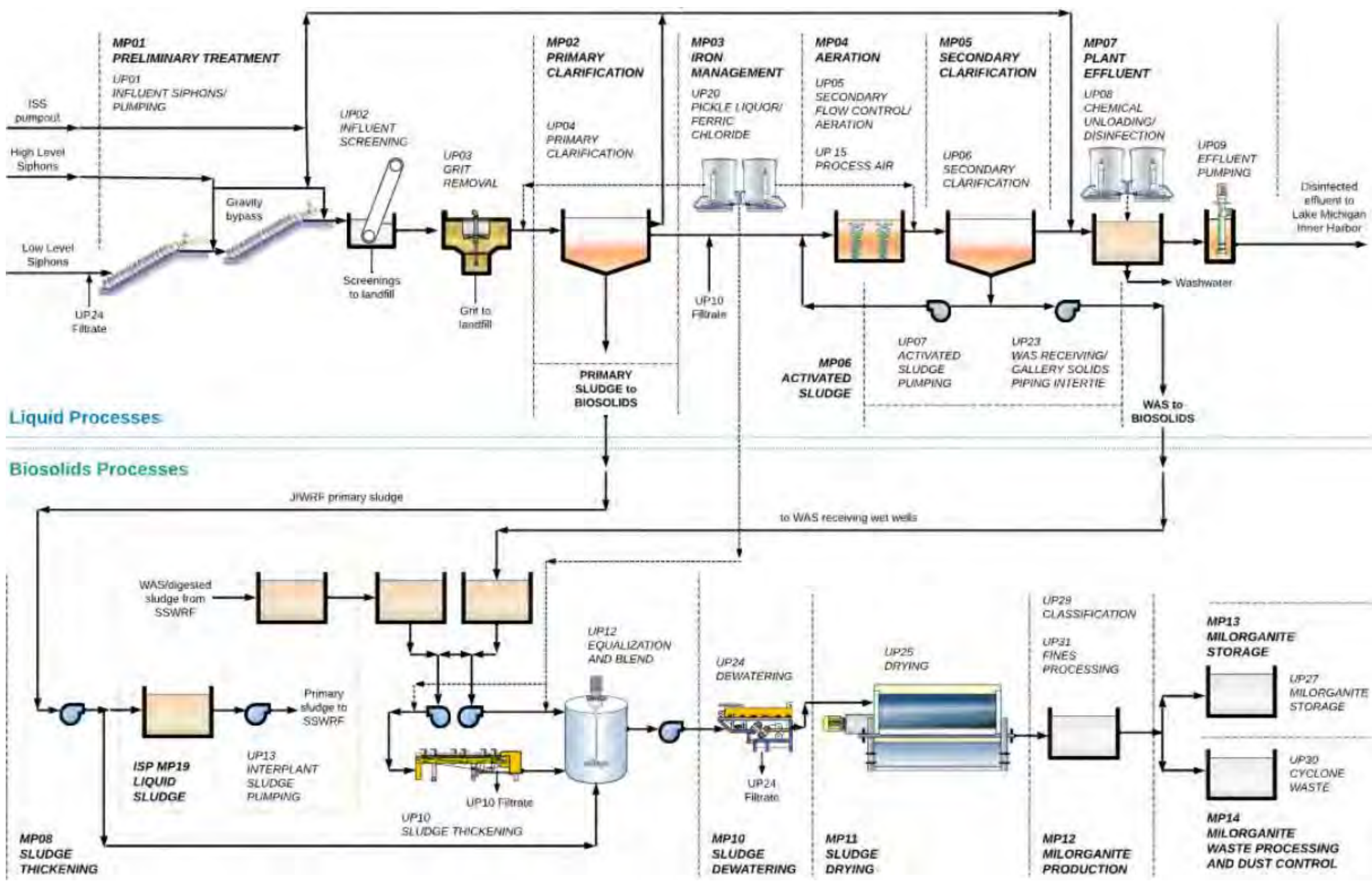

Figure 1-2: JIWRF Process Flow Diagram (Source: 2050 Facility Plan)

The major electricity and energy users at JIWRF include the following equipment and processes:

1. **Influent Pumping**
    - Low Level Pumps – 4 pumps, Screw type, 350 Horsepower (HP) each
    - High Level Pumps – 5 pumps, Screw type, 350 Horsepower (HP) each
2. **Primary Sludge Pumping**
    - 8 pumps, air-operated diaphragm pumps, 195 standard cubic feet per minute (SCFM) air required at 80 pounds per square inch gauge (PSIG).
3. **Secondary Treatment / Aeration Basins**
    - East Plant Basins – 20 Tanks, Single Pass
    - West Plant Basins – 12 Tanks, Single Pass
    - Blowers – 4 Process Air Compressors (PAC)
        - **i.** PAC 1 – Siemens single stage centrifugal high efficiency blower, 4,500 HP
        - **ii.** PAC 2, 3, 4 – Allis-Chalmers blower, 5,500 HP each
4. **Activated Sludge Pumping**
    - East Plant Return Activated Sludge (RAS) Pumps: 4 pumps, Vertical Centrifugal, 200 HP each
    - West Plant RAS Pumps: 3 pumps, Vertical Centrifugal, 125 HP each
    - East Plant Waste Activated Sludge (WAS) Pumps: 3 pumps, Vertical Centrifugal, 50 HP each
    - West Plant WAS Pumps: 2 pumps, Vertical Centrifugal, 25 HP each
5. **Effluent Pumping**
    - 4 pumps, Vertical Propeller, 300 HP each
    - 4 pumps, Horizontal Propeller, 40 HP each
6. **Interplant Sludge Pumping (IPS)**
    - Three 2-stage Pairs, Horizontal Centrifugal, 400 HP per pair
7. **Inline Storage System Pumping (ISS)**
    - 3 pumps, Split Case Horizontal Centrifugal Double Volute, 5500 HP each

8. Dewatering and Drying (D&D) Facility

- Sludge Dewatering:
    i. Belt Filter Presses: 24 Units
- Sludge Drying:
    i. Dryer Drums: 12 Units, Horizontal cylindrical drums, 60 HP drives each, each equipped with a dryer feed mixing screw conveyor, 5 HP each, and dryer feed screw conveyors, 5 HP each
- Dust Collection System Fans
    i. Classification System Fan: 150 HP Centrifugal Fan
    ii. Dryer System Fan: 220 HP Centrifugal Fan
- HVAC Fans
    i. There are approximately 64 fans serving the exhaust, return, and supply for the D&D Facility. These fans range in size from 1 to 75 HP.

Section 2 Existing Conditions

2.1 Baseline Energy Consumption

MMSD provided total energy consumption data for 2018 – 2020 that was used to calculate the baseline energy usage for JIWRF. Energy data for Q1 of 2021 was also provided to compare the energy trends of Q1 of 2021 to the previous years. In general, Q1 of 2021 indicative of the general trend of utilizing the GE turbines less and Solar turbines more.

The energy consumption presented is from 2018-2020 and is a snapshot of what the demands were at this time. 2018-2020 was agreed to be the basis of this reports baseline comparison for the alternatives analysis and energy required for generation with MMSD. This was done to be able to accurately evaluate alternatives and make statements for recommendations based on current information. Future potential projects that affect energy demand were not considered as they may not be implemented, or energy projections could be inaccurate making any recommendations using those projections inaccurate as well. Future projects that are included in MMSD's budget will be incorporated and their energy demands considered in future planning reports.

The energy data provided includes a combination of external and internal energy and types, including electricity, natural gas, landfill gas, and renewable energy sources. All energy was converted to million British Thermal Units (MMBTU). Generally, when discussing energy, units of MMBTU will be used. When discussing electricity, units of kilowatt hour (kWh) will be used.

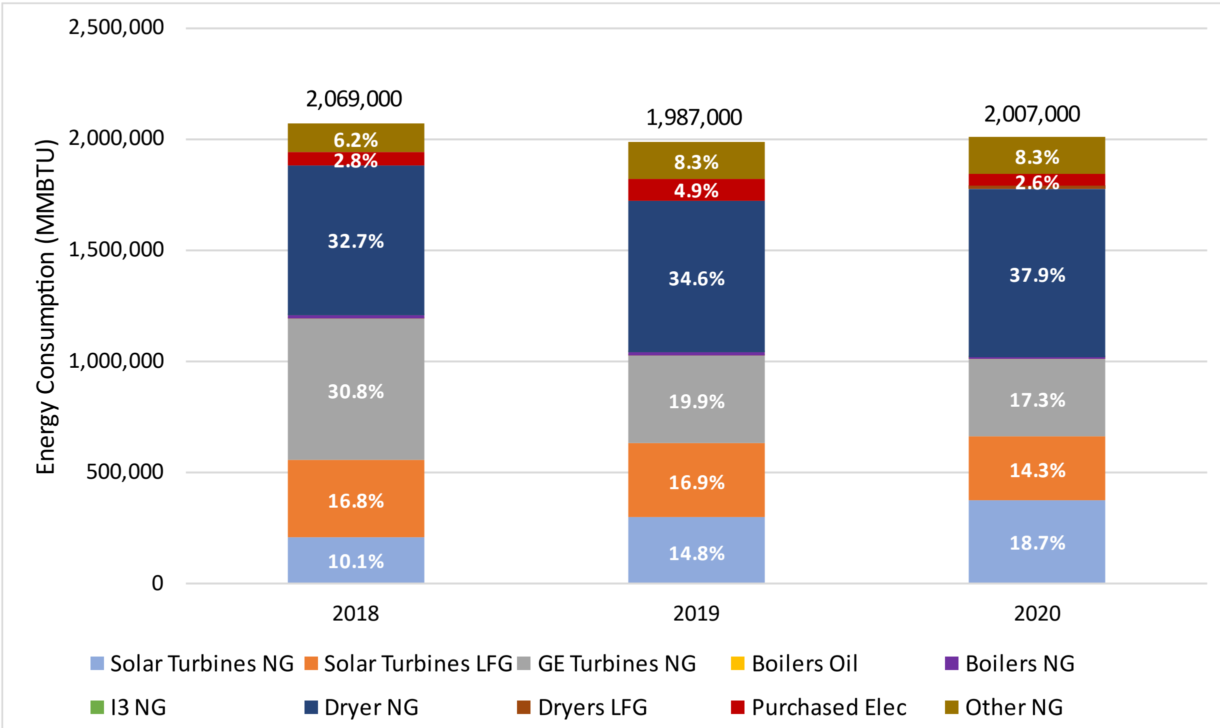

Figure 2-1: Jones Island Energy Consumption

Figure 2-1 shows JIWRF's total energy consumption from 2018 through 2020, the average is approximately 2,021,000 MMBTU per year.

- Natural gas (NG) consumption totals 80.4% (1,625,000 MMBTU) of JIWRFs energy consumption.
- Landfill gas (LFG) consumption totals 16.2% (326,000 MMBTU) of JIWRFs energy consumption.
- Utility purchased electricity accounts for 3.4% (20,500,000 kWh or 70,000 MMBTU) of JIWRF's consumption. Process electricity consumption is detailed in Section 2.8.
- The remaining energy consumption consists of Fuel Oil, Propane, etc. which is small in comparison to the other energy sources.
  - Fuel Oil is used regularly to start the GE Turbines and can be used in the boilers in the powerhouse.
  - Propane is used in forklifts, and can be used, but is rarely in the boilers or space heaters.

- Future equipment not requiring these fuels is recommended. Biodiesel may be a substitute if liquid fuels are required.

Internal energy consists of LFG, while external consists of NG, utility purchased electricity, and the remaining energy sources. Renewable energy consists of LFG, while all other sources are non-renewable, other than a portion of purchased electricity which is discussed in **Section 3.2.4**.

Figure 2-2 shows the JIWRF energy balance as described above and in the following subsections. The left side of the figure shows the fuel sources. These are utility purchased electricity, natural gas, and landfill gas. The right side is the end use of the energy and consist of facility electrical demands, dryer demand, boiler demand, and other natural gas demands. Both the left side fuel source inputs and right-side energy consumers add up to the facility's total energy consumption of 2,021,000 MMBTU.

The facility consumes approximately 105,500,000 kWh (360,000 MMBTU) of electricity. 80% (85,000,000 kWh or 290,000 MMBTU) of that electricity is generated at JIWRF by the turbines. 20% (20,500,000 kWh or 70,000 MMBTU) of that electricity is purchased from the utility.

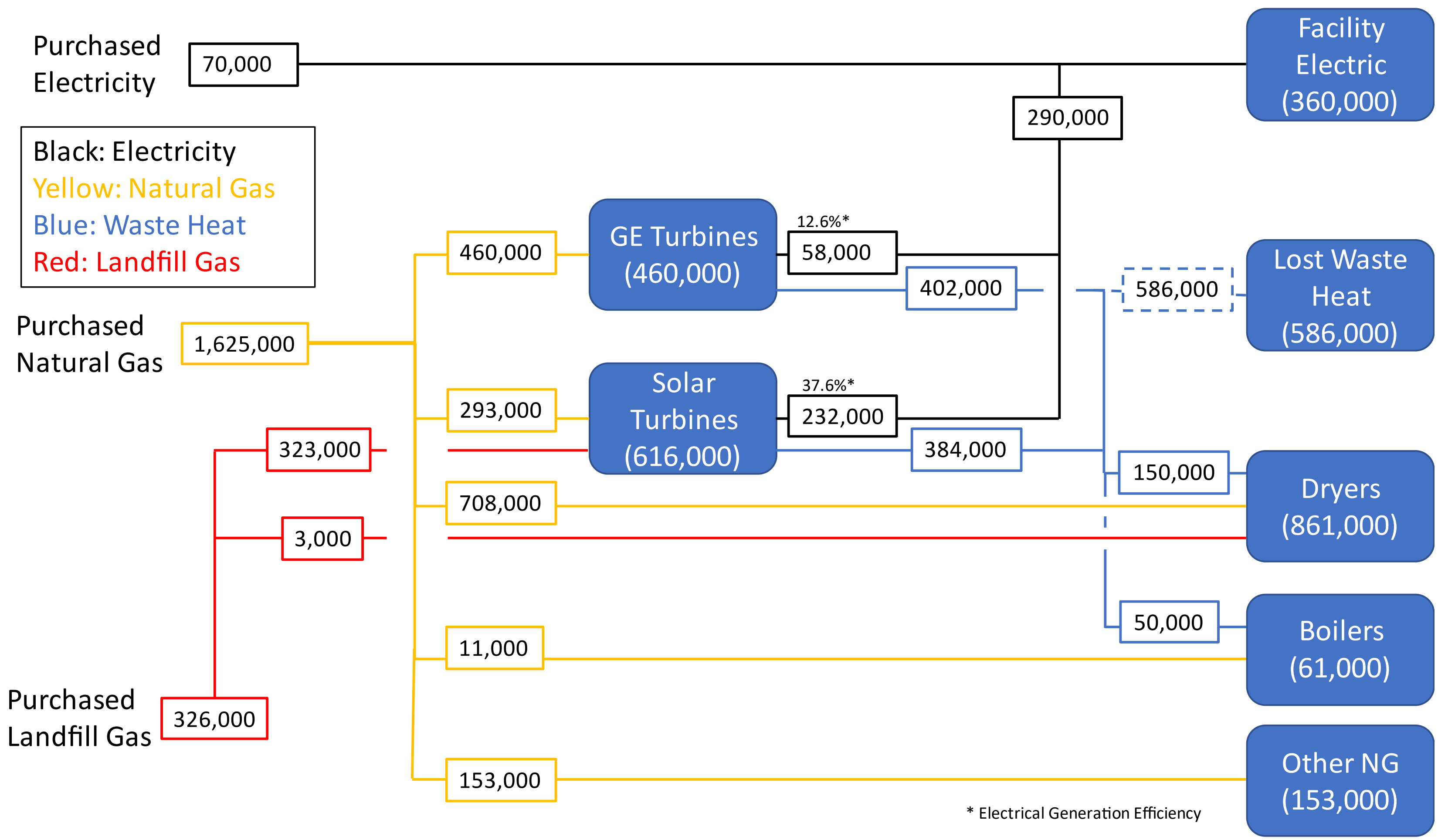

Figure 2-2: Jones Island Energy Consumption Schematic (MMBTU)

2.2 Baseline Electricity Demand

The baseline electricity demand was determined utilizing hour electrical load data from 2018 through 2020. The average dry weather demand during this period was 11.5 MW, while the average wet weather demand was 17.2 MW. The peak wet weather demand is typically around 25.0 MW when discounting a couple anomalous data points.

Table 2-1: JIWRF Electricity Demand

Scenario	Electricity Demand (MW)
Dry Weather	11.5
Wet Weather	17.2
Peak Wet Weather	25.0

2.3 Dryers

The D&D Facility dryers account for, on average, 861,000 MMBTU of energy consumption at JIWRF. 150,000 MMBTU of that total is recaptured waste heat from the turbines. 3,000 MMBTU of that total is landfill gas, while the remaining 708,000 MMBTU is natural gas. Recent years have prioritized fueling the dryers with landfill gas. Recent years have shown a trend of increased dryer energy consumption, however Milorganite® production appears to be stable. **Figure 2-3** and **Figure 2-4**.

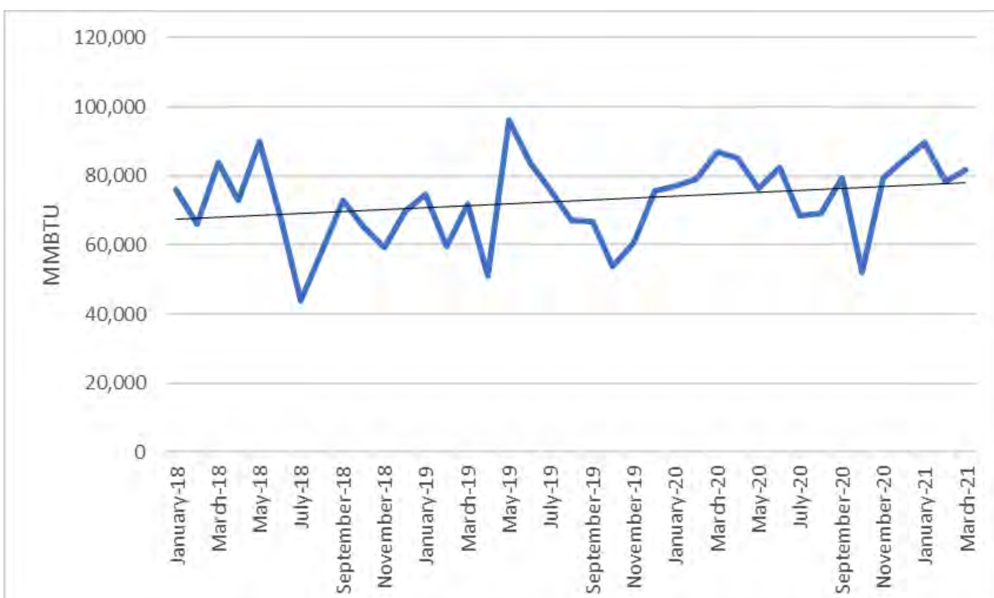

Figure 2-3: Drum Dryer Energy Consumption by Month

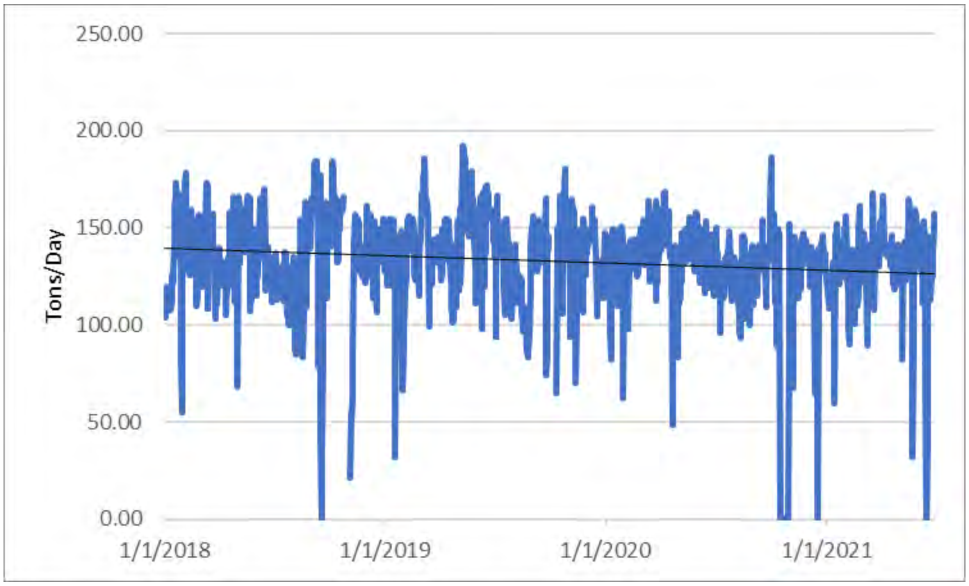

Figure 2-4: Total Milorganite® Production

The trendline in **Figure 2-4** appears to be decreasing, however this may be due to the more frequent days where no data was available near the end of the chart. The trends of dryer energy consumption increasing while Milorganite® production has remained stable or may even be decreasing suggests the dryers are becoming less efficient over time.

2.4 Solar and GE Turbines

The JIWRF has two types of turbines that generate electricity from NG, LFG, or No. 2 Fuel Oil. The on average turbines combine for 1,076,000 MMBTU of JIWRF's energy consumption. This energy consumption is split between the Solar and GE turbines. On average from 2018 through 2020, 616,000 MMBTU was consumed by the Solar turbines and 460,000 MMBTU was from the GE turbines. Turbine landfill gas consumption accounts for 323,000 MMBTU of the Solar turbine's energy consumption, which is considered renewable.

The turbines produce electricity and waste heat for the facility. The turbines generated an average of 85,000,000 kWh (290,000 MMBTU) of electricity from 2018 through 2020. The Solar turbines generated 68,000,000 kWh (232,000 MMBTU) while the GE turbines generated 17,000,000 kWh (58,000 MMBTU) of electricity. The resulting electrical energy generation efficiencies are 37.6% and 12.6% respectively. The Solar turbines generated approximately 384,000 MMBTU of waste heat, while the GE turbines generated 402,000 MMBTU of waste heat. Currently, MMSD utilizes 200,000 MMBTU of the 786,000 MMBTU, resulting in 586,000 MMBTU currently being lost energy. The waste heat utilized per turbine is not known, and therefore the thermal efficiency of each turbine cannot be determined. The overall thermal efficiency of the turbines is approximately 25%. Similarly, the net efficiency of each turbine cannot be determined, however the overall net efficiency of the turbines is approximately 45.5%.

2.5 Purchased Electricity

Electricity is purchased from We Energies with multiple accounts for JIWRF representing different feeds. Reviewing utility bills, purchased electricity accounts for 20,515,000 kWh or 70,000 MMBTU of JIWRF's energy consumption. Purchased electricity consists of both renewable and non-renewable energy which feeds into the facility's electrical distribution system. The purchased electricity makeup is analyzed in Section 3.2.4. JIWRF's We Energies electric utility rate structure for CP1, Summer and Non-Summer is included for reference below in **Table 2-2** and **Table 2-3**. Note that there is the current rate, and proposed rate which includes significant consumption and demand charge increases.

Table 2-2: We Energies Summer Rate Structure

CP1S (CP1 Summer Med Voltage)	Current	Proposed	Unit	% Change
Facilities Charge, $/day	19.76010	19.76010	$/day	0.00%
Additional Meter Charge, $/day			$/day	
Standard/ On-Peak Usage Charge, $/kWh	0.07687	0.09294	$/kWh	20.91%
Off-Peak Usage Charge, $/kWh	0.04949	0.05922	$/kWh	19.66%
On-Peak Demand Charge, $/kW	17.44000	21.43200	$/kW	22.89%
Customer Demand Charge, $/kW	2.23000	2.31100	$/kW	3.63%

Table 2-3: We Energies Non-Summer Rate Structure

CP1N (CP1 Non-Summer Med Voltage)	Current	Proposed	Unit	% Change
Facilities Charge, $/day	19.76010	19.76010	$/day	0.00%
Additional Meter Charge, $/day			$/day	
Standard/ On-Peak Usage Charge, $/kWh	0.06672	0.08066	$/kWh	20.89%
Off-Peak Usage Charge, $/kWh	0.04949	0.05922	$/kWh	19.66%
On-Peak Demand Charge, $/kW	12.54700	15.41900	$/kW	22.89%
Customer Demand Charge, $/kW	2.23000	2.31100	$/kW	3.63%

2.6 Other Gas Loads

In addition to NG and LFG used for the dryers and boilers, there are other miscellaneous NG demands for various buildings, mostly for HVAC systems for heating including gas fired boilers, and HVAC units. These account for approximately 153,000 MMBTU of JIWRF's energy consumption.

2.7 Boilers

Boilers are used at JIWRF to produce hot water for use throughout the facility. The total boiler loop energy consumption is approximately 61,000 MMBTU per year. The boiler's NG consumption accounts for 11,000 MMBTU of this consumption. The boiler loop also receives waste heat from the turbines, which is assumed to be 50,000 MMBTUs of energy annually.

2.8 Electric Loads by Process

JIWRF does not have electrical meters for each building or broken down by wastewater process. To understand electrical usage for various processes throughout the facility, electricity consumption was further broken down. The electrical consumption was estimated for each major wastewater process equipment using data provided and Operation and Maintenance (O&M) Manuals and run time data. The electrical consumption was averaged from 2018-2020.

Table 2-4 and **Figure 2-5** show the processes where generated and purchased electricity is consumed throughout JIWRF. The other loads are likely various motors throughout the D&D Facility and other process equipment, building HVAC equipment, and other various electrical consumers throughout the facility. The average annual electricity consumption consists of a combination of purchased 20,500,000 kWh (70,000 MMBTU) and generated 85,000,000 kWh (290,000 MMBTU), totaling 105,500,000 kWh (360,000 MMBTU).

Table 2-4: Estimated Baseline Electrical Consumption

Equipment/Process	MMBTU/yr	kWh/yr	%
Aeration System	107,500	31,500,000	30%
Other (Misc. Facility Processes)	53,000	15,500,000	15%
ISS Pumps	52,000	15,240,000	14%
Effluent Pumps	30,000	8,800,000	8%
D&D Facility HVAC Fans	30,000	8,800,000	8%
Facility Lighting	29,000	8,500,000	8%
RAS Pumps	26,000	7,600,000	7%
Influent Pumps	14,000	4,100,000	4%
D&D Facility Dust System Fans	7,700	2,250,000	2%
WAS Pumps	4,400	1,300,000	1%
IPS Pumps	4,400	1,300,000	1%
Primary Sludge Pumps	2,000	586,000	1%
Total	**360,000**	**105,500,000**	**100%**

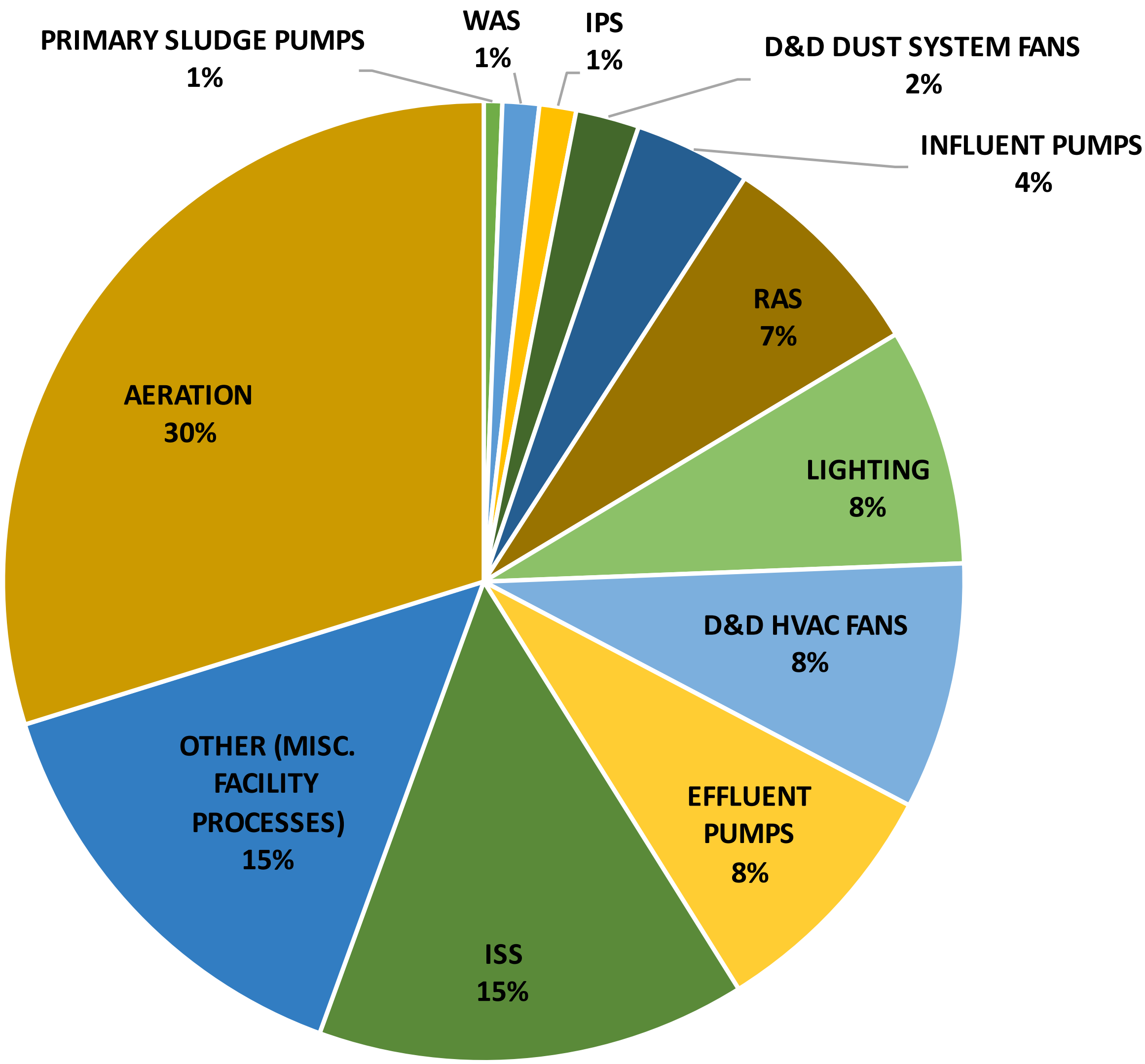

Figure 2-5: Electrical Consumption

Section 3 Energy Alternatives Analysis

3.1 Introduction and Methodology

The significant JIWRF energy consumers were identified in Section 2. This section evaluates potential alternatives to optimize existing energy related assets and systems, generate energy, reduce energy, and reduce the dependence on natural gas.

The analysis is organized as follows: the energy consumer is identified, a description of the potential improvement is provided, and the impact of the improvement is summarized. Finally, a cost analysis is provided, if available and applicable to the alternative. Utility rates were provided by MMSD. A blended electricity rate of $0.042/kwh and an average utility electricity rate of $0.10/kwh were used for comparison. Similarly, a natural gas rate of $5.00/dekatherm (dth) and $10.00/dth, also $5.00/MMBTU and $10.00/MMBTU respectively, were used as bounds for comparison, as the price of natural gas has fluctuated recently. The minimum cost of landfill gas used was $2.11/MMBTU.

The cost opinions are engineers' opinions of probable construction costs and are class 5 estimates in 2022 dollars. The opinions utilize the following assumptions:

- Engineering and Design: 15%
- Overhead and Profit: 20%
- Class 5 Contingency: -50% to +100%

The assumptions are that the facilities will be consistent with the 2050 Facility Plan and the Biosolids Advanced Facility Plan. Purchasing renewable energy certificates (RECs) and renewable power purchasing agreements (PPA) were assumed to be not viable renewable energy approaches due to legal hurdles described by MMSD, stemming from the increased cost occurred to the taxpayers.

3.2 Optimization of Energy Operating Strategy

This section describes operating strategies to maximize renewable energy consumption and minimize non-renewable energy consumption.

3.2.1 LFG

MMSD uses LFG at the JIWRF received via pipeline from the EPL. The gas is used primarily by the Solar turbines to generate electricity and waste heat, and four drum dryers, which are dual fuel gas fired and dry the solids in the production of Milorganite®.

On average, JIWRF uses 310,000 MMBTU of LFG yearly. This number is expected to increase as the D&D Facility has expanded the number of dual fuel drum dryers and the EPL has projected 475,000 MMBTU/yr of gas to be available[3]. This equates to about 54 MMBTU/hr of available gas. The drum dryers consume on average 104 MMBTU/hr. That means the dryers can utilize all LFG available.

It is recommended that MMSD maximize the availability of LFG from the EPL and utilize all the LFG at the dryers.

3.2.2 Turbines

JIWRF has three Solar turbines which can run off landfill gas or natural gas, and two GE turbines that are fueled by natural gas or No. 2 Fuel Oil. MMSD prioritizes operating the solar turbines as they are more efficient at generating electricity.

Electricity and waste heat generated by the turbines when fueled from LFG is considered renewable, while the electricity and waste heat generated by NG is considered non-renewable.

For JIWRF to reduce its non-renewable NG consumption, it is recommended that the dryer fuel requirements be the primary consumer of NG as they are not electric, while electric equipment can receive renewable electricity from other sources. Assuming all renewable LFG is routed to the dryers and other renewable gas cannot be procured, the turbines would only be operating on non-renewable natural gas. If the turbines are not operating, all 85,000,000 kWh that they generated would have to be generated or procured elsewhere.

A downside of not using the turbines is the 150,000 MMBTU waste heat that is beneficially used by the dryers. The same analysis is made for the boilers, which consume 50,000 MMBTU of turbine waste heat.

A levelized cost of energy (LCOE) was developed using the National Renewable Energy Laboratory's Simple Levelized Cost of Energy Calculator to compare the cost of energy the turbines generate to grid purchased energy.[4] The input and results are included in **Appendix B**.

- A capital cost of 1850 $/kW was utilized and was determined using manufacturer and DOE data for similarly sized turbines.
- The capacity factor was calculated using the average plant generated MW, divided by the installed capacity. The average plant generated MW from 2018 through 2021 is 10.45 MW. The installed capacity of the Solar Turbines is 14.4 MW. The resulting capacity factor is 72%

[3] Projected LFG Capacity provided by EPL on December 21, 2021
[4] https://www.nrel.gov/analysis/tech-lcoe.html

- The fixed O&M cost includes LFG pipeline maintenance and compressor maintenance costs. Both these costs were introduced in Section 4.2.4 of *Technical Memorandum 1*. The fixed O&M cost is the total cost, divided by the average kW the turbines produce during the year. The maintenance contract for the EPL is $108,000/yr. The maintenance cost of each compressor is estimated to cost $16,000 to maintain annually, or $48,000 total. The average kW generation is 10,450 kW. The resulting fixed O&M cost is $14.93/kW. This O&M cost is the cost required to maintain operations and this cost is typical for this type of system.
- The variable O&M cost is the cost to maintain the turbines themselves, as their O&M cost includes all costs associated with maintenance and overhauls, divided by the kWh of electricity generated. This value was again discussed in Section 4.2.4 of *Technical Memorandum 1* and is $0.0144/kWh.
- The heat rate is supplied by the turbine manufacturer. For the Mercury 50 Solar turbines, this value is 8865 BTU/kWh[5].
- The fuel cost is the cost of natural gas and was provided by MMSD. It is $5/dth, or $5/MMBTU.
- The Mercury 50 Solar turbines are more efficient than the GE turbines and should be the priority when turbines are in operation. Therefore, this analysis used the Solar turbines as the basis.

The LCOE analysis shows that the breakeven point for Solar Turbine operational cost to produce electricity is approximately $0.06/kWh. This means that if the electricity cost from the utility is above 6 cents/kWh, it is more cost effective to run the turbines on natural gas. If the utility electricity cost is below $0.06/kWh, then it is more cost effective to purchase from the utility. This is an important factor when considering utilizing the turbines for peak shaving. The LCOE for this scenario is approximately $0.08/kWh.

If $10/dth for the cost of natural gas is used instead, this results in a breakeven point of $0.093/kWh for the utility electricity cost. At $10/dth, the turbines cost to produce electricity or LCOE, is approximately $0.125/kWh.

The same LCOE analysis can be done for LFG. MMSD indicated they pay $2.112/MMBTU for LFG. The resulting LCOE for electricity generated by the turbines on landfill gas is $0.055/kWh, with a breakeven utility electricity cost of $0.043/kWh.

Table 3-1 summarizes the LCOE analysis for the different natural gas utility rates, as well as landfill gas.

[5] Solar Turbine Cut Sheet: https://s7d2.scene7.com/is/content/Caterpillar/CM20150710-52396-21070

Table 3-1: LCOE Summary Table

Fuel	Cost ($/MMBTU)	LCOE ($/kWh)	Utility Electricity Breakeven Point ($/kWh)
Natural Gas	5.00	0.080	0.060
Natural Gas	10.00	0.125	0.093
Landfill Gas	2.11	0.055	0.043

It is recommended that the turbines not be run on natural gas to minimize the non-renewable energy consumption and resulting greenhouse gas (GHG) emissions at JIWRF. This is recommended when MMSD has other renewable electricity sources that can offset the non-renewable electricity consumption.

Prior to these renewable electricity sources or agreements, it is recommended to run the turbines to minimize the facility electrical utility demand and consumption charges. It is beneficial to operate the turbines on excess LFG and natural gas when the utility electricity cost is below the breakeven point shown in **Table 3-1.** It is recommended to continue to prioritize operating the Solar Turbines over the GE Turbines as the higher electrical energy generation efficiency is more economically and environmentally beneficial.

An additional benefit to operating the turbines is the waste heat generated from the fuel is utilized in the dryers. Additional buildings or boiler loops can be added to utilize additional waste heat that may currently be lost due to heat exchanger inefficiencies or equipment down times.

Redundancy and availability of equipment and fuel will have to be considered and incorporated into operations. For example, when the dryers are down, it is recommended LFG be burned in the turbines to generate renewable electricity.

3.2.3 Facility Electrification

Transitioning natural gas fired equipment and appliances to electric is important to meet MMSD' energy goals. Natural gas is a finite resource with limited renewable alternatives whereas renewable electricity is more readily available through the utility grid.

The largest natural gas consumers at JIWRF are the D&D Facility dryers, turbines, and the boilers and various natural gas fired air handling units. The turbines and dryers are covered in different sections.

JIWRF utilizes a hot water loop that is fed from either the boilers or the steam to water heat exchangers from the waste heat of the turbines. This system can be transitioned to be fully electric by incorporating effluent heat recovery and water source heat pumps to generate hot water. This will be discussed in more detail in the effluent heat recovery section. The existing boilers could also be replaced with electric boilers.

Air source heat pumps, in conjunction with electric resistance coils, can replace natural gas fired or hot water coil air handlers. This would require all existing air handlers to be replaced and heat pumps be installed outdoors.

Air and water source heat pumps generally have a positive return on investment when there are both heating and cooling load requirements for buildings. It is recommended they be incorporated when equipment is at the end of its useful life and up for replacement. It is estimated that heat pumps can reduce the heating and cooling energy consumption by about 20%. This number is conservative when considering the U.S. Department of Energy references that heat pumps can reduce energy consumption up to 50%.[6] 20% was used because Milwaukee is a colder climate that would require auxiliary heating backup for very cold days, and it will also generally have a lower coefficient of performance, which dictates how much efficiency the unit will gain versus standard electric resistive heating.

3.2.4 Grid Renewable Energy Makeup

Table 3-2 shows We Energies overall power mix including renewable energy percentage. In 2021, 4.7% of We Energies energy was from renewable energy. The projected renewable energy percentage for 2022 is 6.2%[7].

Table 3-2: We Energies Overall Power Mix

Power Mix	2021 Actual	2022 Projected
Renewables	4.7%	6.2%
Coal	36.2%	30.8%
Natural Gas/Oil	28.5%	23.4%
Other	30.7%	39.5%
Total	100%	100%

WEC Energy Group, which owns We Energies, has committed to a 60% reduction in carbon emissions by 2025 and an 80% reduction by the end of 2030. The long-term target is net-zero carbon emissions by 2050.[8]

6 https://www.energy.gov/energysaver/heat-pump-systems
7 https://www.we-energies.com/services/eft
8 https://www.wecenergygroup.com/csr/climate-report2021.pdf

It is recommended to continuously monitor We Energies renewable energy incorporation progress and consider this when planning future renewable energy projects and accounting for renewable energy consumption.

3.3 Energy Generation

3.3.1 Pyrolysis of Chaff to Produce Synthetic Gas and Biochar

Description

Pyrolysis is an alternative for disposal of chaff, which is off specification materials from the D&D Facility. Chaff makes up approximately 11% of production. Chaff is currently disposed of at a landfill.

Pyrolysis is in the early stages of development at wastewater treatment plants for the treatment of biosolids. Pyrolysis can be defined as the thermal decomposition of biosolids with the use of heat and without any addition of extra oxygen. This process produces synthetic gas (syngas) and biochar. Syngas is a fuel gas mixture which is combustible and can be used as an energy source of internal combustion engines. The pyrolysis system can utilize the heat generated by the syngas oxidation to sustain its own process without any external energy. Pyrolysis of biosolids is in the early stages of development for water reclamation facilities.

The evaluation of pyrolysis at JIWRF included coordination with Bioforcetech, a manufacturer of pyrolysis equipment. Bioforcetech has implemented pyrolysis systems in the United States in California (Silicon Valley Clean Water and City of Redding) and Pennsylvania (Ephrata Borough Authority). Per the manufacturer, for a system sized to treat the 14.4 tons/day of chaff, the amount of syngas produced is only enough to keep the pyrolysis system self-sustaining, with no excess syngas produced. The process would generate waste heat that could be used elsewhere, potentially to offset facility heating loads. This may be incorporated in the boiler loop if effluent heat recovery is not found to be feasible. The system can produce hot water at 194 F. Over a year, the heating energy generated is approximately 10,700 MMBTU/yr. This assumes a maximum heat output of 450 kW per machine and each machine operates 7,000 hours per year.

A second manufacturer, Kore Infrastructure, was considered. Kore has a full-scale facility in operation in Los Angeles County that accepts organic waste, including biosolids. Kore’s smallest unit is 25 tons per day. As JIWRF produces only about 14.4 tons per day of chaff, this unit is not feasible. Per Kore, at 25 tons per day, up to one megawatt of energy could be produced, minus about 30% to operate the pyrolysis process. This is depending on the type of organic material being fed into the system.

Engineers Opinion of Probable Construction Cost

The conceptual opinion of capital cost for the pre-assembled machine for chaff pyrolysis at the JIWRF is $30,200,000. This assumes two machines each with a capacity of 9 tons/day. The footprint required for these pre-assembled machines is approximately 1,000 sq. ft. per machine, 25 feet high.

Table 3-3: Pyrolysis Cost Summary

Description	Cost ($mil)	
Pyrolysis Equipment	$	7.7
Misc Mechanical Upgrades (25%)	$	1.9
Conveyance Modifications (25%)	$	1.9
Site Work (25%)	$	1.9
Labor (50%)	$	3.8
Subtotal	**$**	**17.3**
Overhead and Profit (20%)	$	3.5
Contingency (40%)	$	6.9
Design and Engineering Services (15%)	$	2.6
Total	**$**	**30.2**
-50%	$	15.1
+100%	$	60.5

Recommendations

There are benefits to utilizing a pyrolysis process to dispose of biosolids, including the biochar end product and carbon sequestration. Thermal energy through waste heat can be used for other processes. From an energy standpoint, syngas production that could be used as a fuel source for engines is not feasible.

3.3.2 Excess Sludge and Scum

Scum is collected from the primary and secondary clarifiers at JIWRF and concentrated before being disposed off-site. Most water reclamation facilities send their collected scum to landfills or pump it to the digesters for removal. Research is ongoing for different processes to capture the potential energy in scum. The most promising research is from the University of Minnesota, where pilot testing showed about 70%

of the collected scum could be converted to a biodiesel.[9] The system, while showing promise, has not been tested at a large scale or commercialized yet. It is recommended to monitor this research further but no assumption will be made for new energy generated.

3.3.3 Algae and Biofuel

Algae can be used during the wastewater treatment process to remove the nutrients (nitrogen and phosphorus specifically). A Photobioreactor (PBR) is a system used to cultivate algae using light. In addition to treating effluent water, the algae can be harvested to produce algal biodiesel.

Laboratory experiments have proved that the oil content per ton of dry biomass of algae (*Chlorella vulgaris*) grown in ideal conditions are 46%, even higher than the rapeseed oil content of 40%.[10]

The main requirements for algae PBR include:

- Area: sufficient space to accommodate the units to optimize flow and access to sunlight.
- Light: In the case of Wisconsin, at least 4 months in the year will require artificial lighting to keep the algae alive and producing biomass during the winter.
- Proper aquatic habitat: stable water quality depending on the algae species (temperature, pH, salinity, nutrients, etc.).
- Mixing and circulation.

Recommendations
In discussions with manufacturers, due to the Milwaukee's location in the Northern Hemisphere and relative low amounts of sunlight, it is not recommended to install this technology. The system will not produce sufficient quantities of algae to convert to biofuel.

3.3.4 Photovoltaics

Solar photovoltaic (PV) panels can directly generate renewable electricity for consumption. The larger the area, the more electricity that can be generated.

To maximize PV electricity generation, all potential areas at JIWRF were evaluated. These include the area above buildings, secondary clarifiers, aeration basins, chlorination tanks, and above parking spots. The potential areas included for evaluation are shown in **Figure 3-1** and the available area for each is summarized in **Table 3-4** below.

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[9] https://www.cleanenergyresourceteams.org/u-m-researchers-turning-wastewater-scum-profitable-biofuels
[10] Stuart A Scott, Matthew P Davey, John S Dennis, Irmtraud Horst, Christopher J Howe, David J Lea-Smith, Alison G Smith, **Biodiesel from algae: challenges and prospects**, Current Opinion in Biotechnology, Volume 21, Issue 3, 2010, Pages 277-286, ISSN 0958-1669, https://doi.org/10.1016/j.copbio.2010.03.005.

Table 3-4: PV Area Summary

Location	Area (m^2)	kWh/yr
Buildings	10,610	2,114,000
Parking	2,100	419,000
East Clarifiers	13,100	2,611,000
West Clarifiers	18,000	3,587,000
Aeration Basins	44,425	8,854,000
Chlorination Tanks	6,800	1,355,000
Total	95,035	18,940,000

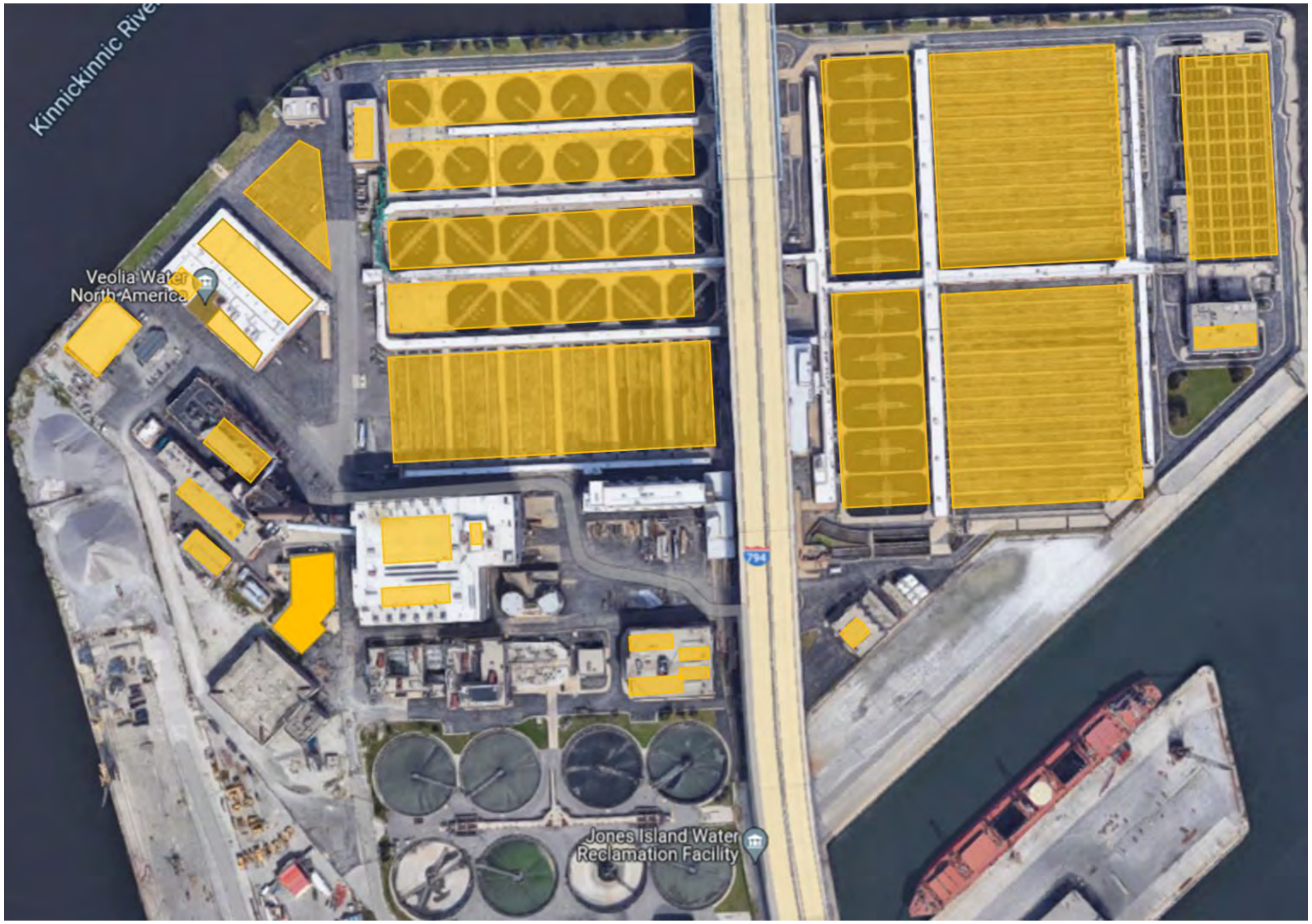

Figure 3-1: Potential PV Locations

Utilizing PV Watts for this available land area results in a 14,250 kW sized PV system, producing 18,940,000 kWh/yr (65,000 MMBTU/yr).[11] Note that this number does not take into account shadows or obstructions and is an estimate of the total generation capacity.

Engineers Opinion of Probable Construction Cost

The cost of PV panels has continued to decrease as they become more prevalent. Using a cost of $2.1/W, the cost to install a system of this size is approximately $30 million. This cost includes all hardware, labor, interconnect, and soft costs. Due to the complexity of installing the panels at the locations evaluated, including building support structures for them, it is estimated to increase the cost to $70 million[12].

Table 3-5: PV Cost Summary

Description	Cost ($ mil)
PV Panels, appurtenances, and labor	$ 40.0
Subtotal	$ 40.0
Overhead and Profit (20%)	$ 8.0
Contingency (40%)	$ 16.0
Design and Engineering Services (15%)	$ 6.0
Total	**$ 70.0**
-50%	$ 35.0
+100%	$ 140.0

The yearly O&M cost for a PV system is estimated to be $20/kW according to an NREL report "PV O&M Cost Model and Cost Reduction"[13]. Considering a 14,250 kW system, this results in a yearly O&M cost of $285,000.

The electricity savings totals $795,500/yr considering a cost of electricity of $0.042/kWh. The resulting years to pay off the system is 78 years, which would exceed the life expectancy of the system.

The electricity savings totals $1,894,000/yr considering a cost of electricity of $0.10/kWh. The resulting years to pay off the system is 25 years, close to the anticipated life of the PV panels.

[11] https://pvwatts.nrel.gov/pvwatts.php
[12] https://www.nrel.gov/docs/fy19osti/72399.pdf
[13] https://www.nrel.gov/docs/fy17osti/68023.pdf

The number, size, and potential locations of PV panels will be evaluated further in *The Planning Report* as a MMSD-wide review of energy usage and energy generation capacity to meet MMSD's goals.

3.3.5 Wind

A wind energy site assessment was prepared for MMSD by Kettle View Renewable Energy in 2008. The study considered 4 small wind turbines of approximately 0.1 MW each. Wind turbines this size would not significantly affect JIWRFs electrical energy consumption. Due to the increasing prevalence and decreasing cost of wind turbine installation, this Memo evaluated installing larger 2.4 MW turbines at JIWRF.

Each 2.4 MW turbine would require approximately 3.7 acres of land for installation.[14] The GE 2 MW-127 turbine was used as a representative size for the footprint for this analysis.[15] This turbine is approximately 300 feet tall with a rotor diameter of 380 feet (190 feet radius), that results in the lowest blade tip being about 100 feet above ground while rotating. **Figure 3-2** shows potential turbine locations at JIWRF. It should be noted that these are conceptual preliminary planning locations evaluated for best possible electricity generation at JIWRF. All locations would have to be reviewed, including by structural and geotechnical engineers for feasibility.

Assuming a capacity factor of 41%[16], four 2.4 MW turbines would generate an average of 4.1 MW of electricity. Extrapolating the average generation over a year result in 35,675,000 kWh (121,700 MMBTU) of electricity.

<u>*Engineers Opinion of Probable Construction Cost*</u>
A typical wind turbine installation of this size would cost around $1470/kW rated[17]. This is the installed project cost including equipment, electrical, and labor. Four installations at this rate amounts to about $6,000,000. However, due to the complexity and deep foundational requirements, the cost is estimated to be about double that at $12,000,000. Factoring in overhead and profit, contingency, and design and engineering services, the expected cost is about $21,000,000.
At $0.042/kWh, the value of electricity generated is $1,500,000/yr. The resulting simple payback not including O&M costs is 8 years.

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[14] https://www.nrel.gov/docs/fy09osti/45834.pdf
[15] https://www.ge.com/renewableenergy/sites/default/files/related_documents/ge-2mw-onshore-wind-turbine-platform.pdf
[16] https://css.umich.edu/publications/factsheets/energy/wind-energy-factsheet
[17] https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Wind%20Technologies%20Market%20Report%20FINAL.pdf

Table 3-6: Wind Cost Summary

Description	Cost	
Wind Turbines (Equipment, installation, appurtenances)	$	12.0
Subtotal	**$**	**12.0**
Overhead and Profit (20%)	$	2.4
Contingency (40%)	$	4.8
Design and Engineering Services (15%)	$	1.8
Total	**$**	**21.0**
-50%	$	10.5
+100%	$	42.0

At $0.10/kWh, the value of electricity generated is $3,568,000/yr. The resulting simple payback not including O&M costs is 3.4 years.

Figure 3-2: Potential Wind Turbine Locations

The number, size, and potential locations of wind turbines will be evaluated in *The Planning Report* as a MMSD-wide review of energy usage and energy generation capacity to meet MMSD's goals.

3.3.6 Effluent Heat Recovery

Heat can be recovered from the plant effluent water by utilizing water source heat pumps. The heat pump withdrawal would take the water from the Effluent Channel after the Chlorine Contact Tank and heat a circulating water loop that could serve heating devices for building loads. Effluent temperatures at JIWRF are above 50 degrees Fahrenheit throughout the year, presenting adequate temperatures for heat pump operation for water-to-water type.

The hot water loop at JIWRF is designed for 200 F water. A water-to-water heat pump water temperature is limited to about 110 F greater than the effluent water temperature. This means that the heat recovery system in conjunction with a heat pump would be limited to approximately 160 F for the hot water temperature. Since the existing heating equipment is designed for 200 F, the air handling unit coils would have to be replaced with coils sized for the lower hot water temperature.

Modifications to the existing infrastructure are required and summarized below:

- Heat exchanger and heat pumps to be installed at the final effluent conduit.
- A water pump to circulate the water taken from the final effluent conduit is required, along with insulated pipe to convey the hot water to a connection to the existing hot water system connection or another desired location.
- Renovation of existing air handling unit hot water coils.

It is estimated the boilers consume approximately 11,000 MMBTU of natural gas. JIWRF consumes 200,000 MMBTU of waste heat, 1/4 of which is consumed by the dryers. The boiler system consumes approximately 61,000 MMBTU's of energy yearly, most of which is consumed during the winter months. Assuming 6 months of cold weather where heat would be required, this averages to be 14 MMBTU/hr. This number correlates with the size of the steam-to-water converters of the waste heat system.

Large water source heat pumps systems are more common in Europe than the U.S. currently. There are examples of large heat pumps being utilized for large facility heating and cooling, which would reduce the boiler energy consumption, and could reduce other electric loads from building air conditioning if a chilled water loop was incorporated.

Manufacturers and representatives have been contacted to size equipment specific to JIWRF. Based on these discussions and the examples of realized projects in Europe, we consider this to be a feasible energy efficient heating system[18]. Preliminary estimates are the total heating energy consumption would be

[18] https://www.ehpa.org/fileadmin/red/03._Media/03.02_Studies_and_reports/Large_heat_pumps_in_Europe_MDN_II_final4_small.pdf

reduced by 20%, and all energy required would be electric. This would reduce JIWRF's natural gas dependence and reduce overall energy consumption. A 20% savings on the existing 61,000 MMBTU results in a new boiler energy consumption of 48,800 MMBTU/yr or 14,302,000 kWh/yr.

3.4 Energy Efficiency

This section focuses on the energy efficiency improvements for the major energy users in the JIWRF. This includes the Secondary Treatment Process, Pumps, D&D Facility, Lighting and Electrification as discussed further in the following subsections. These alternatives evaluate ways to reduce overall energy consumption and consequently GHG emissions.

3.4.1 Secondary Treatment Improvements

Secondary treatment for the conventional activated sludge treatment process is typically the largest energy user at a water reclamation facility. The following subsections includes energy efficiency improvement alternatives that can be considered for the various energy consuming equipment used in the Secondary Treatment process.

3.4.1.1 Diffusers

In both the East and West Plant, the aeration system has porous diffuser plates placed uniformly on the aeration basins floor for aeration and mixing. The designated biosolids storage basins in each Plant have membrane diffusers to allow airflow to the basins to be turned off during the transition from Normal to Storage Model.

In the West Plant, each basin has a length of 222.5 ft and a width of 44 ft, with an effective side-water volume of 0.99 Million Gallons (MG), that gives approximately 14.7 ft of depth. The long and narrow basins allow a greater oxygen demand at the inlet end of the basin, so the air piping allows more air to be delivered at the inlet and less to the remaining zones of the basins. The diffuser plates are arranged in five (5) longitudinal rows with a total of 960 diffusers per basins, while the distribution of plates per zone is as follows:

- Zone 1 – Influent Zone (370 plates)
- Zone 2 – Central Zone (300 plates)
- Zone 3 – Outlet Zone (290 plates)

The diffuser plate density (plates per square foot of basin) is the same at each zone. The West Plant diffuser density is approximately half that used in the East Plant.

In the East Plant Aeration Basins, each basin has a length of 370 ft and a width of 44 ft., with an effective side-water volume of 1.63 MG, that gives approximately 13.4 ft of depth. The basins have three different zones with the following distribution of plates:

- Zone 1 – Influent Zone (1,116 plates)
- Zone 2 – Central Zone (900 plates)
- Zone 3 – Outlet Zone (892 plates)

Basin 1, Zone 1 contains 707 plates, and Zone 1 in basin 2 contains 1,098 plates; otherwise, all the basins have the same diffusers distribution. The biosolids storage basins have 721 membrane diffusers per grid, and two grids per zone, each zone has an equal membrane diffuser count.

Ceramic plates for fine pore diffusion were the preferred technology in the early ages of the activated stage plants. The main advantages of this technology were the long service life, the high oxygen transfer rate, and the ease of in-situ cleaning. Some of the disadvantages include problems with uniform distribution of air, inconvenience of removing plates grouted in place, and difficulty to add diffusers to meet future needs.

Membrane disc diffusers are a newer technology that can reduce the aeration energy with a higher oxygen transfer efficiency and a more uniform distribution on the basins floor. The use of discs can help to manage different oxygen concentrations at each basin zone, and with a correct air system control, a more efficient airflow and air distribution can be achieved that will represent energy savings to the plant.

Ceramic plates have typical airflow rates of 2 to 5 SCFM/sq ft and standard oxygen transfer efficiencies (SOTE) of 30% at 15 ft of submergence, while membrane discs can have airflow rates between 0.2 to 2 SCFM/sq ft, and a SOTE around 2% per ft of submergence.

A study performed in 1969 at the JIWRF showed that the oxygen transfer capabilities for longitudinal plates is 12.9 ± 1.5 %. The plant operation data from the years 2017 to 2021 analyzed in a Jones Island PAC Assessment study of May 2022, showed an approximate average biological oxygen demand (BOD) loading leaving the primary treatment of 60 ton/d (133,000 lb/d), with an average airflow rate of 69,300 SCFM for both plants together. The plant historical data show an average oxygen concentration in the basins between 3 to 4 milligram / liter (mg/l), with an average of 3.12 mg/l, and the PAC assessment study shows that the plants have average daily airflow of 42,558 scfm for the East Plant and 26,757 scfm for the West Plant, totaling 69,315 scfm.

Standard membrane discs diffusers are commercialized with SOTEs around 2% per ft of submergence. In the case of the existing aeration basins that have a depth around 14.7 feet, the SOTE for membrane discs could be around 29%.

Approximate savings in the amount of airflow for the plate and membrane diffusers has been calculated and the calculation table in included in **Appendix A**. The plate diffuser information was calculated to match the existing airflow rates provided by MMSD. The diffuser calculations then used the same variables while updating the SOTE only to provide the potential reduction in airflow required with membrane disc diffusers.

The analysis shows that the amount of air could be reduced from 69,300 SCFM to 64,000 SCFM with membrane diffusers. This equates to a 5.7% decrease in airflow for the aeration tanks. Using PAC 1, this would equate to 165 kW saved. This is a reduction of 1,445,400 kWh/yr (4,900 MMBTU/yr).

Assuming an energy cost of $0.042/kWh, the savings to the plant could be around $60,700 per year. Assuming an energy cost of $0.10/kWh, the savings to the plant could be around $144,540 per year.

3.4.1.2 Aeration Control

The control of the aeration process is critical to achieve an efficient operation of the water reclamation facilities, as over and under aeration have detrimental effects in the system. Over aeration represent high energy expenses and it is evidenced in higher dissolved oxygen (DO) concentrations. Typical DO concentrations to maintain a stable biological activity in a conventional activated sludge system ranges from 1.0 to 2.0 mg/l. Having excess DO increases the energy consumption and can cause other challenges, like poor sludge settling, increased foam by filamentous organisms, and negative impacts in anoxic zones for biological nutrient removal systems. Under aeration can lead to poor treatment performance, and bulking issues.

An automated control of the aeration process saves energy. A key parameter to monitor and control the system is DO, as it fluctuates during the day with influent wastewater characteristics. The aeration control system and the operating logic of the system must allow the operator the flexibility to control the flow of air to the air diffusers grids. The system controls the air to each aeration basin and the air from the blowers.

There are many alternative setups for controlling the aeration system. This evaluation will assume a dual loop DO control system that includes air flow meters and motor operated butterfly valves for throttling airflow for each drop pipe to the diffusers.

- The aeration basins would have a DO probe at each zone to control airflow and pressure gauges for the air distribution piping.
    - A DO setpoint is set by the operator with the butterfly valve used to control airflow to each zone.
    - The butterfly valve will open and close as necessary to meet the DO setpoint.

- The second loop consists of the pressure in the air distribution piping.
  - As the butterfly valves open and close throughout the system, the pressure in the air distribution piping will fluctuate.
  - A most open valve system would be used to ensure one valve is always 100% open and protect the blowers.
  - A pressure setpoint can be used to maintain pressure and modulate the speed of the blower to decrease energy usage.

From the JIWRF operation data between 2016 and 2021, the DO concentrations at the West Plant aeration basins ranged in average DO from 2.78 to 5.25 mg/l, with an average of 3.12 mg/l. For the East Plant, the aeration basins ranged in average DO from 2.96 to 5.58 mg/l. These average values are higher than the DO concentrations required and there is potential to improve efficiency.

Figure 3-3 shows the graphs of the DO concentrations at the aeration basins of the West Plant and **Figure 3-4** shows the graph of DO concentration at the aeration basins of the East Plant.

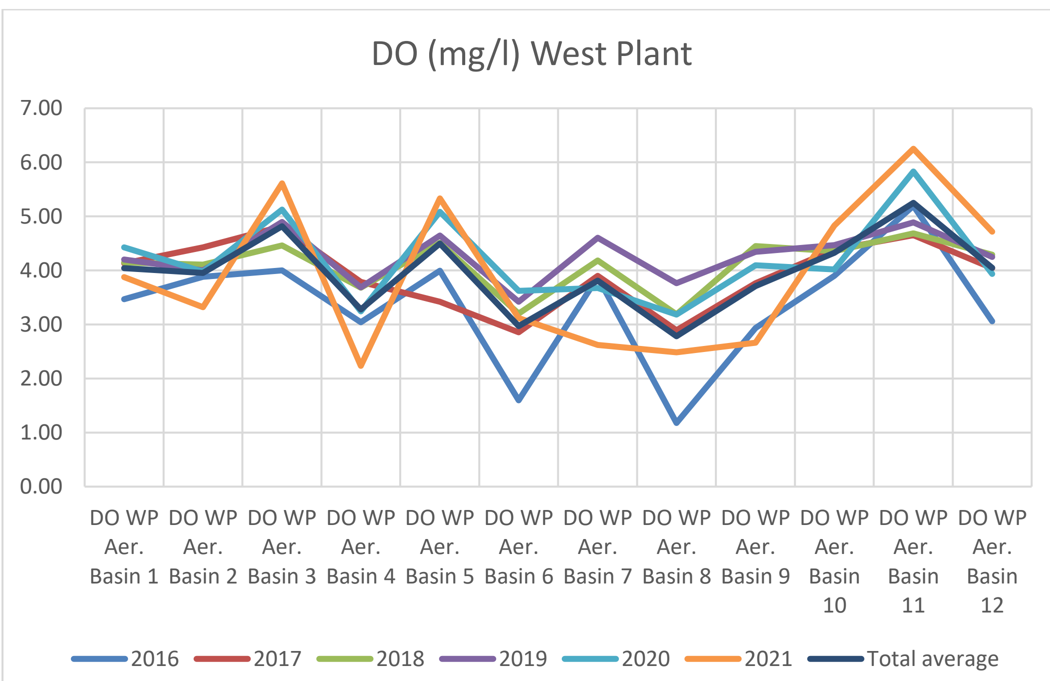

Figure 3-3: West Plant Average DO Concentrations at the Aeration Basin

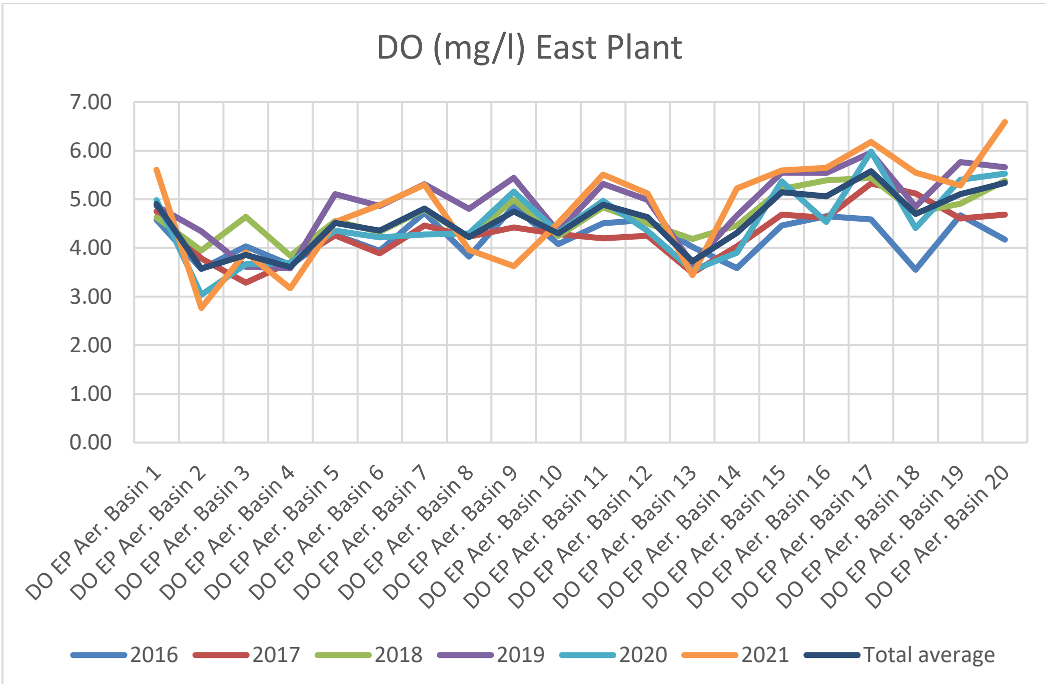

Figure 3-4: East Plant Average DO Concentrations at the Aeration Basin

An analysis comparing the current operating conditions of the plant with the existing diffusers and the current DO concentration, and a scenario with disc membrane diffusers with a target DO concentration of 2.0 mg/l was performed. The calculation table is included in Appendix A.

The results show that achieving a concentration of 2 mg/l DO at the West and East Plants, the airflow could be reduced from 69,300 to 54,800 SCFM for average flow conditions. This equates to a 16% decrease in air for the aeration tanks. Using PAC 1, this would equate to 450 kW saved. This is a reduction of 3,942,000 kWh/yr (13,500 MMBTU/yr).

Assuming an energy cost of $0.042/kWh, the potential savings to the plant could be around $165,600 per year. Assuming an energy cost of $0.10/kWh, the potential savings to the plant could be around $394,200 per year.

Cost Analysis

The conceptual opinion of capital cost for installing membrane diffusers and DO control are estimated to be $36,900,000 in all the 32 aeration basins. This includes piping modifications, cleaning, installation, startup and commissioning.

Table 3-7: Diffuser Cost Summary

Description	Cost ($ mil)	
Diffuser Equipment Costs	$	5.4
Piping Modifications and new valves	$	4.3
Demolition (10%)	$	0.5
Instruments and Electrical Upgrades (25%)	$	1.4
Integration (10%)	$	5.4
Labor (75%)	$	4.1
Subtotal	**$**	**21.1**
Overhead and Profit (20%)	$	4.2
Contingency (40%)	$	8.4
Design and Engineering Services (15%)	$	3.2
Total	**$**	**36.9**
-50%	$	18.4
+100%	$	73.7

3.4.1.3 Blower Improvements

JIWRF operates four (4) PACs to provide air to the secondary treatment aeration basins. Blowers are identified as PAC 1, 2, 3 and 4.

PACs 2, 3, and 4 are Allis-Chalmers 5,500 HP blowers, each with Benshaw medium voltage Reduced Voltage Solid-state Starters (RVSS). Each synchronous motor is rated at 4,000V with the RVSS rated at 4,160V.

PAC 1 is a Siemens 4,500 HP single stage centrifugal high efficiency blower with a Siemens medium voltage Variable Frequency Drive (VFD). The VFD has an integral 13,200V to 4,160V input phase shifting transformer followed by a 24 pulse 4,160V drive.

Energy usage data for the four PAC Blowers was obtained from Veolia Water Milwaukee (VWM) from January 1, 2018 through February 6, 2022. During this period, PAC 1 was operated 93.7% of the time, PAC 2 was operated 4.8% of the time and PAC 4 was operated 1.5% of the time. PAC 3 was not operated. Blowers were operated individually during the analyzed period and there were no times when multiple blowers were in operation.

To calculate the energy usage difference between the blowers, existing data from 2018 through 2022 was evaluated and the average of 93,000 SCFM air flows were selected and averaged for PAC 1 and PAC 2's power consumption (selected as representative of the Allis-Chalmers type blowers PAC 2, 3, or 4).

- At 93,000 SCFM PAC 1 averaged 2,885 kW.
- At 93,000 SCFM PAC 2 averaged 3,095 kW.

This means that at 93,000 SCFM, the PAC 2 load was 210 kW more than PAC 1, a 7% difference. This difference would mean that over a one-year period running only PAC 1, a savings of approximately 1,839,600 kWh would be realized versus running one of the other PAC blowers.

- Using an electric rate of $0.042/kWh equates to annual cost savings of $77,300.
- Using an electric rate of $0.10/kW that equates to annual cost savings of $184,000.

When not in operation, PAC 1, 2, 3, and 4 showed a kW load of approximately 20 kW. This is called a parasitic load and with three blowers offline, totals approximately 60 kW. If the parasitic loads were removed by fully disconnecting each blower when not in use, for a one-year period, it is anticipated to save approximately 525,600 kWh.

- Using an electric rate of $0.042/kWh equates to annual cost savings of $22,075.
- Using an electric rate of $0.10/kWh that equates to annual cost savings of $52,560.

The energy usage data show an advantage when operating the PAC 1 over the older PAC 2 through 4 and is recommended, as is feasible, as a no capital cost change to reduce energy usage.

To further decrease energy usage, a different style of blower could be used that is more efficient. High efficiency turbo blowers incorporate technology used in the turbo jet engine industry that has evolved to produce low pressure aeration blowers for wastewater treatment plants. High efficiency turbo blowers are a single stage centrifugal type blower with the impeller mounted directly to the high-speed motor shaft. These units use permanent magnet motors due to their high energy efficiency and power factor, especially at high speeds and temperatures. The permanent magnet motor is directly coupled to the drive allowing it to operate at high speeds of 20,000 to 40,000 revolutions per minute (RPM). Turbo blowers use special low-friction bearings to support the rotating shaft and require no lubrication. Shaft bearings or supports can be magnetic or air foil.

Turbo blowers are supplied in ready to plug and install packages with a variable frequency drive and internal control panels. As they do not have bearings, this equipment requires less maintenance because they do not require lubrication, they produce less noise, they have a high efficiency in energy consumption and their capacity to work at minimum air flows is high compared to the other technologies.

The largest high efficiency turbo blower unit in the market is a 1,100-kW turbo blower that can provide an air flow close to 40,000 SCFM at 8 PSIG. This analysis evaluates the expected energy savings expected from turbo blowers, compared to the existing PAC-1 after the diffuser and DO control reductions to airflow are incorporated. The airflow after recommendations is approximately 60,000 SCFM per **Section 3.4.1.2**. For this, two turbo blower units are needed with an estimated power consumption of 1,500 kWh.

The energy usage of the existing PAC 1 and PAC 2 units in comparison with the two turbo blowers is shown in Error! Reference source not found..

Table 3-8 Comparison of Energy Usage per Blower Unit

Type of Blower	Number of units	Air flow rate SCFM	Pressure PSIG	Energy rate HP	Energy usage kWh
High Efficiency Turbo Blower	2	60,000	8	1105	1,500
PAC 1 Siemens High Eff	1	60,000	8	3375	1,750

The turbo blower units could have 250 kW less load than PAC 1 at 60,000 SCFM. Over a hypothetical period of one year running, the difference in power consumption and cost between the units is shown in Error! Reference source not found..

Table 3-9 Energy Consumption Potential Savings

Type of Blower	No. of units	Energy Consumption in One Year of Operation (kWh)	Energy Consumption Difference (kWh)	Energy Consumption Cost Difference from Turbo Blowers ($0.042/kWh)	Energy Consumption Cost Difference from Turbo Blowers ($0.10/kWh)
High Efficiency Turbo Blower	2	13,140,000	--	--	--
PAC 1 Siemens High Eff	1	15,330,000	2,190,000	$91,980	$219,000

Utilizing turbo blowers instead of PAC 1 saves approximately 14% in energy usage. Utilizing turbo blowers instead of PAC-1 would result in 2,190,000 kWh/yr (7,500 MMBTU/yr) in electricity savings.

This analysis shows that there would be sufficient capacity to satisfy historical loadings with one PAC. Installing two new turbo blowers while keeping PAC-1 would maintain N+1 operations with historical loadings. Therefore, this analysis is consistent with the findings and recommendations in MMSD's *J02016: Jones Island Process Air Compressor Assessment* from May of 2022. The recommendation from that report of removing PAC-2, replacing PAC-3, and rehabilitating PAC-4 is consistent with this *TM-3's* analysis in that PAC-3 can be replaced with two turbo blowers to achieve additional energy savings.

Engineers Opinion of Probable Construction Cost

The conceptual opinion of capital cost for installing high efficiency blowers are estimated to be $11,300,000 per unit blower.

Table 3-10: Blower Cost Summary

Description	Cost ($mil)	
Equipment Costs (assume new 4 blowers)	$	3.0
Demolition (10%)	$	0.3
Electrical Upgrades (25%)	$	0.8
Piping Modifications (30%)	$	0.9
Labor (50%)	$	1.5
Subtotal	**$**	**6.5**
Overhead and Profit (20%)	$	1.3
Contingency (40%)	$	2.6
Design and Engineering Services (15%)	$	1.0
Total	**$**	**11.3**
-50%	$	5.6
+100%	$	22.6

3.4.1.4 Process Modifications

There are several process modifications that could be implemented to decrease energy usage from conventional activated sludge. These include but are not limited to:

- Enhanced biological nutrient removal would implement anoxic and anaerobic zones where no aeration is required.
  - o While mixing would still be required to prevent settling, this could be done with less air or mixers, which are low horsepower.
- Side stream nutrient treatment for phosphorus or nitrogen could be implemented to reduce nutrient loading recycled within the plant from the thickening and dewatering process.
  - o Processes like DEMON Annamox by World Water Works or ANITA MOX by VWM reduce ammonia in the side stream, therefore decreasing overall energy usage for the aeration basins. Algal-based side stream solutions such as Gross-Wen Technologies also have the potential to produce recoverable products that may provide beneficial use as well.
  - o In addition to energy advantages, the introduction of side stream treatment on concentrated side streams offers significant capacity enhancement in the system.
- State of the art processes like aerobic granular sludge can further reduce aeration requirements from conventional activated sludge and decrease energy usage significantly.

For this evaluation, a conservative potential energy savings range of 5 – 15% is estimated, although higher savings could be realized. Additional savings can be realized through new technologies that are continuing to be implemented in the wastewater industry. For the energy analysis, an energy savings of 10% is used. As indicated in Section 2.8, aeration consumes 107,500 MMBTU of electricity. A 10% savings results in a 10,700 MMBTU reduction.

Engineers Opinion of Probable Construction Cost

The conceptual opinion of capital cost for the ANITA MOX process system and DEMON Annamox system is estimated to be $20,700,000.

At $0.042/kWh, the value of electricity saved is $131,700/yr. The resulting simple payback not including O&M costs is 158 years.

At $0.1/kWh, the value of electricity saved is $313,586/yr. The resulting simple payback not including O&M costs is 66 years.

Table 3-11: New Sidestream Treatment Cost Summary

Description	Cost ($mil)	
ANITA MOX Equipment Cost (screen, blowers, diffusers, media, mixers, control valves)	$	2.8
Piping Modifications	$	2.0
Equalization Tanks and Site Work	$	5.0
Electrical Upgrades (25%)	$	0.7
Labor (50%)	$	1.4
Subtotal	**$**	**11.8**
Overhead and Profit (20%)	$	2.4
Contingency (40%)	$	4.7
Design and Engineering Services (15%)	$	1.8
Total	**$**	**20.7**
-50%	$	10.4
+100%	$	41.4

3.4.1.5 Secondary Treatment Improvements Summary

As one of the most energy intensive processes at JIWRF, there are multiple improvements to secondary treatment process that could be made to decrease energy consumption. **Table 3-12** below summarizes potential energy savings for the aeration basins, including high efficiency turbo blowers, new diffusers, aeration control, and process modifications.

Table 3-12: Secondary Treatment Energy Reduction Summary

Process	Reduction (MMBTU/yr)
High Efficiency Turbo-Blowers	7,500
Diffusers and Aeration Control	13,500
Process Modifications (10%)	10,700
Total	31,700

3.4.2 Pump Efficiency Improvements

3.4.2.1 Install VFDs for Pumps, Fans, and other Equipment

VFD Background

VFDs control the amount of voltage and frequency supplied to a motor and can be used to reduce energy usage compared to constant speed motors. Equipment like pumps, blowers and fans represent the most potential for cost savings from the application of VFDs by operating the equipment at more efficient operating points.

VFDs have more energy due to inefficiencies losses than an across the line starter because the semiconductors which change the frequency of the power sent to the motor to change speed cause voltage drop which leaves the VFD as waste heat. Harmonic mitigation devices and motor protection output filters are often required to keep the VFD from sending potentially harmful noise back into the electrical system and protect inverter duty motors. Harmonic filters typically consume about 1.5 % of the energy being sent into the drive system. Output filters typically consume about 1% of the energy being sent to the motor.

Background Energy/Cost Saving Applications using VFDs
The torque requirements of the driven equipment are the main factor affecting potential energy savings. Examples of Constant Torque (CT), Linear Torque (LT) and Variable Torque (VT) motor loads are listed below:

Equipment	Torque
Belt Conveyor	CT
Screw Compressor	LT
Centrifugal Pump	VT
Centrifugal Blower	VT

Both CT and LT applications both have less energy savings potential than VT. Both CT and LT applications have linear torque requirements that motor energy will be proportion to speed of driven equipment. At 80% driven speed, energy requirement will be at least 80% of the full speed. With VT applications, torque requirements increase in proportion of to the square of the driven equipment speed and reach full torque requirement around or at full speed. This translates into the cube law relation between speed and power. At 80% driven speed, energy requirements will be about 50% of full speed depending on the pumps or blowers design curve.

VT loads can yield power savings proportional to the speed reduction cubed. (Power is the product of torque and speed, and variable torque load requirements decrease in proportion to the square of the speed.)

MMSD Energy/Cost Saving Applications using VFDs
At JIWRF, the new blower PAC 1 is a recent example of the energy saving that can be achieved with the right process application. The application would be yielding about a 12% annual energy use reduction if it could be run 100% of the time.

Other equipment that was reviewed to determine energy saving potential with the use of VFDs are listed below:

1. 5,500 HP PAC 2,3,4 Blowers which have RVSS (Soft Starters) (3 total)
2. 125 HP D&D Facility Rotary Dryer Induced Draft Fans (12 total)
3. 400 HP Fire Pumps (2 total)
4. 400 HP GE Turbine Gas Compressors (2 total)
5. 400 HP Solar Turbine Gas Compressors (3 total)
6. 300 HP Influent Low Level Screw Pumps (4 total)
7. 300 HP Influent High Level Screw Pumps (5 total)

MMSD has replaced PAC 1 with a high efficiency blower and VFD driven 4,500HP motor. PAC 2,3,4 are constant speed with RVSS starting.

For item 2, MMSD has already added VFDs. Items 3 through 7 above are CT or LT type loads with the exception of the Fire Pump, which is not used frequently. Adding VFDs to the above loads will not yield any significant energy savings. What may have value is changing the controls on the influent screw pumps to optimize operating points such that the pumps run at the most efficient point on their pump curve.

Engineers Opinion of Probable Construction Cost
The PAC Blower have VFDs currently. The cost of VFDs for new turbo blowers is included in the cost for installing that equipment. The rotary dryer induced draft fans already have VFDs. The remaining equipment are not recommended to have VFDs installed and have no associated costs.

Recommendations
When motors are replaced on existing systems, install new motors that are specified as inverter duty and high efficiency so output filters are not needed. Remove dv/dt filters after motor replacement. (May still be needed when cable lengths between VFD and motor are over 500ft.). dv/dt filters control voltage spikes and are typically needed when longer cable lengths are used.

Consider the use of Active Front End (AFE) VFDs when existing VFDs are replaced. These could potentially have better overall efficiency than the combination of a traditional pulse width modulation (PWM) VFD and a harmonic filter. AFE drives can provide additional benefits if mechanical breaking is required during normal operation, but not typically needed for pumping and blower applications.

Check existing VFDs to see if they have Dynamic Voltage to Frequency settings available. Set drives to dynamic voltage to frequency when motors are at low load conditions. What this does is reduce the motor losses when torque load is low by lowering the Voltage to Frequency ratio the VFD sends to the motor.

3.4.2.2 Install High-Efficiency Motors for Pumps, Fans, and other Equipment at JIWRF

Background

Most motors at JIWRF are National Electrical Manufacturers Association (NEMA) Design B Motors. The minimum required full load efficiencies are shown below:

HP Range	Minimum Eff.
1-4	78.8
5-9	84.0
10-19	85.5
20-49	88.5
50-99	90.2
100-124	91.7
>125	92.4

High efficiency motors have been available and have been specified and installed on most recent projects at MMSD. The efficiencies for high efficiency motors are defined by tables in NEMA standard MG-1-1998. Some examples for typical enclosed 1800 RPM high efficiency motors are shown below:

HP	Nominal Eff.
1	82.5
5	87.5
10	89.5
20	91.0
50	93.0
100	94.5
125	94.5
150-500	95 – 95.8

Energy Analysis

The typical energy efficiency improvements from standard motors to high efficiency motors is approximately 3%. Section 2.8 shows the baseline electricity consumption by process. A 3% efficiency improvement for all process pump motors and D&D Facility fan motors is shown in **Table 3-13**.

Table 3-13: Process Pumps and D&D Facilty Fan Energy Reduction (MMBTU/yr)

Process	Baseline	Reduction	New
RAS	26,000	800	25,200
WAS	4,400	100	4,300
IPS	4,400	100	50,400
Influent Pumps	14,000	400	4,300
Effluent Pumps	30,000	900	13,600
Primary Sludge Pumps	2,000	100	29,100
Process Pumps Total	**80,800**	**2,400**	**78,400**
D&D Dust System Fans	7,700	200	7,500
D&D HVAC Fans	30,000	900	29,100
D&D Fans Total	**37,700**	**1,100**	**36,600**

Engineers Opinion of Probable Construction Cost

Motors smaller than 50 HP were assumed to cost $500/HP, while motors larger than 50 HP were assumed to cost $300/HP. The conceptual opinion of capital cost for installing high efficiency motors are estimated to be $7,900,000. The 1,100 MMBTU/yr is equivalent to 322,375 kWh/yr. This results in a yearly savings of $13,500 using $0.042/kWh and $32,200 using $0.10/kWh. There is no positive return on investment if these motors are replaced prior to the existing equipment's end of useful life.

Table 3-14: High Efficiency Motors Cost Summary

Description	Cost	
New Motors	$	3.0
Labor (50%)	$	1.5
Subtotal	**$**	**4.5**
Overhead and Profit (20%)	$	0.9
Contingency (40%)	$	1.8
Design and Engineering Services (15%)	$	0.7
Total	**$**	**7.9**
-50%	$	3.9
+100%	$	15.8

Recommendation
When motors are scheduled to be replaced due to age, specify that the new motors are replaced with high efficiency motors. It is recommended MMSD incorporate language into their MCRR process to allow for high efficiency motor replacement.

3.4.2.3 ISS Pumps

The ISS is a large network of storage tunnels that convey separate and combined sewer system flow. The ISS Pumps are located at JIWRF and lift water approximately 300 feet that can be conveyed to either JIWRF or SSWRF for treatment. The ISS Pumps were evaluated in *Technical Memorandum 2 – Conveyance and Administration Facilities*. The ISS Pumps are powered from the electrical distribution system and are included in the total JIWRF energy consumption numbers. The analysis from *Technical Memorandum 2* did not estimate significant energy savings from the alternative evaluated. The existing ISS pumps energy consumption is 52,000 MMBTU/yr.

3.4.3 D&D Facility

3.4.3.1 Sludge and Biosolids Analysis

For biosolids handling and treatment at JIWRF, MMSD completed the Biosolids Advanced Facilities Plan (BAFP). Modifications to the biosolids handling and treatment system were evaluated as part of the BAFP and will not be re-evaluated as part of this project.

The sludge dryers at JIWRF are used to dehydrate WAS from both plants, and the digested sludge (DSD) from SSWRF. Thus, the primary market for biosolids is Milorganite® production, fertilizer pellets from Class A Biosolids. Milorganite® is currently produced with a ratio of 70% WAS to 30% DSD (mass basis). The D&D Facility at JIWRF produces on average 117 tons/day of dried biosolids. After classification, 103 tons/day of Milorganite® are shipped to the fertilizer market and 14 tons of Chaff and fines (off-spec materials), approximately are collected, and shipped to landfill.

3.4.3.1.1 D&D Process Energy Optimization

Adjustments to the dewatering and drying system were proposed as part of the BAFP. MMSD agreed to rehabilitate the existing dryers.

For dewatering, MMSD is planning to rehabilitate the 24 existing belt filter presses (BFPs) that were installed in 2012 to prolong their useful life. This is scheduled for completion in February 2025 (occurring under Phase 1 of the BAFP). During Phase 2, loadings should be reduced at JIWRF as MMSD plans to construct a drying facility at SSWRF. This is done in preparation of the major construction that will occur during Phase 3 at the D&D facility at JIWRF.

Reviewing the BAFP, there does not appear to be significant energy savings from the new Milorganite® dryers proposed. It is assumed that all 861,000 MMBTU of energy currently used to not change in the future. Assuming all LFG volume available is provided to the dryers (326,000 MMBTU), the resulting non-renewable energy consumption would be 535,000 MMBTU. The resulting 535,000 MMBTU would have to be offset by renewable energy credits, obtained through acquiring additional landfill gas, or other renewable gasses.

According to the Emerald Park Landfill (EPL), the landfill will produce an average of 475,000 MMBTU in the future. **Section 3.2.1** discusses the LFG further. If all the landfill gas can be utilized, the non-renewable natural gas required to be offset is 386,000 MMBTU.

3.4.3.1.2 Quantify Milorganite® Energy Content

Milorganite® is a 6-4-0 organic fertilizer (6% nitrogen, 4% phosphorous, and 0% potassium) produced sustainably from MMSD biosolids and used instead of other non-renewable available fertilizers. The potential energy savings from the production of Milorganite® versus commercially available fertilizers was calculated to determine the energy savings by using Milorganite® instead of non-renewable fertilizers.

Approximately 103 dry tons of Milorganite® are produced daily and requires 861,000 MMBTU per year of energy. This equates to 21.3 MMBTU per Wet Ton for 93% solids content in the final dried product. The production of nitrogen inorganic fertilizers requires approximately 25,000 BTUs per pound of nitrogen (55.1 MMBTU per metric ton of N, see **Table 3-15**) [19], depending on the nitrogen content.

Based on the nitrogen content, the rate of application per area differs. Milorganite® is typically used in residential and commercial applications, not large scale agricultural applications. As such, the analysis utilizes a recommendation rate for nitrogen fertilizers for lawn application of 1 pound nitrogen per 1000 square feet[20].

A summary of the analysis is shown in **Table 3-15** comparing commercial nitrogen rates for lawn application for Milorganite® and three nitrogen fertilizers.

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[19] Energy-Efficient Use of Fertilizer and Other Nutrients in Agriculture. Farm Energy. April 3, 2019. https://farm-energy.extension.org/energy-efficient-use-of-fertilizer-and-other-nutrients-in-agriculture/
[20] New Jersey Agricultural Experiment Station. How to Calculate the Amount of Fertilizer Needed for Your Lawn. https://njaes.rutgers.edu/FS839/

Table 3-15: Energy requirements per area- Milorganite® and Nitrogen fertilizers

Parameter / Fertilizer	Milorganite®	Urea 46-0-0	Urea Amm. NO3 (UAN 32-0-0)	Amm. NO3 (AN 34-0-0)	Units
Nitrogen content, N	6%	46%	32%	34%	%
N requirements, Un	37.50	48.20	48.20	48.20	kg N/Ha
N limit load, Rn	0.625	0.105	0.151	0.142	Ton/Ha
Energy	-	55.1	55.1	55.1	MMBTU/Ton N
Energy	21	120	172	162	**MMBTU/Ton**
Energy for N req.	13.3	12.6	25.9	23.0	**MMBTU/Ha**

Considering commercial application rates for lawn, the Urea fertilizer has the less energy requirements per area (12.6 MMBTU/Ha) than Milorganite® (13.3 MMBTU/Ha), follow by AN (23.0 MMBTU/Ha) and finally the highest requirements are for UAN (25.9 MMBTU/Ha). It is important to mention that the nitrogen fertilizers analyzed release quickly, and it is possible that the frequency of applications needs to be higher than organic fertilizers that are slow release. "*Granular fertilizers are generally applied about every six to eight weeks while slow-release fertilizers work for months, so one application is generally all that is needed for a growing season*"[21].

The alternative, non-sustainable fertilizer's average production energy consumption is 20.5 MMBTU/Ha, while Milorganite's® is 13.3 MMBTU/Ha. Therefore, on average, Milorganite® offsets 7.2 MMBTU/Ha of energy. Using JIWRF's Milorganite® production of 103 DT/day, the resulting area of fertilization covered by production using the information in **Table 3-15** is 177 Ha/day. Therefore, 1,280 MMBTU/day of energy is offset by the utilization of Milorganite® on lawns.[22] Extrapolating to an entire year, 466,000 MMBTU of energy is offset. Using $5/MMBTU and $10/MMBTU for the value of energy, natural gas, offset, the resulting value offset is $2,330,000 and $4,660,000 respectively.

Conclusion

The production of Milorganite® is a major energy consumer at JIWRF. However, Milorganite® is a sustainable product that offsets the use of non-renewable fertilizers. Milorganite® uses less energy to produce when compared to non-renewable fertilizers, especially in its primary application for lawn

[21] When and how often should you apply plant fertilizer. https://www.nola.com/entertainment_life/home_garden/article_b0aa27e7-4bc5-58f7-bc54-665f56398b78.html

[22] 177 Ha/day x 7.2 MMBTU/Ha = 1,276 MMBTU/day

fertilization. Approximately 466,000 MMBTU of energy is offset, when compared to alternative, non-renewable fertilizers, by the production and utilization of Milorganite®. While this energy does not actively push the needle towards MMSD's stated goals in the 2035 vision, it may be considered offsetting non-renewable energy outside of MMSD.

3.4.4 Lighting

The purpose of this section is to quantify the energy reduction expected from past projects and future efforts replacing all High-Pressure Sodium (HPS) and fluorescent lights with light emitting diodes (LEDs).

MMSD has completed three contracts that have upgraded almost all the lighting at JIWRF. These contracts and their substantial completion dates are included in **Table 3-16** below.

Table 3-16: MMSD Lighting Project Summary

Contract	Substantial Completion Date
J06026C01	7/2020
J06026C02	7/2020
J06026C04	2/2022

The substantial completion dates are mostly after the 2018-2020 energy evaluation range this report utilizes. Therefore, it was assumed the electricity consumption included, does not include most LED lighting upgrades. This section estimates this electricity demand reduction and future lighting electricity consumption for planning purposes.

The average energy use for an industrial facility lighting is 8%, which includes the use of fluorescence lamps.[23] LED lights are an energy efficient lighting source that are replacing the older fluorescent lighting sources and are actively being installed throughout JIWRF to reduce energy usage. This analysis quantifies the energy reductions expected from these efforts. In addition to saving energy, the lighting quality and performance improves. LED lighting operates for decades without replacement or maintenance.

[23] Quadrennial Technology Review. September 2015. "Assessment of Energy Technologies and Research Opportunities", U.S. Department of Energy. **Figure 5.10**.
https://www.energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf

The D&D Facility was used as a representative basis for this analysis. All previous HPS and wall pack fixtures have been replaced with LED fixtures and all fluorescent T8 lamps with LED retrofit lamps. The D&D Facility had approximately 2,440 industrial grade 2'x4' 64 W fluorescent fixtures, 390 HPS lights, 150W wall packs, and 94 HPS 250W Low-Bay fixtures.

Modifications to the infrastructure are summarized below:

- Replacement of fluorescent T8 lamps with LED lamps
- Replacement of 150W Wall Pack fixtures with LED fixtures
- Replacement of 250W High-Pressure Sodium (HPS) Low-Bay fixtures with LED fixtures

By replacing the fixtures and lamps with LEDs, a decrease of 128.15 kW is expected, see **Table 3-17**. This reduction is equivalent to 53.8% of the total lighting electricity consumption.

Table 3-17: D&D Facility LED Lighting Comparison

D&D Facility Light Fixtures	Count	kW/ Fixture	Total kW		LED Equivalent	kW/ Fixture	Total kW
Fluorescent, 2x4, 64W	2440	0.064	156.16		LED Lamps, 2x4, 36W	0.036	87.84
Wall Pack HPS, 150W	390	0.15	58.5		Wall Pack LED, 39W	0.039	15.21
Low-Bay HPS, 250W	94	0.25	23.5		Low-Bay LED, 74W	0.074	6.96
			238.16				**110.01**

Energy Savings (compared to 2018-2020)
MMSD's annual average electricity consumption was 360,000 MMBTU/yr or 105,500,000 kWh/yr. Assuming 8% of this total represents the lighting energy usage, this equates to 8,440,000 kWh/yr (28,800 MMBTU/yr). Utilizing the 53.8% energy savings with the retrofit projects results in a total JIWRF savings in lighting electricity consumption of 4,500,000 kWh/yr (53.8% x 8.44 Megawatt-hour (MWh)).

Utilizing the JIWRF blended energy rate of $0.042/kWh, the retrofit projects have an annual savings of $190,000 (4,500,000 kWh x $0.042/kWh). Utilizing an electricity rate of $0.10/kWh, the annual savings is $450,000.

Engineers Opinion of Probable Construction Cost
The total cost to upgrade the lighting is $2,600,000. This cost was found by assuming 15,000 fixtures were replaced which was approximated by dividing the total lighting electric consumption by the average

kW/fixture. The total number of fixtures was then multiplied by $67/fixture.[24] This value includes installation cost.

Table 3-18: LED Lighting Cost Summary

Description	Cost ($m)	
Lighting Equipment Cost	$	1.0
Labor (50%)	$	0.5
Subtotal	**$**	**1.5**
Overhead and Profit (20%)	$	0.3
Contingency (40%)	$	0.6
Design and Engineering Services (15%)	$	0.2
Total	**$**	**2.6**
-50%	$	1.3
+100%	$	5.3

Recommendations

Installing LED high-efficiency lighting to reduce energy consumption is recommended to be prioritized throughout JIWRF.

24 RS Means: 265119107040

Section 4 Summary of Alternatives

4.1 Summary of Alternatives

This section summarizes the recommendations from the various alternatives discussed in the Section 3 as shown in the **Table 4-1** below.

Table 4-1: Energy Reduction Summary

Alternatives	Description	kWh/yr	MMBTU/yr	% Reduction
Secondary Treatment				
Blower Improvements	This alternative recommends using a High Efficiency Turbo Blower which can produce an energy saving of 13% and 22% over Siemens High Efficiency blower (PAC 1) and Allis Chalmers blower (PAC 2, 3 & 4) respectively.	2,189,000 Reduction	7,500 Reduction	7%
Diffusers and Aeration Control	These alternatives recommend installing using a disc diffuser over the existing porous diffusers plates in the aeration system to reduce energy consumption and an automated control of the aeration process which can most essentially monitor and control the dissolved oxygen in the system, and hence save energy.	3,956,000 Reduction	13,500 Reduction	6%
Process Modifications	This alternative recommends installing a biological selector to control the problems that microorganisms with poor sedimentation characteristics can cause in the process of separating liquids and solids.	3,136,000 Reduction	10,700 Reduction	10%
Pump Efficiency Improvements				

Alternatives	Description	kWh/yr	MMBTU/yr	% Reduction
VFDs	This alternative recommends reducing energy loss in existing VFD systems by specifying inverter duty, high efficiency motors; Active front end VFDs; setting drives to dynamic voltage to frequency settings when motors are at low load conditions, etc.	--		
High Efficiency Motors	This alternative recommends installing high efficiency motors.	1,026,000 Reduction	3,500 Reduction	3%
ISS Pumps	This alternative discusses utilizing smaller pumps to dewater the ISS between rain events.	0	0	0
D&D Facility				
Sludge and Biosolids Analysis				
D&D Process Energy Optimization	This alternative discusses adjustments to the dewatering and drying system by rehabilitating the existing dryers.	0	0	0
Install New JI Milorganite® Dryers That Use Less Energy	This alternative discusses the decision to rehabilitate the existing dryers in the BAFP.	0	0	0
Lighting	This alternative recommends installing LED lighting throughout JIWRF.	4,540,000 Reduction	15,500 Reduction	54%
Electrification	This alternative recommends natural gas fired equipment to be transitioned to be fully electric when equipment is at the end of its useful life and up for replacement.	--		
Energy Generation				
LFG	This alternative discusses maximizing the EPL LFG availability.	--		

Alternatives	Description	kWh/yr	MMBTU/yr	% Reduction
Turbines	This alternative discusses minimizing the non-renewable energy consumption by running the turbines less when renewable electricity is available.	--		
Pyrolysis of Chaff Produce Synthetic Gas (syngas) and Biochar	This alternative studies pyrolysis at Jones Island as a potential option to thermally process and destroy pollutants to produce syngas and biochar. Pyrolysis for syngas and biochar production is also an alternative for reuse of a considerable amount of Chaff (11% of production).	--	--	--
Photovoltaics	The number, size, and potential locations of PV panels will be evaluated in *the Planning Report* as a MMSD-wide review of energy usage and energy generation capacity to meet MMSD's goals.	--	34,000 Generation	--
Wind	The number, size, and potential locations of wind turbines will be evaluated in the *Planning Report* as a MMSD-wide review of energy usage and energy generation capacity to meet MMSD's goals.	--	121,700 Generation	--
Effluent Heat Recovery	Heat can be recovered from the plant effluent water by utilizing water source heat pumps. The recommendation is to electrify the boiler loop. Additional analysis is required if effluent heat recovery using a water source heat pump is viable.	--	12,200 Reduction	20%

Section 5 Conclusion

5.1 Summary

This *TM-3* breaks down the baseline energy consumption baseline at JIWRF, potential energy reductions, renewable energy generation opportunities, and the resulting energy breakdown after the recommendations are implemented.

5.2 Renewable Energy Generation Summary

Table 5-1 summarized the potential energy generation achievable from the analysis included in **Section 3**.

Table 5-1: Renewable Energy Generation Summary

Source	Electricity (MMBTU)	Gas (MMBTU)	Total (MMBTU)
Photovoltaic	65,000	0	65,000
Wind	121,700	0	121,700
Pyrolysis	0	0	0
Algae Bioreactor	0	0	0
LFG	0	475,000	475,000
Total	**186,700**	**475,000**	**661,700**

5.3 Energy Reduction Summary

Table 5-2 summarizes the energy reductions achievable from the analysis included in Section 3.

Table 5-2: Energy Reduction Summary

Consumer	Baseline (MMBTU)	Reduction (MMBTU)	New (MMBTU)
Dryers	861,000	0	861,000
Aeration and Blowers	107,500	31,700	75,800
Process Pumps	80,800	2,400	78,400
Lighting	29,000	15,500	13,500
Boiler	61,000	12,200	48,800
ISS Pumps	52,000	0	52,000
D&D Dust System and HVAC	37,700	1,100	36,600
Other Electric Loads	53,000	0	53,000
Other Natural Gas Loads	153,000	0	153,000
Total	**1,435,000**	**62,900**	**1,372,100**

Using $0.042/kWh the 62,900 MMBTU (18,434,000 kWh) is equivalent to $774,200/yr or savings. Using $0.10/kWh, the savings is $1,843,400.

The cost of transitioning the 153,000 MMBTU of natural gas to electricity results in increased utility costs ranging between $360,000 and $3,720,000 using $5/MMBTU and $10/MMBTU for the price of natural gas, and $0.042/kWh and $0.10/kWh for the cost of electricity.

5.3.1 Greenhouse Gas Reduction

Reducing non-renewable energy consumption including grid purchased electricity, natural gas, and electricity generated from natural gas on-site directly reduces overall GHG emissions. Therefore a 4% reduction in non-renewable energy consumption is a 4% reduction in GHG emissions. A 20% reduction in a processes non-renewable energy consumption results in a 20% reduction in that processes GHG emissions. As MMSD's renewable energy generation increases and non-renewable energy consumption decreases, MMSD's GHG emissions will consequently also be reduced. GHG emissions will be further quantified, with an established baseline in the Carbon Free portion of this project's scope.

5.4 Combined Energy Breakdown

Assuming the previous recommendations are incorporated, the new JIWRF energy breakdown is summarized in **Table 5-3** as follows:

Table 5-3: Energy Source by Consumer

Consumer	LFG (MMBTU)	NG (MMBTU)	Electricity (MMBTU)	Total (MMBTU)
Dryers	475,000	386,000	--	861,000
Aeration and Blowers	--	--	75,800	75,800
Process Pumps	--	--	78,400	78,400
Lighting	--	--	13,500	13,500
Boiler	--	--	48,800	48,800
ISS Pumps	--	--	52,000	52,000
D&D Dust System and HVAC	--	--	36,600	36,600
Other Electric Loads	--	--	53,000	53,000
Other Natural Gas Loads	--	--	153,000	153,000
Total	**475,000**	**386,000**	**511,100**	**1,372,100**

The purpose of **Table 5-3** is to show what the energy profile of the end using consumption equipment would look like after the energy recommendations and improvements are incorporated. The other natural gas loads column has the energy demand allocated under electricity because the recommendation is to transition those loads to electric fuel sources. The end goal would be to have renewable electricity fuel the electricity loads at JIWRF. It is recommended that non-renewable natural gas consumption be phased out to achieve MMSDs goals.

Other electric loads refer to various electrical energy consuming equipment otherwise not tabulated in the table. Other natural gas loads refer to purchased natural gas that various equipment consumes at the facility. These loads are recommended to be electrified as discuss in **Section 3.2.3.**

The total energy consumption is 1,372,100 MMBTU. This value is lower than the value shown in Section 2.1 (2,021,000 MMBTU) because it doesn't include energy from the inefficiencies of the turbines for power generation discounting waste heat utilized (586,000 MMBTU).[25] It also includes the efficiencies realized by incorporating the alternatives evaluated in **Section 3** (62,900 MMBTU).

For JIWRF, 386,000 MMBTU of natural gas would have to be offset with renewable energy. 511,100 MMBTU or 150,000,000 kWh of renewable electricity would have to be generated or purchased.

Comparing the 1,372,100 MMBTU energy consumption to the 661,700 MMBTU of internally generated renewable energy results in 48% of energy being internally produced.

5.4.1 Sankey Diagram

Figure 5-1 shows the energy breakdown after all recommendations in **Section 3** are incorporated.

[25] 2,021,000 – 586,000 – 62,900 = 1,372,100 MMBTU

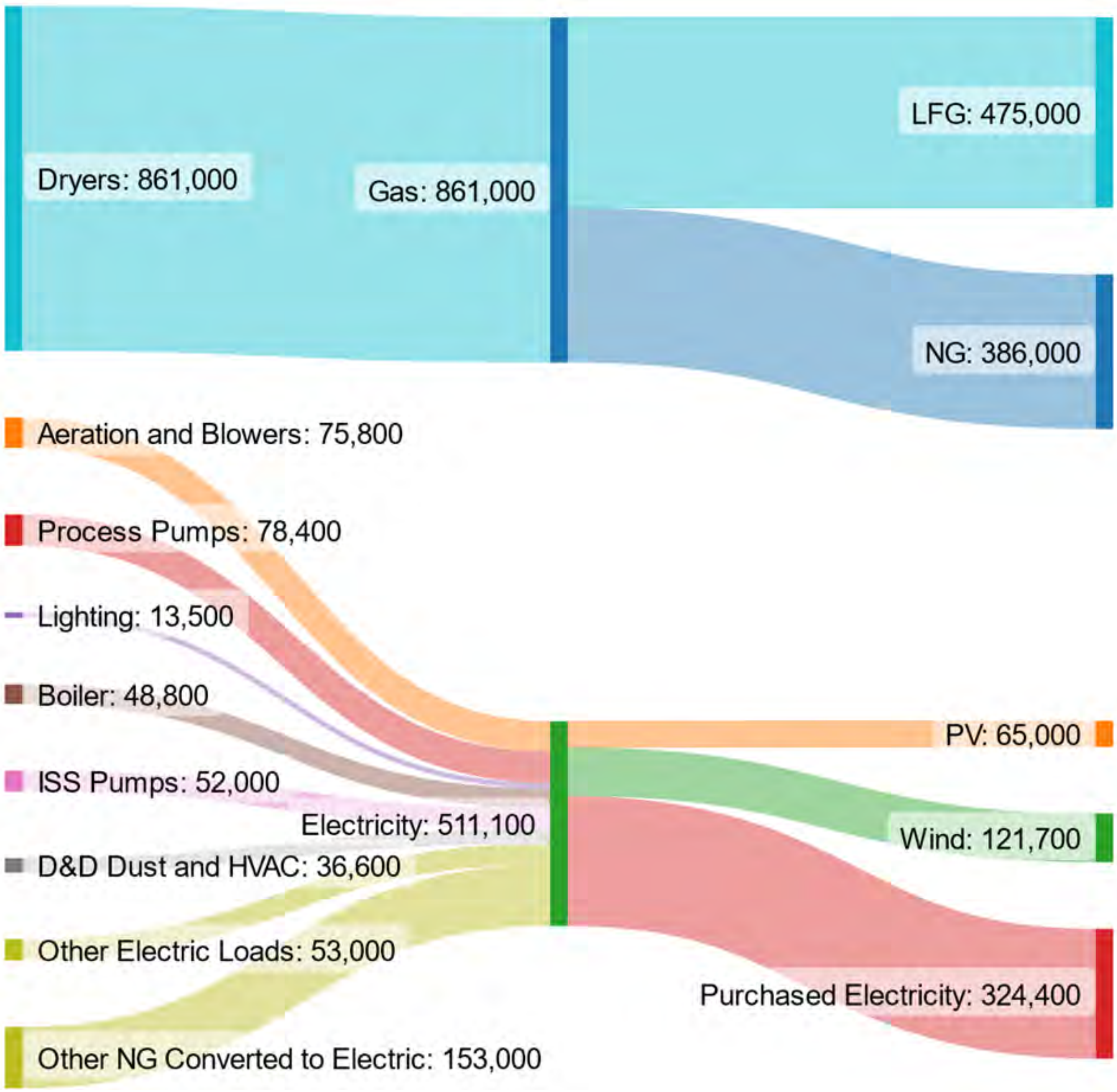

Figure 5-1: Sourced Energy by Consumer (MMBTU)

Renewable energy comprises 48% of the total energy consumption shown in the Sankey Diagram. The remaining 52% would have to be offset with excess renewable energy generated at other MMSD assets such as South Shore Water Reclamation Facility (SSWRF) or other methods.

The production of Milorganite® is a major energy consumer at JIWRF. However, Milorganite® is a sustainable product that offsets the use of non-renewable fertilizers. Milorganite® uses less energy to produce when compared to non-renewable fertilizers, especially in its primary application for lawn fertilization. Approximately 466,000 MMBTU of energy is offset, when compared to alternative, non-renewable fertilizers, by the production and utilization of Milorganite®. While this energy does not actively push the needle towards MMSD's stated goals in the 2035 vision, it may be considered offsetting non-renewable energy outside of MMSD.

As part of this project, additional technical memorandums are being prepared and be submitted at a later date.

- *Technical Memorandum 4 – SSWRF Energy Plan* will detail the energy plan at SSWRF.
- *The Planning Report* will be a MMSD-wide document to meet the MMSD energy goals. *The Planning Report* will include a plan to offset all non-renewable energy consumption. Non-renewable energy consumption at JIWRF may be offset through excess renewable energy generation at SSWRF, energy generation at other MMSD properties, or a combination of them.
- *Technical Memorandum 5 – Carbon Free Needs Assessment*

Appendix A

Aeration Calculation Tables

	Plate Diffusers	Membrane Diffusers
a. Influent Conditions		
BOD_5, pound/day (lb/d)	133,000	133,000
NH3-N, lb/d	9,900	9,900
Wastewater Temperature, ºC	20	20
b. Aeration System		
Actual Oxygen Requirement (AOR)		
BOD_5 demand, lb O_2/lb BOD_5	1.1	1.1
NH_3-N demand, lb O_2/lb NH_3-N	4.6	4.6
AOR, lb O_2/d	191,840	191,840
Standard Oxygen Transfer Rate (SOTR)		
a	0.65	0.65
F	0.98	0.98
q	1.024	1.024
P_b, psia	14.2	14.2
P_s, psia	14.7	14.7
W	0.97	0.97
b	0.95	0.95
$C^*_{S,20}$, mg/l	9.09	9.09
$C^*_{S,T}$, mg/l	9.09	9.09
g_W, lb/cf	62.3	62.3
Basin Depth, ft	14.7	14.7
Effective Saturation Depth, d_e, ft	6.5	6.5
P_{vt}, psi	0.36	0.36
$C^*_{inf,20}$, mg/l	10.56	10.56
$C^*_{inf,T}$, mg/l	10.56	10.56
C, mg/l	3.12	3.12
t	1.00	1.00
OTR_f/SOTR	0.399	0.399
SOTR, lb O_2/d	480,402	480,402
SOTR, kg O_2/d	217,907	217,907
Air Flow		
SCFM air/lb O_2/d	0.04	0.04
SOTE, %	27.72	30.00
Air Flow, SCFM	**69,322**	**64,054**

Section 3.4.1.1: Airflow Comparison Between Membrane and Disc Diffusers Calculation

	Manual DO Control	Aeration Control (DO to 2mg/l)
a. Influent Conditions		
BOD_5, lb/d	133,000	133,000
NH3-N, lb/d	9,900	9,900
Wastewater Temperature, ºC	20	20
b. Aeration System		
Actual Oxygen Requirement (AOR)		
BOD_5 demand, lb O_2/lb BOD_5	1.0	1.0
NH_3-N demand, lb O_2/lb NH_3-N	4.6	4.6
AOR, lb O_2/d	191,840	191,840
Standard Oxygen Transfer Rate (SOTR)		
a	0.65	0.65
F	0.98	0.98
q	1.024	1.024
P_b, psia	14.2	14.2
P_s, psia	14.7	14.7
W	0.97	0.97
b	0.95	0.95
$C^*_{S\,20}$, mg/l	9.09	9.09
$C^*_{S\,T}$, mg/l	9.09	9.09
g_W, lb/cf	62.3	62.3
Basin Depth, ft	14.7	14.7
Effective Saturation Depth, d_e, ft	6.5	6.5
P_{vt}, psi	0.36	0.36
$C^*_{inf\,20}$, mg/l	10.56	10.56
$C^*_{inf\,T}$, mg/l	10.56	10.56
C, mg/l	3.12	2.0
t	1.00	1.00
OTR_f/SOTR	0.399	0.467
SOTR, lb O_2/d	480,402	410,892
SOTR, kg O_2/d	217,907	186,378
Air Flow		
SCFM air/lb O_2/d	0.04	0.04
SOTE, %	27.72	30.00
Air Flow, SCFM	**69,322**	**54,786**

Section 3.4.1.2: Airflow Calculation Comparison Current Conditions vs Reduced DO to 2mg/l

Appendix B
Turbine LCOE

Levelized Cost of Energy Calculator

The levelized cost of energy (LCOE) calculator provides a simple way to calculate a metric that encompasses capital costs, operations and maintenance (O&M), performance, and fuel costs of renewable energy technologies.

Note that this does not include financing issues, discount issues, future replacement, or degradation costs. Each of these would need to be included for a thorough analysis.

To estimate the cost of energy, enter values in the fields below. The calculator will return the LCOE expressed in cents per kilowatt-hour (kWh).

For specific values, please see the NREL Annual Technology Baseline (ATB).

Simple Levelized Cost of Energy Calculator	
Financial	
Periods (Years):	20
Discount Rate (%):	3.0
Renewable Energy System Cost and Performance	
Capital Cost ($/kW):	1850
Capacity Factor (%):	72
Fixed O&M Cost ($/kW-yr):	14.93
Variable O&M Cost ($/kWh):	0.0144
Heat Rate (Btu/kWh):	8865
Fuel Cost ($/MMBtu):	5
Today's Utility Electricity Cost	
Electricity Price (cents/kWh):	6
Cost Escalation Rate (%):	3.0
Results	
Levelized Cost of Utility Electricity (cents/kWh):	8.0
Simple Levelized Cost of Renewable Energy (cents/kWh):	8.1

How are these numbers calculated? See documentation

The U.S. Department of Energy Federal Energy Management Program sponsored the distributed generation data used within this calculator.

The NREL Comparative Photovoltaic Levelized Cost of Energy Calculator can help you understand a more detailed impact of different PV component prices on LCOE.

LCOE for Natural Gas at $5/dth

Levelized Cost of Energy Calculator

The levelized cost of energy (LCOE) calculator provides a simple way to calculate a metric that encompasses capital costs, operations and maintenance (O&M), performance, and fuel costs of renewable energy technologies.

Note that this does not include financing issues, discount issues, future replacement, or degradation costs. Each of these would need to be included for a thorough analysis.

To estimate the cost of energy, enter values in the fields below. The calculator will return the LCOE expressed in cents per kilowatt-hour (kWh).

For specific values, please see the NREL Annual Technology Baseline (ATB).

Simple Levelized Cost of Energy Calculator

Financial

Periods (Years): 20 ?

Discount Rate (%): 3.0 ?

Renewable Energy System Cost and Performance

Capital Cost ($/kW): 1850 ?

Capacity Factor (%): 72 ?

Fixed O&M Cost ($/kW-yr): 14.93 ?

Variable O&M Cost ($/kWh): 0.0144 ?

Heat Rate (Btu/kWh): 8865 ?

Fuel Cost ($/MMBtu): 10 ?

Today's Utility Electricity Cost

Electricity Price (cents/kWh): 9.3 ?

Cost Escalation Rate (%): 3.0 ?

Results

Levelized Cost of Utility Electricity (cents/kWh): 12.5 ?

Simple Levelized Cost of Renewable Energy (cents/kWh): 12.5 ?

How are these numbers calculated? See documentation

The U.S. Department of Energy Federal Energy Management Program sponsored the distributed generation data used within this calculator.

The NREL Comparative Photovoltaic Levelized Cost of Energy Calculator can help you understand a more detailed impact of different PV component prices on LCOE.

LCOE for Natural Gas at $10/dth

Levelized Cost of Energy Calculator

The levelized cost of energy (LCOE) calculator provides a simple way to calculate a metric that encompasses capital costs, operations and maintenance (O&M), performance, and fuel costs of renewable energy technologies.

Note that this does not include financing issues, discount issues, future replacement, or degradation costs. Each of these would need to be included for a thorough analysis.

To estimate the cost of energy, enter values in the fields below. The calculator will return the LCOE expressed in cents per kilowatt-hour (kWh).

For specific values, please see the NREL Annual Technology Baseline (ATB).

Simple Levelized Cost of Energy Calculator

Financial

Periods (Years):	20
Discount Rate (%):	3.0

Renewable Energy System Cost and Performance

Capital Cost ($/kW):	1850
Capacity Factor (%):	72
Fixed O&M Cost ($/kW-yr):	14.93
Variable O&M Cost ($/kWh):	0.0144
Heat Rate (Btu/kWh):	8865
Fuel Cost ($/MMBtu):	2.112

Today's Utility Electricity Cost

Electricity Price (cents/kWh):	4
Cost Escalation Rate (%):	3.0

Results

Levelized Cost of Utility Electricity (cents/kWh):	5.4
Simple Levelized Cost of Renewable Energy (cents/kWh):	5.5

How are these numbers calculated? See documentation

The U.S. Department of Energy Federal Energy Management Program sponsored the distributed generation data used within this calculator.

The NREL Comparative Photovoltaic Levelized Cost of Energy Calculator can help you understand a more detailed impact of different PV component prices on LCOE.

LCOE for Landfill Gas

Greeley and Hansen LLC
100 S Wacker Dr. STE 1400
Chicago, IL 60606
312-558-9000
www.greeley-hansen.com

GREELEY AND HANSEN

Appendix D

SSWRF Energy Plan (TM-4)

Energy Plan for MMSD Facilities

Technical Memorandum 4: SSWRF Energy Plan

Milwaukee Metropolitan Sewerage District
Contract M03109P01

FINAL – January 2023

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Executive Summary

Background and Purpose

The Milwaukee Metropolitan Sewerage District (MMSD) adopted its 2035 Vision on January 24, 2011, that set strategic objectives for the next 25 years. The 2035 Vision focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency, including the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

This Technical Memorandum 4 (TM-4) focuses on energy planning for the South Shore Water Reclamation Facility (SSWRF). The baseline energy demand is described, alternatives identified to be implemented to meet MMSD's energy goals are evaluated, and a strategy to achieve those goals is developed. The following reports are a part of this project:

- TM-1: Energy Review and Renewables
- TM-2: Administration Buildings and Conveyance System
- TM-3: JIWRF Energy Plan
- **TM-4: SSWRF Energy Plan**
- Planning Report

Existing Conditions

SSWRF began operation in 1968 and has been upgraded in the decades since. It has a current treatment capacity of 300 Million Gallons per Day (MGD).

For this project, MMSD provided total energy consumption data for 2018 – 2020 that provides the baseline energy usage for SSWRF. The energy consumption presented is from 2018-2020 and is a snapshot of what the demands were at this time. Future planning reports will consider anticipated demands and future projects.

The energy data provided includes a combination of external and internal energy types, including electricity, natural gas (NG), and digester gas (DG).

Internal energy consists of LFG, while external consists of NG, utility purchased electricity, and the remaining energy sources. Renewable energy consists of LFG, while all other sources are non-renewable, other than a portion of purchased electricity.

All energy was converted to Million British Thermal Units (MMBTU). The facility's average total energy consumption from 2018-2020 is approximately 543,000 MMBTU/yr. **Figure ES-1** shows the total approximate energy consumption by major energy using equipment at SSWRF.

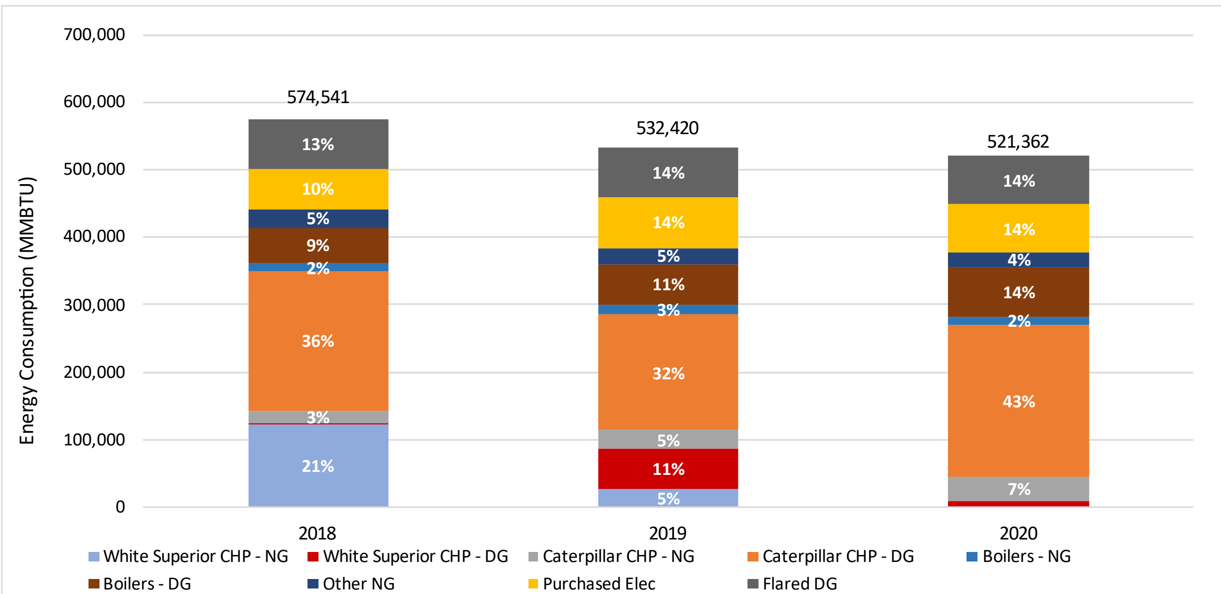

Figure ES-1: SSWRF Energy Consumption

The flare energy consumption is wasted energy and not a required facility energy demand that can be eliminated to immediately reduce SSWRF's energy footprint.

SSWRF does not have electrical meters for each building or broken down by wastewater process. The electrical consumption was estimated for each major wastewater process equipment using plant data, Operation and Maintenance (O&M) Manuals, and equipment run time data. The electrical consumption was averaged from 2018-2020 was approximately 45,490,000 kWh (155,000 MMBTU). This consumption was composed of an average of 25,200,000 kWh (86,000 MMTBU) produced by the engines, and 20,222,000 kWh (69,000 MMBTU) of purchased electricity annually. **Table ES-1** shows the estimated baseline electrical consumption in MMBTU per year and kilowatt hour (kWh) per year for major equipment and processes.

Table ES-1: Estimated SSWRF Baseline Electrical Consumption

Consumer	MMBTU/yr	kWh/yr
AERATION	83,700	24,600,000
OTHER (HVAC, MISC PROCESS)	22,300	6,510,000
RAS	16,700	4,890,000
LIGHTING	12,400	3,630,000
EFFLUENT PUMPS	8,900	2,610,000
IPS	4,400	1,300,000
RAS/WAS TRANSFER PUMPS	4,400	1,300,000
WAS	1,300	390,000
PRIMARY SLUDGE PUMPS	900	260,000
Total	155,000	45,490,000

Planned Improvements

MMSD has a number of projects in the planning, design, and construction phase at SSWRF. To capture the effect of these upgrades on the energy usage, a revised Baseline+ has been developed to incorporate these projects that have assigned project numbers. Projects that are anticipated to be completed within the next 10 years are included in the revised Baseline+. A new dewatering and drying facility at SSWRF is discussed in the Biosolids Advanced Facility Plan (BAFP) but not included in the revised Baseline+ because it would finish construction after 2032. **Table ES-2** and **Table ES-3** summarize the changes to digester gas generation and energy consumption with the planned improvement projects incorporated into the Baseline+.

Table ES-2: SSWRF Baseline+ Digester Gas Generation

	Baseline (MMBTU/yr)	Change (MMBTU/yr)	Baseline+ (MMBTU/yr)
Digester Gas	359,000		473,880
Primary Clarifier Improvements (S01013)		+96,930	
Acid Phase Digestion (S04039)		+17,950	
Total	359,000	+114,880	473,880

Table ES-3: SSWRF Baseline+ Energy Consumption

Consumer	Baseline		Change		Baseline+	
	MMBTU/yr	kWh/yr	MMBTU/yr	kWh/yr	MMBTU/yr	kWh/yr
AERATION	83,700	24,600,000			59,219	17,356,067
Primary Clarifier Improvements (S01013)	--	--	-3,497	-1,025,000	--	--
Aeration System Upgrade (S02015)	--	--	-16,787	-4,920,000	--	--
Process Air Header Improvements (S02017)	--	--	-4,197	-1,230,000	--	--
UV DISINFECTION IMPROVEMENTS (S03005)	0	0	3,839	+1,125,000	3,839	1,125,000
OTHER (HVAC, MISC PROCESS)	22,300	6,510,000			21,450	6,261,000
Replace W3 Flushing Water Pumps (S06019)	--	--	-850	-249,000	--	--
Bldg. 378 HVAC Improvements (S06050)	--	--	-8	-2,333	--	--
Bldg. 383 HVAC Improvements (S04036)	--	--	-4	-1,167	--	--
RAS	16,700	4,890,000			16,700	4,890,000
LIGHTING	12,400	3,630,000			12,400	3,630,000
EFFLUENT PUMPS	8,900	2,610,000			8,633	2,531,747
Effluent Pump MCC and VFD Upgrade (S03004)	--	--	-267	-78,253	--	--
IPS	4,400	1,300,000			3,916	1,158,148
Primary Clarifier Improvements (S01013)	--	--	-484	-141,852	--	--
RAS/WAS TRANSFER PUMPS	4,400	1,300,000			4,400	1,300,000
WAS	1,300	390,000			1,300	390,000
PRIMARY SLUDGE PUMPS	900	260,000			900	260,000
BOILER	129,500	37,952,565			129,500	37,952,565
WASTE HEAT	161,500	47,330,805			161,500	47,330,805
OTHER NATURAL GAS	24,000	7,033,680			24,000	7,033,680
Bldg. 378 HVAC Improvements (S06050)	--	--	-56	-16,412	--	--
Bldg. 383 HVAC Improvements (S04036)	--	--	-28	-8,206	--	--
Total	470,000	137,807,050	-22,339	-7,672,223	447,757	131,219,012

SSWRF Energy Plan

The plan for MMSD to meet their energy goals at SSWRF is divided into three parts: optimizing existing energy operations, energy generation, and energy efficiency.

Optimization of Energy Operating Strategy

SSWRF has four Caterpillar (CAT) engine generators, capable of using two fuel sources: the engine generator is rated for 925 kW utilizing digester gas (DG) and 773 kW utilizing natural gas (NG). There is one White Superior (WS) engine generator rated for 1,500 kW on both DG and NG. The engine generators have a total capacity of 5,200 kW when using DG.

A simplified levelized cost of energy (sLCOE) analysis was performed to quantify the cost incurred from generating electricity using the engine generators at SSWRF. The evaluation includes capital costs, O&M costs, fuel cleaning costs, capacity factor, and equipment heat rates. **Table ES-4** summarizes the sLCOE analysis and variables for the CAT engines.

Table ES-4: SSWRF Engine LCOE Analysis

Variable	Value
Analysis Period	20 years
Discount Rate	3.375%
Capital Recovery Factor	7%
Overnight Capital Cost	\$2,800/kW
Fixed O&M Cost	\$0/kW-yr
Capacity Factor	69%
Fuel Cost	\$2.11/MMBTU
Heat Rate	9,896 Btu/kWh
Variable O&M Cost	\$0.02709/kWh
sLCOE	**\$0.079/kWh**

This sLCOE results in the cost breakeven point of generating electricity vs purchasing electricity. This means that if the total electricity cost including demand charges from the utility is above 7.9 cents/kWh, it is more cost effective to run the engines on DG to generate electricity. If the utility electricity cost is below 7.9 cents/kWh, it is more cost effective to purchase from the utility. This is an important factor when considering utilizing the engines for peak shaving. SSWRFs on-peak and off-peak charges for the summer and included below for reference.

- On-Peak Usage Charge: $0.09294/kWh
- On-Peak Demand Charge: $21.532/kW
- Off-Peak Usage Charge: $0.05922/kWh
- Customer Demand Charge: $2.311/kW

It is recommended to continue to operate the engines on digester gas when there is digester gas available and to maximize the renewable electricity generated.

Facility Electrification
Transitioning NG fired equipment and appliances to electric is important to meet MMSD's energy goals. NG is a finite resource with limited renewable alternatives. Renewable electricity is more readily available to install or through the utility grid.

Air source heat pumps, in conjunction with electric resistance coils, can replace NG fired or hot water coil air handlers. Electric resistance coils are required for backup heating in cold climates when air source heat pumps cannot operate. This would require all existing air handlers to be replaced and heat pumps be installed outdoors and likely also require electrical distribution system improvements.

Air and water source heat pumps generally have a positive return on investment when there are both heating and cooling load requirements for buildings. It is recommended they be incorporated when equipment is at the end of its useful life and up for replacement. It is estimated that heat pumps can reduce the heating energy consumption by about 20%. This number is conservative when considering the U.S. Department of Energy references that heat pumps can reduce energy consumption up to 50%.[1]

Energy Generation Summary

Alternatives for potential energy generation utilizing renewable processes like DG, photovoltaic, wind, pyrolysis, algae bioreactor, and effluent heat recovery were evaluated. The potential energy generation listed in **Table ES-5** below is all the renewable energy that can be generated internally a SSWRF based on this memorandum's analysis. There are benefits to utilizing a pyrolysis process to dispose of biosolids, including the biochar end product and carbon sequestration. Thermal energy through waste heat can be used for other processes. For a system this size, syngas production that could be used as a fuel source for

[1] https://www.energy.gov/energysaver/heat-pump-systems

engines is not feasible. An algae system to treat sidestream flows has benefits of reducing energy usage of secondary treatment and potentially the algae could be used in the anaerobic digesters to increase DG generation. Algae to a biofuel is still being researched and commercialized.

Table ES-5: SSWRF Renewable Energy Generation Summary

Source	Electricity (MMBTU/yr)	Gas (MMBTU/yr)	Total (MMBTU/yr)
Photovoltaic	161,500	0	161,500
Wind	352,950	0	352,950
Pyrolysis	0	0	0
Algae Bioreactor	0	0	0
DG	0	642,300	642,300
Total	514,450	642,300	1,156,750

sLCOEs were also performed for photovoltaic and wind energy to find the breakeven point of utility purchased electricity and costs MMSD would incur to generate electricity with these technologies and are summarized below.

- Photovoltaic sLCOE: $0.123/kWh
- Wind sLCOE: $0.042/kWh

A technology evaluation was completed to determine the most efficient equipment to generate electricity utilizing DG. A facility's thermal to power (T/P) ratio shows the amount of thermal energy demand versus electrical power demand that is used to determine generator type[2]. **Table ES-6** shows different generation equipment types have different electrical and thermal generation efficiencies and depending on what a facilities thermal and electrical demands are, certain technologies may be more favorable and efficient. SSWRF on average consumes 129,500 MMBTU of heat in the main boiler loop, while consuming 155,000 MMBTU of electricity per year. SSWRF's T/P ratio is 0.84, which results in engines being the preferred equipment for generating electricity from DG.

[2] https://www.energy.gov/sites/prod/files/2013/11/f4/webcast_2009-0514_chp_in_facilities.pdf

Table ES-6: Generator T/P Ratio

T/P Ratio	Preferred Type
0.5 to 1.5	Engines
1 to 10	Gas Turbines
3 to 20	Steam Turbines

Additionally, SSWRF has an average hourly dry weather demand of 5.2 MW. For redundancy and flexibility, this demand can be generated by multiple, appropriately sized reciprocating engines as reciprocating engines are typically 5 MW and less in size.

The optimal size for generators is determined using the facility's thermal demand and the digester gas available. **Table ES-7** shows the engine generation capacity when sized for thermal demand or digester gas availability.

Table ES-7: Generator System Sizing (kW)

System Sized Using	Generation Capacity kW
Thermal Demand	4,200
Digester Gas Available	4,750

The installed engine generator capacity at SSWRF is 5,200 kW. This does not provide sufficient capacity to use all DG if an engine generator is out of service and approximately 71,000 MMBTU of DG is flared annually. It is recommended to have sufficient engine generator capacity to eliminate flaring of DG under normal operations. The upcoming *Planning Report* will include a District wide recommendation that discusses where and at what volume DG should be consumed. A recommendation for the resulting engine generator capacity at SSWRF to meet an N+1 installation for the DG allocation this equipment will be included.

Energy Efficiency Alternatives Summary

There are a number of projects already underway at SSWRF to reduce energy usage, including significant upgrades to the secondary treatment system, the largest energy user. Additional energy efficiency alternatives are summarized below.

- Secondary Treatment Aeration and Blowers
  - Installation of higher efficiency blowers, such as turbo blowers
    - 9,950 MMBTU/yr reduction
  - Incorporation of Ammonia Sidestream Treatment

        - 1,000 MMBTU/yr reduction
- Process Pumps:
    - High-efficiency motor replacements
- Anaerobic Digester Mixing
- Lighting:
    - Replacement of high-pressure sodium (HPS) lighting with light emitting diode (LED)
        - Lighting replacement projects were completed in 2019 and 2022, mostly after the period used in the baseline energy analysis

The energy efficiency improvements are summarized by equipment type in **Table ES-8** below.

Table ES-8: Energy Efficiency Improvements Summary

Consumer	Baseline+ (MMBTU/yr)	Reduction (MMBTU/yr)	New (MMBTU/yr)
AERATION	59,219	10,950	48,269
Blowers		9,950	
Ammonia Sidestream Treatment		1,000	
UV IMPROVEMENTS	3,839	0	3,839
OTHER (HVAC, MISC PROCESS)	21,450	3,764	17,674
RAS	16,700	500	16,200
LIGHTING	12,400	8,275	4,125
EFFLUENT PUMPS	8,633	260	8,373
IPS	3,916	120	3,796
RAS/WAS TRANSFER PUMPS	4,400	130	4,270
WAS	1,300	40	1,260
PRIMARY SLUDGE PUMPS	900	30	870
BOILER	129,500	0	129,500

Consumer	Baseline+ (MMBTU/yr)	Reduction (MMBTU/yr)	New (MMBTU/yr)
OTHER NATURAL GAS	23,916	0	23,916
Total	286,161	24,069	262,092

Other electric loads refer to various electrical consumers throughout SSWRF, including air conditioning, dewatering, and other processes, and various other process motors and equipment not identified in **Table ES-8**. Other Natural Gas loads refer to various NG consumers throughout SSWRF including other small boilers, water heaters, and natural gas fired HVAC units.

Conclusions

Incorporating the energy efficiency and generation alternatives, **Table ES-9** shows the new total energy consumption by equipment after the recommendations are incorporated:

Table ES-9: SSWRF Energy Source by Consumer with Recommended Improvements

Consumer	NG (MMBTU/yr)	Electricity (MMBTU/yr)	Waste Heat (MMBTU/yr)	Total (MMBTU/yr)
AERATION	0	48,269	0	48,269
UV IMPROVEMENTS	0	3,839	0	3,839
OTHER (HVAC, MISC PROCESS)	0	17,674	0	17,674
RAS	0	16,200	0	16,200
LIGHTING	0	4,125	0	4,125
EFFLUENT PUMPS	0	8,373	0	8,373
IPS	0	3,796	0	3,796
RAS/WAS TRANSFER PUMPS	0	4,270	0	4,270
WAS	0	1,260	0	1,260
PRIMARY SLUDGE PUMPS	0	870	0	870
BOILER	0	0	129,500	129,500
OTHER NATURAL GAS	0	23,916	0	23,916
Total	0	132,592	129,500	262,092

The purpose of **Table ES-9** is to show what the energy profile of the end using consumption equipment would look like after the energy recommendations and improvements are incorporated. The "Other Natural Gas" loads row has the energy demand allocated under "Electricity" because the recommendation is to transition those loads to electric fuel sources. The end goal would be to have renewable electricity fuel the electricity loads at SSWRF. It is recommended that non-renewable natural gas consumption be phased out to achieve MMSD's goals.

The total end user energy consumption is 262,092 MMBTU/yr. This value is lower than the baseline value of 543,000 MMBTU because it does not include the inefficiencies of the engines for power generation discounting waste heat utilized (161,500 MMBTU/yr) or energy lost due to flaring of DG (73,000 MMBTU/yr). It includes the efficiencies realized by incorporating the alternatives evaluated in **Section 4** (24,069 MMBTU/yr) and the difference in energy from the original baseline to the planned improvements summarized in **Section 3** (22,339 MMBTU/yr)[3].

The information and alternatives in this Technical Memorandum are informational and will be taken into account in the upcoming *Planning Report* where specific recommendations on where energy should be consumed and generated will be made. This includes digester gas consumption and renewable energy generation.

With the improvements made, it is feasible for renewable energy to comprise 100% of the total energy consumption at SSWRF. The evaluation includes potential excess energy (714,777 MMBTU/yr) could be used to offset with non-renewable energy consumption at other MMSD assets such as Jones Island Water Reclamation Facility (JIWRF), Administration Facilities, or the Conveyance System. The energy balance is shown in the Sankey Diagram shown in **Figure ES-2**.

[3] 543,000 - 161,500 - 73,000 – 24,069 - 22,339 - = 262,092 MMBTU/yr

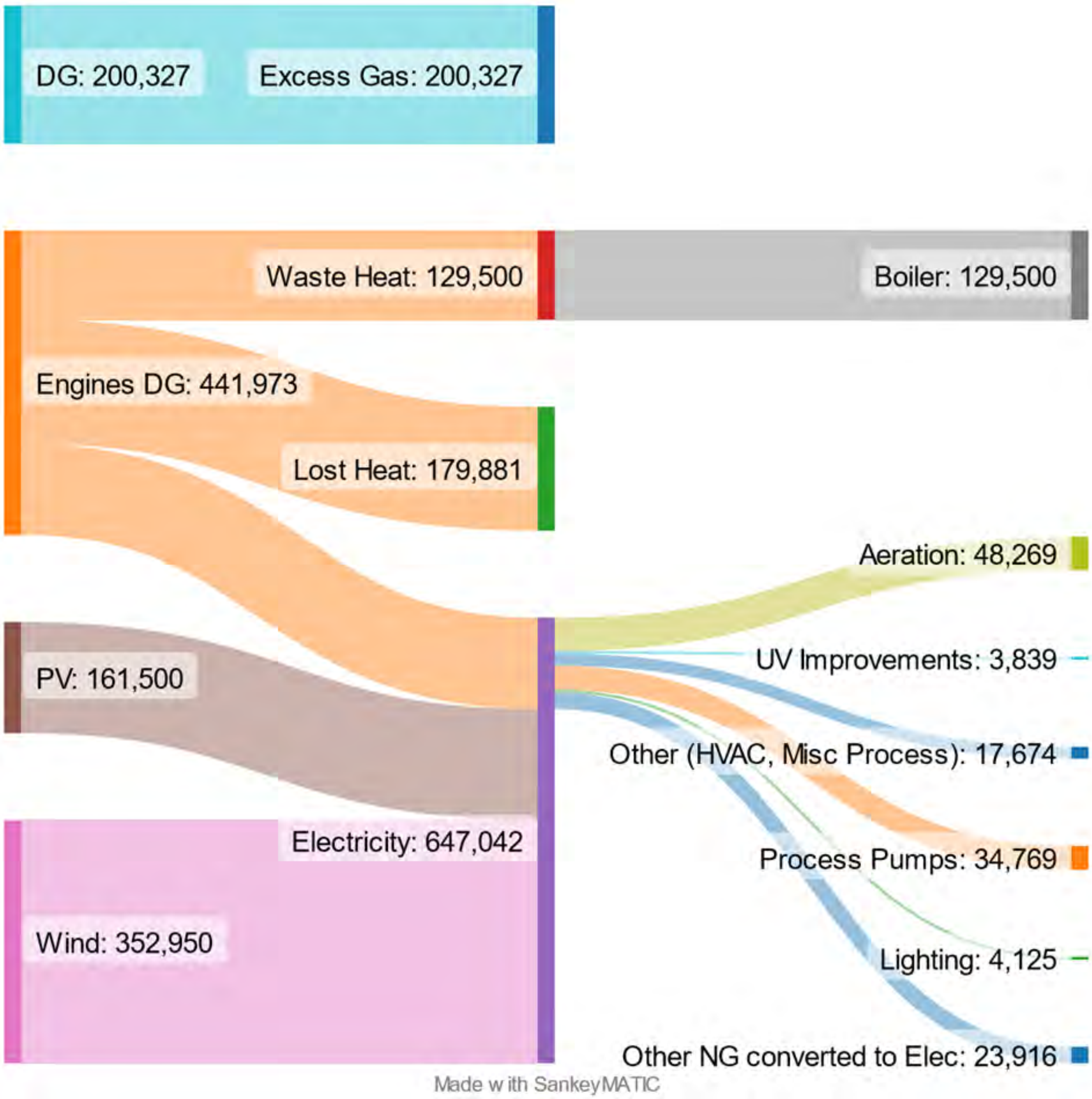

Figure ES-2: SSWRF Sourced Energy by Consumer (MMBTU)

As part of this project, additional technical memorandums are being prepared and will be submitted at a later date.

- The *Planning Report* will be a MMSD-wide document to meet the MMSD's energy goals. Non-renewable energy consumption at JIWRF may be offset through excess renewable energy generation at SSWRF, energy generation at other MMSD properties, or a combination of them.
- *Technical Memorandum 5 – Carbon Free Needs Assessment*

Section 1 Introduction

1.1 Purpose

The Milwaukee Metropolitan Sewerage District (MMSD) is a leading regional government agency that provides water reclamation and flood management services for approximately 1.1 million people in 28 municipalities in the Greater Milwaukee area. The wastewater collected within MMSD's service area through the conveyance and storage asset system is sent to two water reclamation facilities: Jones Island Water Reclamation Facility (JIWRF) and the South Shore Water Reclamation Facility (SSWRF).

MMSD is a leader in the water industry in protecting the environment and sustainability. MMSD adopted the 2035 Vision on January 24, 2011 by the commission, that focuses on integrated watershed management and climate change mitigation with an emphasis on energy efficiency and includes the following energy goals:

- Meet a net 100% of MMSD's energy from renewable energy sources.
- Meet 80% of MMSD's energy needs from internal, renewable sources.
- Reduce MMSD's carbon footprint by 90% from its 2005 baseline.

This Technical Memorandum (TM-4) defines SSWRF's energy baseline demand, identifies alternatives to be implemented to improve energy efficiency and generate energy through renewable sources, and develops a strategy to achieve MMSD's goals at SSWRF. The following reports are a part of this project:

- TM-1: Energy Review and Renewables
- TM-2: Administration Buildings and Conveyance System
- TM-3: JIWRF Energy Plan
- **TM-4: SSWRF Energy Plan**
- Planning Report

1.2 SSWRF Background

SSWRF began operation in 1968 and has been upgraded in the decades since. It has a full treatment capacity of 300 Million Gallons per Day (MGD). SSWRF generates energy from digester gas from the anaerobic digesters. The gas is collected and burned to produce electricity. An aerial photo showing SSWRF is included as **Figure 1-1**.

Figure 1-1: SSWRF Aerial Photo

The SSWRF Process Flow Diagram is shown in **Figure 1-2** and includes both the liquid and solids treatment systems.

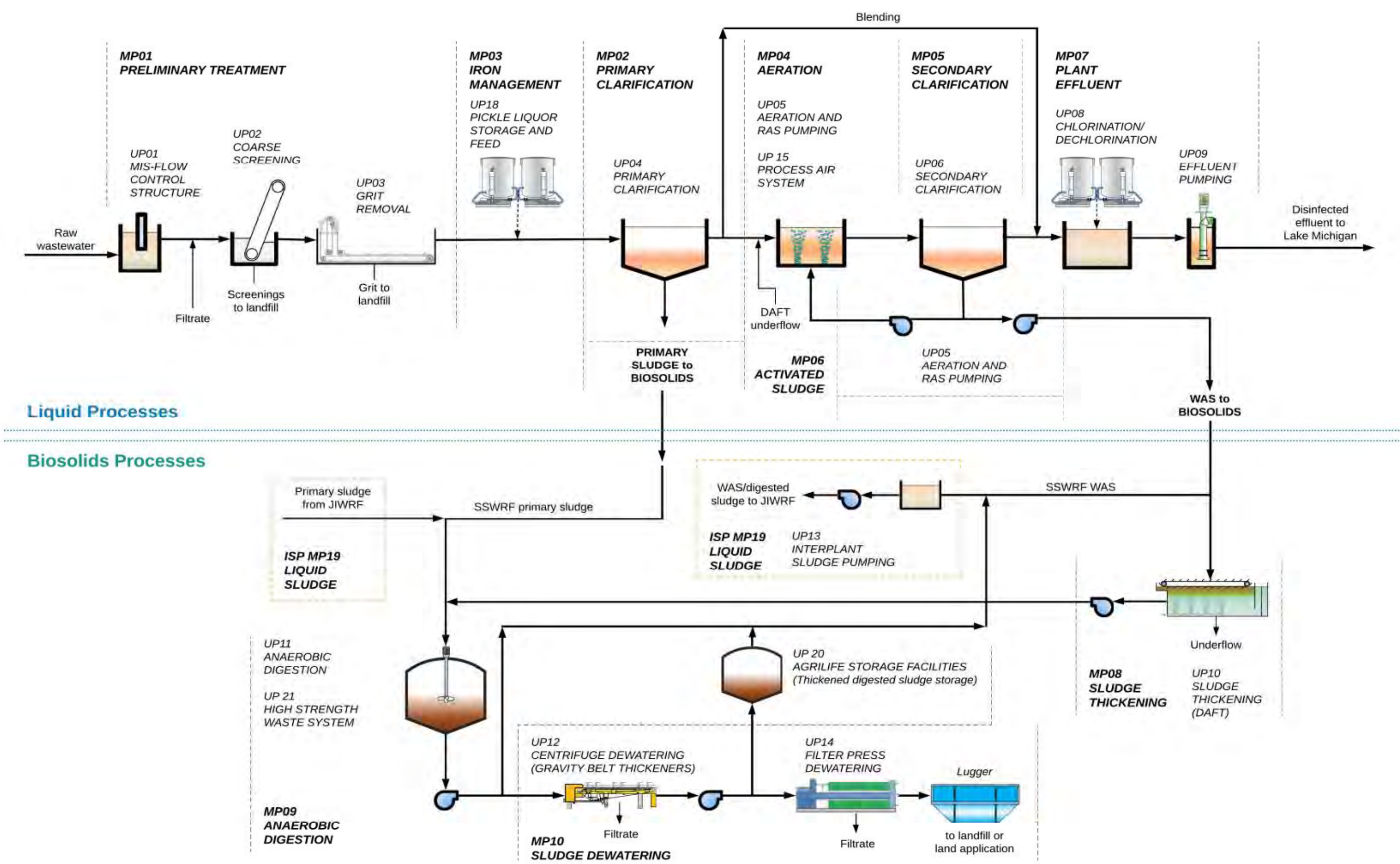

Figure 1-2: SSWRF Process Flow Diagram (Source: 2050 Facility Plan)

The major energy users at SSWRF include the following equipment and processes:

1. **Preliminary Treatment, Sludge Screening, and Scum Handling**
   - Grit Pumps – 3 pumps, Submersible recessed impeller, 600 GPM, 30 Horsepower (HP) each
2. **Primary Clarification**
   - Primary Sludge Pumps – 4 pumps, progressing cavity adjustable speed two stage, 450 GPM, 40 HP each.
   - Scum Pumps – 4 pumps, Progressing cavity with mechanical variable speed drive, 200 GPM, 20 HP each
   - Basin Drain Pumps – 2 pumps, Centrifugal heavy duty vertical non-clog, 20 HP each
3. **Aeration and RAS**
   - Basins – 28 rectangular basins arranged in plant halves (East and West) of 14 basins each. Each basin is 378 feet by 30 feet wide by 15 feet SWD, holding 1.25 MG. The total volume of all aeration basins is 35 MG
   - RAS Pumps – 8 pumps, Centrifugal type variable speed, 10,850 GPM, 150 HP each
   - Basin Drain Pumps – 4 pumps, Centrifugal type, 3 MGD, 60 HP each
4. **Secondary Clarification**
   - RAS/WAS Transfer Pumps: 6 pumps, Centrifugal type non clog, 5,300 GPM, 50 HP each
   - Scum Subnatant Pumps Battery 1 - 4: 4 pumps, Submersible Centrifugal
     i. Pumps for Battery 1 – 4 do not have listed GPMs or HPs in O&Ms
   - Scum Subnatant Pumps Battery 5 and 6: 4 pumps, Submersible Centrifugal, 300 GPM
5. **Interplant Sludge Pumping (IPS) Pump Station**
   - IPS Transfer Pumps: 6 pumps, CW Centrifugal, Two Stage, 1,160 GPM, 200 HP each
   - Basin Drain Pump: 4 pump, Centrifugal, 300 GPM, 60 HP each
6. **Effluent Pumping**
   - Effluent Pumps: 5 pumps, Centrifugal axial flow, 75 MGD, 200 HP each
   - Primary Basin Drain Pumps: 2 pumps, Centrifugal non clog, 20 HP each

7. **Blower System**

    - Turblex Blowers: 4 blowers, Centrifugal, 35,000 CFM, 1,500 HP each, 4,160 Volts

8. **Engine Generator System**

    - Four Caterpillar (CAT) engine generators, Dual Fuel Sources – Digester Gas (DG) 925 ekW and Natural Gas (NG) 773 ekW
    - One White Superior (WS) engine generator, 1,500 kW (DG or NG)
    - Four gas compressors – Rotary, positive displacement, water cooled units
        i. The three gas compressors compress raw gas through moisture removal and activated carbon beds. The conditioned gas is stored at 10 to 50 psig in storage spheres, with a discharge pressure of 50-55 psig.
        ii. The conditioned gas from the spheres goes directly to the CAT CHPs through a pressure regulator.
        iii. The White Superior engine generator has a booster skid that increases the gas pressure after the spheres.
        iv. The three Conditioning Compressors are each rated for 600 scfm at 51 psig discharge pressure and driven by a 150 HP variable speed motor.
        v. The single Booster Compressor is rated for 510 scfm at 60 psig discharge pressure and driven by a 100 HP constant speed motor.

Section 2 Existing Conditions

2.1 Baseline Energy Consumption

MMSD provided total energy consumption data for 2018 – 2020 to calculate the baseline energy usage for SSWRF. The energy data provided includes a combination of external and internal energy and types, including electricity, natural gas (NG), and digester gas (DG). DG is the only internal and renewable energy source currently at SSWRF. All energy was converted to Million British Thermal Units (MMBTU). Generally, when discussing energy, units of MMBTU will be used. When discussing electricity, units of kilowatt hour (kWh) will be used.

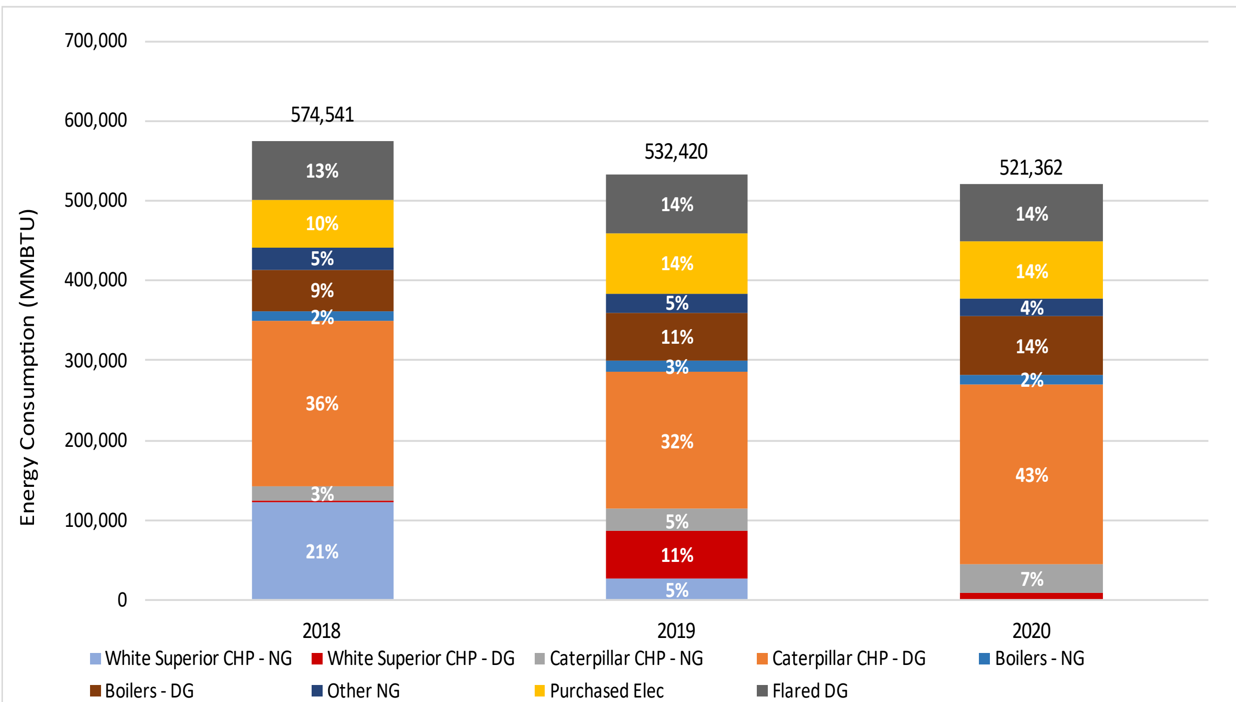

Figure 2-1: SSWRF Energy Consumption

Figure 2-1 shows SSWRF's total energy consumption from 2018 through 2020. The average is approximately 543,000 MMBTU per year.

- NG consumption totals 21.2% (115,000 MMBTU) of SSWRF's energy consumption.
- DG consumption totals 66.1% (359,000 MMBTU) of SSWRF's energy consumption.
- Utility purchased electricity accounts for 12.7% (20,222,000 kWh or 69,000 MMBTU) of SSWRF's consumption. Process electricity consumption is detailed in Section 2.8.
- The remaining energy consumption consists of fuel oil, propane, diesel, etc., which is small in comparison to the other energy sources.
  - Future equipment not requiring these fuels is recommended. Biodiesel may be a substitute if liquid fuels are required.

Figure 2-2 shows the SSWRF energy balance as described above. The left side of the figure shows the fuel sources: utility purchased electricity, NG, and DG. The right side is the end use of the energy and consists of facility electrical demands, boiler demand, and other NG demands. Both the left side fuel source inputs and right-side energy consumers add up to SSWRF's average total energy consumption of 543,000 MMBTU.

The facility consumes approximately 45,422,000 kWh (155,000 MMBTU) of electricity. 55% (25,200,000 kWh or 86,000 MMBTU) of that electricity is generated at SSWRF by the engine generators and 45% (20,222,000 kWh or 69,000 MMBTU) of that electricity is purchased from the utility.

308,500 MMBTU/yr is required consumption from electricity, boilers, and other NG loads, while 234,500 MMBTU is lost to waste heat and flaring. The resulting SSWRF required versus total energy consumption shows that SSWRF is about 56.8% (308,500/543,000) efficient in its energy consumption. Reducing unnecessary flaring alone would improve this efficiency to 65.6% [308,500/(543,000-73,000)], which is closer to the nameplate total combined heat and power (CHP) efficiency of the CAT engine generators of 72.2%. The 72.2% efficiency is the goal required versus total energy consumption efficiency for SSWRF when generating energy on site from the CHP system.

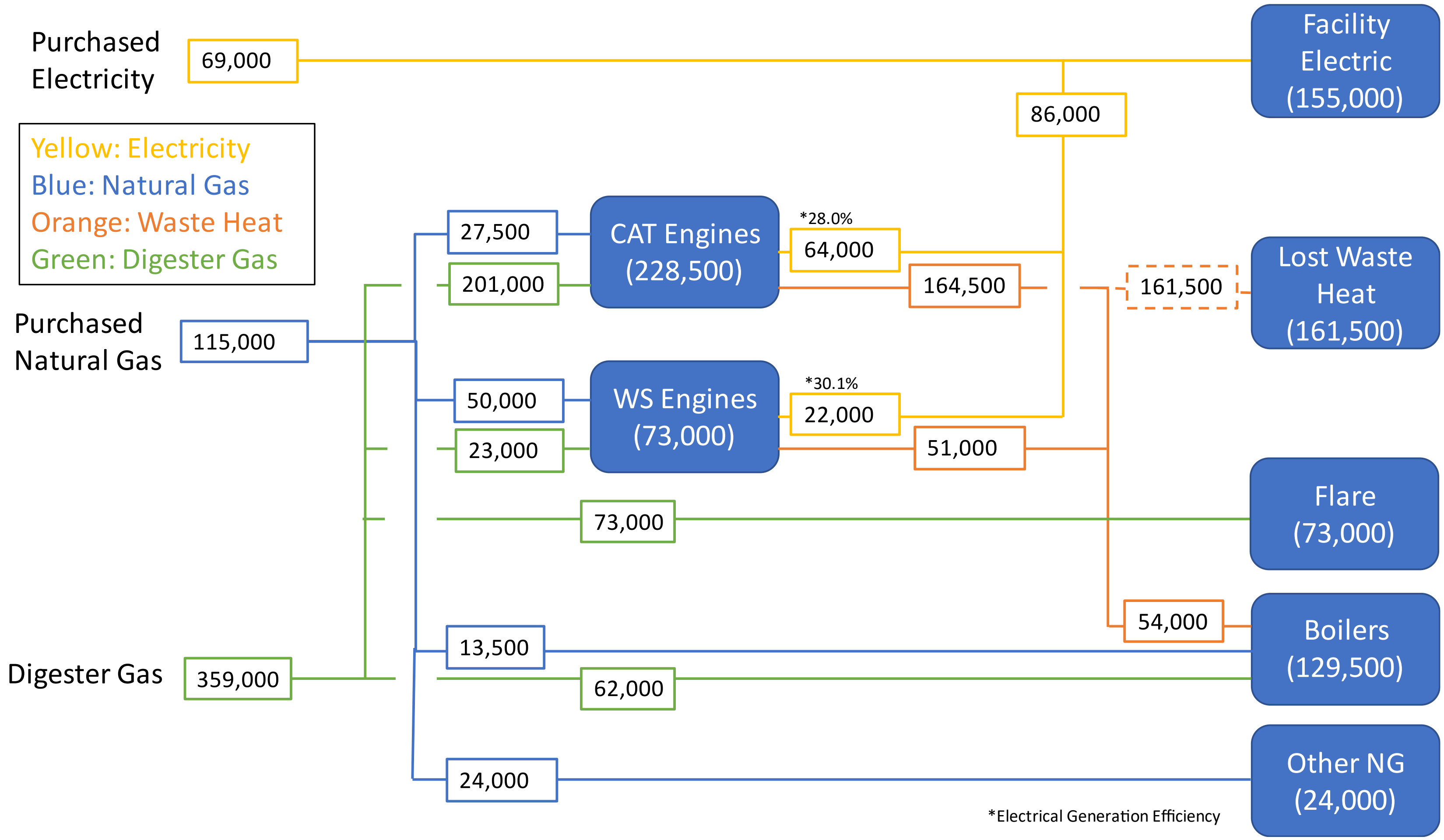

Figure 2-2: SSWRF Energy Consumption Schematic in MMBTU

2.2 Baseline Electricity Demand

The baseline electricity demand was determined utilizing hour electrical load data from 2018 through 2020.

Table 2-1: SSWRF Electricity Demand

Scenario	Electricity Demand (MW)
Dry Weather	5.4
Wet Weather	6.2

2.3 CAT and WS Engine Generators

SSWRF has two types of engine generators that generate electricity from NG or DG. The engines combine for 301,500 MMBTU of SSWRF's energy consumption. This energy consumption is split between the four CAT engines and single White Superior (WS) engine. On average from 2018 through 2020, 228,500 MMBTU/yr was consumed by the CAT engines and 73,000 MMBTU/yr was from the WS engines. DG consumption accounts for 224,000 MMBTU/yr of the engine's energy consumption, which is considered renewable. The CAT engines consumed 201,000 MMBTU/yr of DG on average. The WS engines consumed 23,000 MMBTU/yr on average.

The engines produce electricity and waste heat, in the form of process heating water. The engines generated an average of 25,200,000 kWh/yr (86,000 MMBTU/yr) of electricity from 2018 through 2020. The CAT engines generated 18,800,000 kWh/yr (64,000 MMBTU/yr) while the WS engine generated 6,400,000 kWh/yr (22,000 MMBTU/yr) of electricity. The resulting electrical energy generation efficiencies are 28.0% and 30.1% respectively. These are lower than the engine generator nameplate ratings, however this is likely due to partial loading of the engines which results in lower efficiencies. The CAT engine generator is rated for 34% electrical generation efficiency, however 28% efficiency is observed.

The CAT engines generated approximately 164,500 MMBTU/yr of waste heat, while the WS engine generated 51,000 MMBTU of waste heat. Currently, MMSD utilizes 54,000 MMBTU/yr of the 215,500 MMBTU/yr, resulting in 161,500 MMBTU/yr currently being lost energy. The waste heat utilized per engine is not known, and therefore the thermal efficiency of each engine cannot be determined. The overall thermal efficiency of the engines is approximately 25%. Similarly, the net efficiency of each engine cannot be determined, however the overall net efficiency of the engines is approximately 46.4%.

2.4 Purchased Electricity

Electricity is purchased from We Energies with multiple accounts for SSWRF for different feeds. Reviewing utility bills, purchased electricity accounts for 20,222,000 kWh/yr, or 69,000 MMBTU/yr, of SSWRF's energy consumption. Purchased electricity consists of both renewable and non-renewable energy which feeds into the facility's electrical distribution system. SSWRF's We Energies electric utility rate structure is classified as CP1, Summer and Non-Summer, and is included for reference below in **Table 2-2** and **Table 2-3**. Note that there is a current and proposed rate that includes significant consumption and demand charge increases. The proposed rate is under negotiation with We Energies. This report uses, an average utility rate of $0.10/kWh that includes facility, peak demand, and other utility charges that was agreed to with MMSD to be used for cost comparisons. Additionally SSWRF's blended rate, which incorporates SSWRF's costs of utility purchased electricity and generated electricity, of $0.052/kWh is used in analyses.

Table 2-2: We Energies Summer Rate Structure

CP1S (CP1 Summer Med Voltage)	Current Rate	Proposed Rate	Unit	% Change
Facilities Charge, $/day	19.76010	19.76010	$/day	0.00%
Additional Meter Charge, $/day			$/day	
Standard/ On-Peak Usage Charge, $/kWh	0.07687	0.09294	$/kWh	20.91%
Off-Peak Usage Charge, $/kWh	0.04949	0.05922	$/kWh	19.66%
On-Peak Demand Charge, $/kW	17.44000	21.43200	$/kW	22.89%
Customer Demand Charge, $/kW	2.23000	2.31100	$/kW	3.63%

Table 2-3: We Energies Non-Summer Rate Structure

CP1N (CP1 Non-Summer Med Voltage)	Current Rate	Proposed Rate	Unit	% Change
Facilities Charge, $/day	19.76010	19.76010	$/day	0.00%
Additional Meter Charge, $/day			$/day	
Standard/ On-Peak Usage Charge, $/kWh	0.06672	0.08066	$/kWh	20.89%
Off-Peak Usage Charge, $/kWh	0.04949	0.05922	$/kWh	19.66%
On-Peak Demand Charge, $/kW	12.54700	15.41900	$/kW	22.89%
Customer Demand Charge, $/kW	2.23000	2.31100	$/kW	3.63%

2.5 Other Gas Loads

In addition to NG and DG used for the boilers and engines, there are other miscellaneous NG demands for various buildings. Most of the NG used at SSWRF is for HVAC systems for heating, including gas fired boilers, and HVAC units. These loads account for approximately 24,000 MMBTU/yr of SSWRF's energy consumption.

2.6 Flare

The flare is used at SSWRF when not all the digester gas can be beneficially utilized to generate heat or electricity in the engines due to limited boiler loop thermal demands or engine generator availability. The flare accounts for 14% of SSWRFs energy consumption, which equals 73,000 MMBTU/yr. The flare energy consumption is wasted energy and not a required facility energy demand that can be eliminated to immediately reduce SSWRF's energy footprint. It is recommended to prioritize DG consumption.

2.7 Boilers

Boilers are used at SSWRF to produce hot water for use throughout the facility. The total boiler loop energy consumption is approximately 129,500 MMBTU/yr. The boiler's NG consumption accounts for 13,500 MMBTU/yr of this consumption, while DG accounts for 62,000 MMBTU/yr. The boiler loop also receives waste heat from the engines, approximately 54,000 MMBTU/yr of energy.

2.8 Electric Loads by Process

To understand electrical usage for various processes throughout the facility, electricity consumption was further broken down. The electrical consumption was estimated for each major wastewater process equipment using plant data, Operation and Maintenance (O&M) Manuals, and equipment run time data.

Table 2-4 and **Figure 2-3** show the processes where generated and purchased electricity is consumed throughout SSWRF. The Other loads include smaller process motors throughout the SSWRF, building HVAC equipment, and other various electrical consumers throughout the facility. The average annual electricity consumption consists of a combination of purchased 20,222,000 kWh/yr (69,000 MMBTU/yr) and generated 25,200,000 kWh/yr (86,000 MMBTU/yr), totaling 45,422,000 kWh/yr (155,000 MMBTU/yr).

Table 2-4: Baseline Electrical Consumption

Consumer	MMBTU/yr	kWh/yr
AERATION	83,700	24,600,000
OTHER (HVAC, MISC PROCESS)	22,300	6,510,000
RAS	16,700	4,890,000
LIGHTING	12,400	3,630,000
EFFLUENT PUMPS	8,900	2,610,000
IPS	4,400	1,300,000
RAS/WAS TRANSFER PUMPS	4,400	1,300,000
WAS	1,300	390,000
PRIMARY SLUDGE PUMPS	900	260,000
Total	155,000	45,490,000

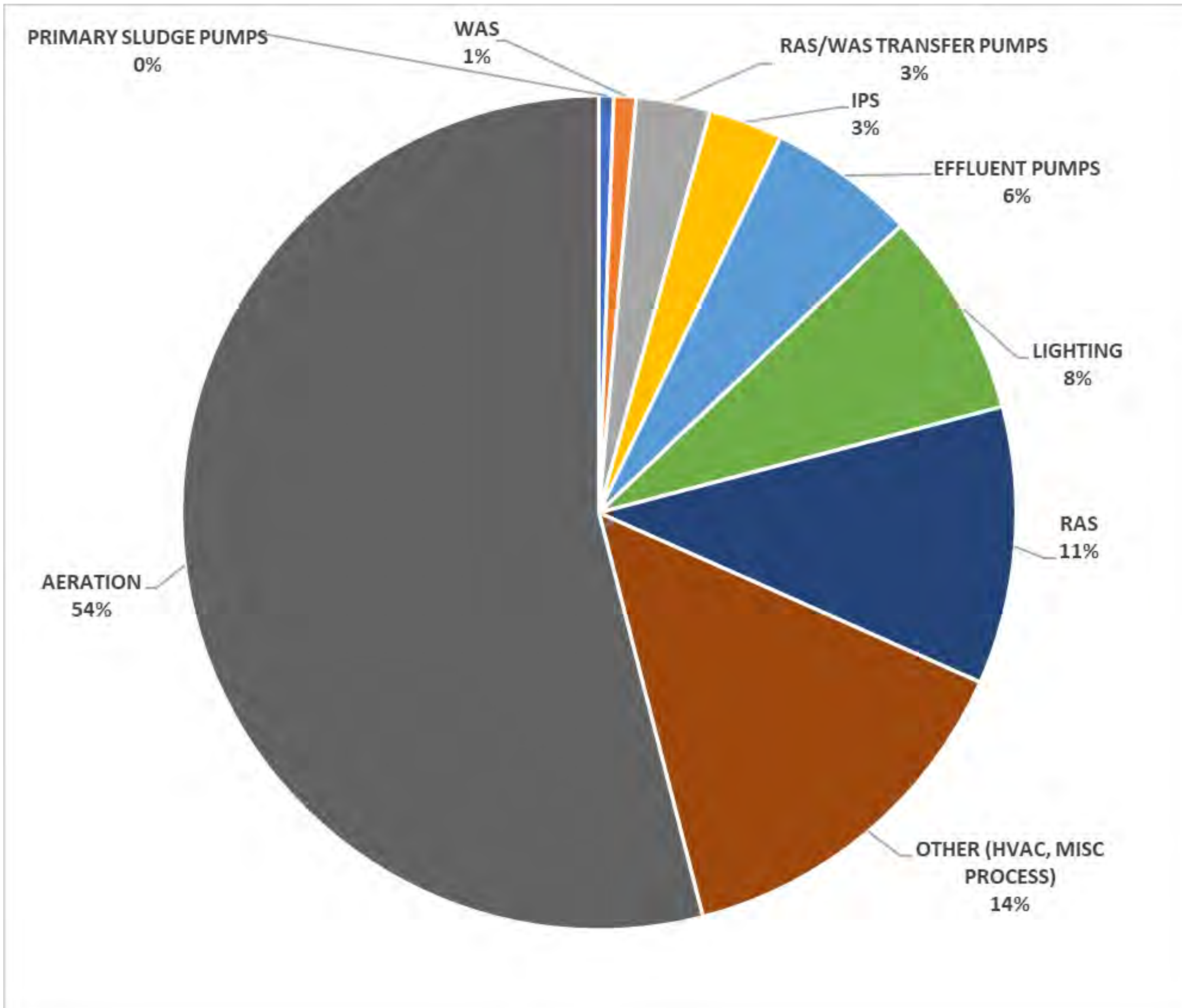

Figure 2-3: Electrical Consumption

Section 3 Planned Improvements

3.1 Introduction

Section 3 summarizes the planned projects at SSWRF that have assigned project numbers. A revised Baseline+ was then developed.

3.2 Planned Improvements

Table 3-1 summarizes the planned projects at SSWRF, if they will impact energy usage, the project's estimated construction substantial completion date, and estimated change in energy usage. These are all projects already planned for implementation and were evaluated by others.

Table 3-1: Planned Improvements Summary Table

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
S01009	Scum System Improvements	2023	No	-	-	-	No	-	
S01013	Primary Clarification System Improvements	2028	Yes	-	-	-	Yes	-	Preliminary values from the project used. Increase in digester gas (27%), decrease in aeration energy (4.2%), decrease in solids (11%). Energy decrease at JIWRF is not included in the energy total.
	Aeration System		Yes	-1,025,000	-	-4.2%	No	-	
	IPS		Yes	-141,852	-	-11.1%	No	-	
	D&D Facility at JIWRF (not included in energy savings at SSWRF)		Yes		-95,654	-11.1%	No	-	
	Digesters		Yes				Yes	27.3%	
S01015	Grit Equipment Replacement	2027	No	-	-	-	No	-	
S02008	SS Capacity Improvements	2025	No	-	-	-	No	-	
S02013	Aeration Galleries RAS Header Piping Rehab	2023	No	-	-	-	No	-	
S02014	Secondary Clarifier Idling Control	2022	No	-	-	-	No	-	
S02015	Aeration System Upgrade	2028	Yes	-4,920,000	-	-20.0%	No	-	Improvements include tapered membrane diffusers, aerobic/anaerobic swing zone, and DO control. Assumed 20% reduction in aeration energy usage.
S02017	Process Air Header Improvements	2027	Yes	-1,230,000	-	-5.0%	No	-	Assumed 5% energy decrease of aeration system due to a decrease in leaks.
S02018	RAS Pumps Replacement	2026	No	-	-	-	No	-	
S03003	Post-Secondary Capacity Improvements	2023	No	-	-	-	No	-	
S03004	Effluent Pump MCC and VFD Upgrade	2023	Yes	-78,253	-	-3.0%	No	-	Assumed 3% energy savings based on new electrical equipment and VFD.
S03005	Disinfection Process Improvements	2028	Yes	+1,125,000	-	New Load	No	-	Assumed new hybrid UV/chemical disinfection system.
S04010	Thickening Process Capacity Enhancements	2026	No	-	-	-	No	-	
S04012	Plate and Frame Press Upgrade	2023	No	-	-	-	No	-	
S04029	Digester Mixing II	2026	Yes	-	-	Negligible	Yes		New linear motion mixers (3 per digester at 15HP/ea) for AD9 and 11.
S04034	High Strength Waste Mixing Improvements	2028	Yes	-	-	Negligible	No	-	

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
S04035	Digester 6 & 8 Mixer Replacement	2023	Yes	-	-	Negligible	No	-	The existing mechanical draft tube mixers will be replaced with new linear motion mixers. The draft tube mixers were not operational during 2018-2020 and not included in the energy data. The four 10 HP mechanical draft tubes will be replaced with four 7.5 HP linear motion mixers.
S04036	Bldg. 383 HVAC Replacement	2023	Yes	-1,167	-28	-10.0%	No	-	Assumed 10% energy savings for new HVAC equipment.
S04037	Pyrolysis Evaluation	2025	No	-	-	-	No	-	
S04038	Digester Capacity Restoration	N/A	No	-	-	-	No	-	Digester cleaning project will restore capacity. Assumed no impact to energy.
S04039	Gravity Thickening & Acid Phase Digestion	2028	Yes	+490,000	-	New Load	Yes	5%	New energy loads for gravity thickeners and pumps. Assumed 5% increase in digester gas production rate per BAFP.
S04040	Dewatering and Drying Facility	2032	Yes	+6,300,000	+430,500	New Load	No	-	
S06019	Replace W3 Flushing Water Pumps	2023	Yes	-249,000	-	-	No	-	Lower site has a proposed savings of 36,000 kWh/yr. Upper site has a proposed savings of 213,000 kWh/yr. This project was recently completed, energy effects not included in the original baseline calculations.
S06027	Tunnels Concrete Rehabilitation	2023	No	-	-	-	No	-	
S06038	2018 SS Capital Equipment Rehabilitation/Replacement	N/A	No	-	-	-	No	-	
S06040	SS Network Optimization	N/A	No	-	-	-	No	-	
S06042	SS WRF Odor Assessment	N/A	No	-	-	-	No	-	
S06047	Protective Relay Synchronization	N/A	No	-	-	-	No	-	
S06048	Building Roof Replacement Phase 5	Completed	No	-	-	-	No	-	
S06049	2025-2029 SS Capital Equipment Replacement	N/A	No	-	-	-	No	-	
S06050	Bldg. 378 HVAC System Upgrade	2027	Yes	-2,333	-55	-10.0%	No	-	Assumed 10% energy savings for new HVAC equipment. Also touches Building B380.
S06053	W3 Flushing Water System Fire Flow	2028	Yes	-	-	Negligible	No	-	
S06054	SSWRF Feeder, LCUS, and MCC Replacements	N/A	No	-	-	-	No	-	
S06055	Secondary Clarifier Batteries 1, 2, 3, 4 Walkways Replacement	N/A	No	-	-	-	No	-	
S99001	Allowance for Plant Rehabilitation	N/A	No	-	-	-	No	-	
S99003	Operator Contribution to CIP	N/A	No	-	-	-	No	-	

3.3 Adjusted Energy Baseline+ with Planned Improvements

Table 3-2 summarizes the DG changes associated with the planned improvement projects.

Table 3-2: Digester Gas Production with Planned Improvements Summary

	Baseline (MMBTU/yr)	Change (MMBTU/yr)	Baseline+ (MMBTU/yr)
Digester Gas	359,000		473,880
Primary Clarifier Improvements		+93,930	
Acid Phase Digestion		+17,950	
Total	359,000	+114,880	473,880

Table 3-3 summarizes the adjusted energy baseline after all planned improvements are incorporated. This adjusted Baseline+ does not include the addition of a new dewatering and drying facility at SSWRF as described in the Biosolids Advanced Facility Plan (BAFP) but not included in the revised Baseline+ of this evaluation as if it is constructed, it would occur after 2032.

Table 3-3: Adjusted Baseline with Planned Improvements Detailed List

CONSUMER	Baseline		Change		Baseline+			Reduction
	dth/yr	kWh/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	MMBTU/yr	MMBTU/yr
AERATION	0	24,600,000			0	17,425,000	59,457	-24,482
Primary Clarifier Improvements	--	--	0	-1,025,000	--	--	--	
Aeration System Upgrade	--	--	0	-4,920,000	--	--	--	
Process Air Header Improvements	--	--	0	-1,230,000	--	--	--	

CONSUMER	Baseline		Change		Baseline+			Reduction
UV Disinfection Improvements	0	0	0	+1,125,000	0	1,125,000	3,839	3,839
OTHER (HVAC, MISC PROCESS)	0	6,510,000			0	6,257,500	21,352	-862
Replace W3 Flushing Water Pumps	--	--	0	-249,000	--	--	--	
Bldg. 378 HVAC Improvements	--	--	0	-2,333	--	--	--	
Bldg. 383 HVAC Improvements	--	--	0	-1,167	--	--	--	
RAS	0	4,890,000			0	4,890,000	16,685	0
LIGHTING	0	3,630,000			0	3,630,000	12,386	0
EFFLUENT PUMPS	0	2,610,000			0	2,531,700	8,639	-267
Effluent Pump MCC and VFD Upgrade	--	--	0	-78,300	--	--	--	
IPS	0	1,300,000			0	1,158,148	3,952	-484
Primary Clarifier Improvements	--	--	0	-141,852	--	--	--	
RAS/WAS TRANSFER PUMPS	0	1,300,000			0	1,300,000	4,436	0
WAS	0	390,000			0	390,000	1,331	0
PRIMARY SLUDGE PUMPS	0	260,000			0	260,000	887	0
BOILER	129,500				129,500	0	129,500	0
WASTE HEAT	161,500				161,500	0	161,500	0
OTHER NATURAL GAS	24,000	7,033,680			23,916	0	23,916	-84
Bldg. 378 HVAC Improvements	--	--	-56	0	--	--	--	
Bldg. 383 HVAC Improvements	--	--	-28	0	--	--	--	
Total	315,000	52,523,680	-84	-7,647,652	314,916	38,967,348	447,879	-22,340

Section 4 Energy Alternatives Evaluation

4.1 Introduction and Methodology

The significant SSWRF energy consumers were identified in Section 2. This section evaluates potential alternatives to optimize existing energy related assets and systems, generate additional energy, and reduce energy usage.

The evaluation is organized as follows: the energy consumer is identified, a description of the potential improvement is provided, and the impact of the improvement is summarized. A conceptual cost analysis is provided, if available and applicable to the alternative. Utility rates were provided by MMSD. A blended electricity rate of $0.052/kwh and an average utility electricity rate of $0.10/kwh were used for comparison. Similarly, a NG rate of $5.00/dekatherm (dth) and $10.00/dth (also written as $5.00/MMBTU and $10.00/MMBTU respectively) were used as bounds for comparison, as the price of NG has fluctuated recently. It is assumed that any recovered energy will be used internally and not returned to the grid.

Engineers' opinions of probable construction costs (OPCC) are Association for the Advancement of Cost Engineering (AACE) Class 5 estimates in 2022 dollars. The OPCC utilizes the following assumptions:

- Engineering, Design, Legal and Administrative Cost: 15%
- Overhead and Profit: 20%
- Class 5 Contingency: -50% to +100%

The assumptions are that the facilities will be consistent with the 2050 Facility Plan and the BAFP. Purchasing renewable energy certificates (RECs) and renewable power purchasing agreements (PPA) were assumed to be not viable renewable energy approaches due to legal hurdles described by MMSD, stemming from the increased cost occurred to the taxpayers. These evaluations are based off 2018-2020 flow rates and loadings. The *Planning Report* that looks at district-wide facilities will incorporate both the existing conditions and future flows and loadings and recommendations for improvements.

4.2 Optimization of Energy Operating Strategy

This section describes operating strategies to maximize renewable energy consumption and minimize non-renewable energy consumption.

4.2.1 Engine Generators

SSWRF has four CAT engine generators, capable of using two fuel sources. The engine generator is rated for 925 kW utilizing DG, and 773 kW utilizing NG. There is one WS engine rated for 1,500 kW for both DG and NG. The engine generators have a total capacity of 5,200 kW when using DG. The engine generators supply electrical power to the 4.16 kilovolts (kV) power distribution system for peak shaving. The CAT engines were installed in 2009 and placed into operation in 2010 while the White Superior engine was placed into operation in 2000.

The waste heat from the engines is captured and is used to heat the facilities boiler loop, which heats digester sludge and building HVAC loads.

Electricity and waste heat generated by the engines when fueled from DG is considered renewable, while the electricity and waste heat generated by NG is considered non-renewable.

A simple levelized cost of energy (sLCOE) was developed using the National Renewable Energy Laboratory's Simple Levelized Cost of Energy Calculator to compare the cost of energy the turbines generate to grid purchased energy.[4] This analysis is for the CAT engines and shows the LCOE of the engines operating on digester gas, including gas compression, cleaning, and O&M. The following assumptions were made:

- A capital cost of $2,800/kW was utilized and was determined using manufacturer and DOE data for similarly sized engines (650 kW) and gas cleaning equipment (~1,000 SCFM system).
- The capacity factor was calculated using the average plant generated kWh per year, divided by the installed capacity. The average plant generated kWh from 2018 through 2021 is 18,787,897 kWh/yr. The installed capacity of the CAT engines is 27,085,920 kWh/yr. The resulting capacity factor is 69%
- The fixed O&M would include facility maintenance costs. For this analysis, the building costs were not included because future engines would be appropriately sized to fit in the same building, with minor changes. Therefore, this analysis used $0/kW-yr for the fixed O&M cost. Installation of new generators would have to be sequenced to minimize interruptions in operation.
- The variable O&M cost is the cost to maintain the engines as their O&M cost includes all costs associated with maintenance and overhauls, including labor, divided by the kWh of electricity generated. These values were determined utilizing the EPAs Catalog of CHP Technologies[5] The O&M costs for used is $0.02709/kWh. This value was adjusted to current day costs utilizing

[4] https://www.nrel.gov/analysis/tech-lcoe.html

[5] https://www.epa.gov/sites/default/files/2015-07/documents/catalog_of_chp_technologies_section_2._technology_characterization_-_reciprocating_internal_combustion_engines.pdf

inflation rates provided by the Consumer Price Index as the reference provided data in 2013 dollars.

- This cost was compared to actual CAT engine generator O&M data and electricity generation data (18,800,000 kWh/yr) provided by MMSD from 2010 – 2020. Average CAT engine generator O&M data for previous years was analyzed.
  - 10-year average: $368,000 or $0.196/kWh
  - 5-year average: $641,000 or $0.0341/kWh
  - 3-year average: $706,000 or $0.0376/kWh
- Considering the range of O&M and the increase in cost in recent years, the DOE number of $0.02709/kWh is appropriate.

- The heat rate was determined using data from the EPAs Catalog of CHP Technologies for similarly sized engines. For 650 kW engines, this value is 9896 BTU/kWh.
- The fuel cost is the operation and maintenance cost of conditioning the digester gas. This was determined using the EPAs project economics and financing for gas conditioning[6]. The fuel cost used is $2.11/MMBTU. This value was adjusted to current day costs utilizing inflation rates provided by the Consumer Price Index as the reference provided data in 2020 dollars.
- An analysis period of 20 years was utilized with a discount rate of 3.375%, consistent with the Biosolids Advanced Facility Plan. The capital recovery factor (CRF) is a calculation using the analysis period and the discount rate. The resulting CRF is approximately 7%.
- 0% inflation for utility purchased electricity and fuel costs over the 20-year period

Table 4-1: Engine sLCOE Analysis

Variable	Value
Analysis Period	20 years
Discount Rate	3.375%
Capital Recovery Factor	7%
Overnight Capital Cost	$2,800/kW
Fixed O&M Cost	$0/kW-yr
Capacity Factor	69%
Fuel Cost	$2.11/MMBTU

[6] https://www.epa.gov/system/files/documents/2021-07/pdh_chapter4.pdf

Variable	Value
Heat Rate	9,896 Btu/kWh
Variable O&M Cost	$0.02709/kWh
sLCOE	**$0.079/kWh**

Table 4-1 summarizes the sLCOE analysis and variables for the CAT engines, which is approximately $0.079/kWh. This $0.079/kWh is the cost breakeven point of generating electricity versus purchasing utility. This means that if the average total electricity cost from the utility is above 7.9 cents/kWh including electricity consumption and demand charges, it is more cost effective to run the engines on DG to generate electricity. If the utility electricity cost is below 7.9 cents/kWh, then it is more cost effective to purchase from the utility. This is an important factor when considering utilizing the engines for peak shaving.

Section 2.4 shows the proposed off-peak usage cost increasing to $0.059/kWh with on-peak increasing to $0.0929/kWh. When demand charges are included, it is expected for utility costs to be above the $0.079/kWh average total electricity cost. Therefore, it is recommended to operate the engines on DG whenever there is DG available and to maximize the renewable electricity generated.

A side benefit to operating the engines is the waste heat generated from the fuel is utilized in the boiler loop. Additional buildings or boiler loops can be added to utilize additional waste heat that may currently be lost due to heat exchanger inefficiencies or equipment down times.

4.2.2 Facility Electrification

Transitioning NG fired equipment and appliances to electric is important to meet MMSD's energy and greenhouse gas emission goals. NG is a finite resource with limited renewable alternatives and releases greenhouse gases. Renewable electricity is more readily available through the utility grid and DG can be used to offset non-renewable NG consumption. In general, MMSD's NG consumption is larger than its DG production. It could be beneficial to transition NG fired equipment to either DG or electrically powered equipment. This will be evaluated further in the *Planning Report* based on the recommended use for the DG.

The largest NG consumers at SSWRF are the engine generators, boilers and various air handling units with natural gas furnace sections. The engine generators are analyzed under **Section 4.3.2**.

SSWRF utilizes a hot water loop that is fed from either the boilers or the waste heat of the engines. This system can be transitioned to be fully electric by incorporating effluent heat recovery and water source heat pumps to generate hot water and will be discussed in more detail later in the report. The existing boilers could also be replaced with electric boilers.

Air source heat pumps, in conjunction with electric resistance coils, can replace NG fired or hot water coil air handlers. This would require all existing air handlers to be replaced and heat pumps be installed outdoors and likely also require electrical distribution system improvements.

Examples of buildings that can be transitioned away from NG fired boilers are Buildings 378 and 380. The heating systems in these buildings consist of NG fired boilers and a heating water loop that feeds various unit heaters and air handlers. The unit heaters are good candidates for electric resistance heating. The air handlers can be retrofitted or replaced with new equipment that heats using either electric resistance coils or an air source heat pump with electric resistance backup. Another option is to keep the existing hot water loop and replace the boiler with an electric resistance boiler. The most appropriate retrofit or replacement should be evaluated during the engineering phase of the building's HVAC renovation project.

- Building 380 is a relatively small water loop without cooling. Retrofitting this loop to be fueled from a water source heat pump that utilizes facility effluent is not recommended due to the complexity and large infrastructure required. Air source heat pumps and electrical resistance coil should be evaluated.
- Installation of a water source heat pump utilizing SSWRF effluent for Building 378's loop for heating and cooling loads should be evaluated and considered when the equipment is due for replacement. Additionally, the facilities main boiler loop may be transitioned to a heating only water source heat pump or electric resistance heating when that equipment is due for replacement.

Air and water source heat pumps generally have a positive return on investment when there are both heating and cooling load requirements for buildings. It is recommended they be incorporated when equipment is at the end of its useful life and up for replacement. It is estimated that heat pumps can reduce the heating energy consumption by about 20%. This number is conservative when considering the U.S. Department of Energy references that heat pumps can reduce energy consumption up to 50%.[7] A value of 20% was used because of Milwaukee's colder climate that would require auxiliary heating backup for very cold days. Heat pumps will generally have a lower coefficient of performance (COP) during colder weather. COP dictates how much efficiency the unit will gain versus standard electric resistive heating, with higher COPs being indicative of higher energy efficiency.

[7] https://www.energy.gov/energysaver/heat-pump-systems

4.2.2.1 Facility Metering

MMSD has prioritized metering MCCs and buildings, and this report recommends to continue the commitment to provide building level metering. Specific metering on process equipment such as pumps is also recommended.

4.2.3 Grid Renewable Energy Makeup

Table 4-2 shows We Energies overall power mix including renewable energy percentage. In 2021, 4.7% of We Energies energy was from renewable energy. The projected renewable energy percentage for 2022 is 6.2%[8].

Table 4-2: We Energies Overall Power Mix

Power Mix	2021 Actual	2022 Projected
Renewables	4.7%	6.2%
Coal	36.2%	30.8%
Natural Gas/Oil	28.5%	23.4%
Other	30.7%	39.5%
Total	100%	100%

WEC Energy Group, which owns We Energies, has committed to a 60% reduction in carbon emissions by 2025 and an 80% reduction by the end of 2030. The long-term target is net-zero carbon emissions by 2050.[9]

It is recommended to continue to monitor We Energies renewable energy generation and consider this when planning future renewable energy projects and accounting for renewable energy consumption.

[8] https://www.we-energies.com/services/eft
[9] https://www.wecenergygroup.com/csr/climate-report2021.pdf

4.3 Energy Generation

4.3.1 Existing Digester Gas Production

Historical DG production and consumption was analyzed from 2016 through August 2022 to review trends and utilize this data for planning purposes.

Figure 4-1 shows SSWRF's daily total digester gas use (Blue) and how much of that use is flaring (Orange). The difference of the use and flaring is the volume of gas beneficially utilized by equipment at SSWRF. The equipment consuming digester gas are the boilers and engines. The engines consist of CAT and WS engines.

The average total digester gas produced (var5003) is approximately 1.5 MMCF/day or 1,051 scfm. This is digester gas at about 60% methane (var6336).

For energy consumption purposes, the digester gas numbers have been converted to energy content using the 60% methane value. The resulting average digester gas produced is approximately 975 dth/day (975 MMBTU/day). Approximately 200 dth/day (200 MMBTU/day) of that is flared and 775 dth/day (775 MMBTU/day) is consumed by the boilers and engines. **Figure 4-2** shows the daily digester gas consumption by equipment.

On average from 2016 through August of 2022, the boilers consumed 110 dth/day of DG. The engines averaged 665 dth/day, 610 dth/day of which is consumed by the CATs while 55 dth/day is consumed by the WS engines. Recent trends show the WS engine operating more frequently than in the past, most likely due to CAT engines downtimes. **Section 2.3** shows there is not a significant difference in electrical generation efficiency between the engines to warrant an operational preference.

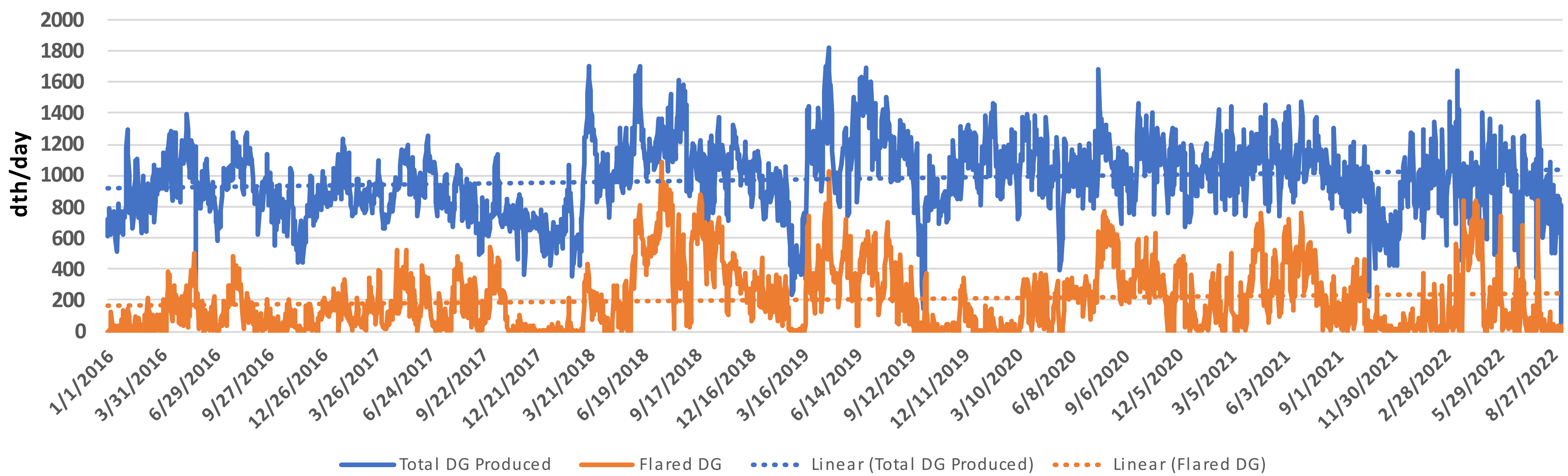

Figure 4-1: SSWRF Total Digester Gas Use and Flaring (100% Methane)

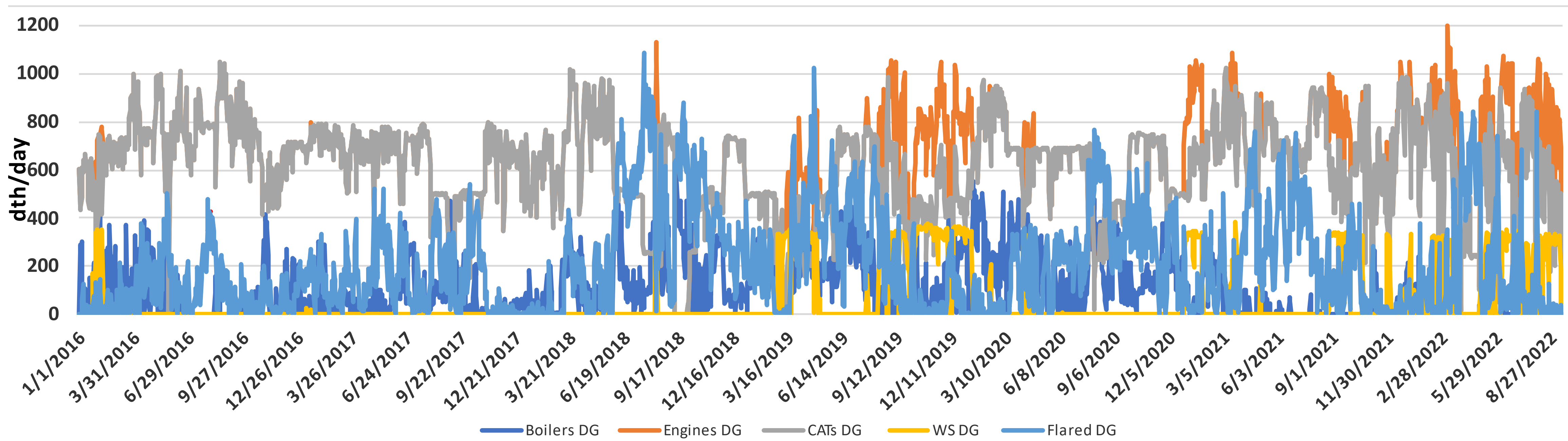

Figure 4-2: SSWRF Digester Gas Consumption by Equipment (100% Methane)

4.3.2 Digester Gas Energy Generation

Existing System – Digester Gas Usage

SSWRF has an existing engine generator system that operate using DG that is being produced from the anerobic digesters. There are four CAT engine generators rated for dual fuel source – DG 925 kW and NG 773 kW. The fifth engine generator is a WS and is rated for 1,500 kW for both DG and NG. Installed with the generators are gas compressors – rotary, positive displacement, water cooled units. These generators are located in Building 326. The engine generators supply electrical power to the 4.16 kV power distribution system for peak shaving. The CAT Engines were installed in 2009 and placed into operation in 2010 while the White Superior engine was placed into operation in 2000.

Electrical power distribution is not the only process to which the engine generators are related. Through cogeneration, the engine generators provide sludge heating and building heating. The waste heat at SSWRF is recovered from the generators and circulated through the plant's heat recovery loop to heat the digesters and several facility buildings. The heat recovery loop provides the primary cooling for the engine's jacket water.

The electrical energy output of the generators is only 30 to 40%. The rest of the energy output comes out as heat. The waste heat is beneficially used to heat buildings in the winter and to heat the digesters year-round.

Digester Gas Overview

SSWRF beneficially consumes approximately 286,000 MMBTU/yr of digester gas. The CAT Engine Generators use 201,000 MMBTU/yr, the WS Engine Generator uses 23,000 MMBTU/yr and the boiler's use 62,000 MMBTU/yr. 73,000 MMBTU/yr of DG is flared, bringing the total consumption to 359,000 MMBTU/yr.

The CAT engine generators consume approximately 9 MMBTU/hr of gas each. The 975 MMBTU/day of gas produced equates to about 40 MMBTU/hr. Therefore, there is enough gas on average for all four CAT engine generators to be operating at full load, with some additional gas available for the boiler or WS engine generator. There is not N+1 capacity if the engine generators are the only consumers of the DG.

Generator Overview – Digester Gas

There are different types of generators that operate off digester gas. The existing generators are reciprocating internal combustion engines and are common for CHP applications less than 5 MW. These units are good for hot water/low pressure steam applications. Gas turbines are generally used for applications greater than 4 MW and generate significant amounts of high-pressure steam that can be captured and used in processes or fed to a steam turbine to generate additional electricity. Microturbines are a type of gas turbine but are compact in size and can be installed in parallel to match the current size the CHP requires. They primarily generate electricity and hot water/low pressure steam. Microturbines are generally utilized where smaller electrical demand or fuel availability is limited. Microturbines installations can utilize multiple units to increase total capacity, however each unit is typically 200 kW or smaller.

Technology Evaluation

When considering CHP at a facility, the facilities thermal to power (T/P) ratio is a ratio that shows the amount of thermal energy demand versus electrical power demand and is a good indicator of what technology is preferable. Different generation equipment types have different electrical and thermal generation efficiencies and depending on what a facilities thermal and electrical demands are, certain technologies may be more favorable and efficient. **Table 4-3** lists the preferred generator type based on the facilities T/P Ratio[10].

Table 4-3: Generator T/P Ratio

T/P Ratio	Preferred Type
0.5 to 1.5	Engines
1 to 10	Gas Turbines
3 to 20	Steam Turbines

SSWRF on average consumes 129,500 MMBTU of heat in the main boiler loop, while consuming 155,000 MMBTU of electricity per year. This results in a T/P ratio of 0.84, which is within the engine generator range and is recommended to continue to be used.

Table 4-4 shows typical prime mover capacity ranges as summarized by the National Renewable Energy Laboratory (NREL)[11].

Table 4-4: Prime Mover Capacity Range

Prime Mover	Preferred Type
Microturbine	<300 kW
Fuel Cell	200 kW
Reciprocating Engine	<5 MW
Gas Turbine	>5 MW
Steam Turbine	>5 MW

10 https://www.energy.gov/sites/prod/files/2013/11/f4/webcast_2009-0514_chp_in_facilities.pdf
11 https://www.nrel.gov/docs/fy04osti/34783.pdf

SSWRF has an average hourly dry weather demand of 5.2 MW as discussed in **Section 2.2**. For redundancy and flexibility, this demand can be generated by multiple, appropriately sized reciprocating engines as reciprocating engines are typically 5 MW and less in size.

System Sizing

A CHP system operating on NG is sized based on thermal demand. The boiler loop yearly energy consumption is 129,500 MMBTU and the average thermal demand per hour is approximately 14.8 MMBTU/h. Reciprocating engines typically generate 3,500 btu/h per kW installed of recoverable useful heat. If the engine is sized to meet the thermal loads, this results in a system size of approximately 4,200 kW. This is less than SSWRF average dry weather demand of 5.4 MW as discussed in Section 2.2 and all electricity can be utilized. The existing CATs have an installed capacity of approximately 3,000 kW when operating on NG, and 3,700 kW when operating on DG. The size of the existing equipment appears to be similar to the optimal size based on this analysis.

Engines can also be sized based on DG availability. SSWRF averages 975 MMBTU/day or 40,600,000 btu/h (40,600 MBH) of DG. These numbers consider the heating value of the DG. The gas flow is equivalent to 650 scfm. The resulting nominal output of electricity generated from engines by this DG is 4,740 kW, slightly under the 5,200 kW total capacity of all the CATs and WS engines installed. The estimated thermal output is 155,900 MMBTU/yr, which is more than the boiler's 129,500 MMBTU/yr demand, meaning all boiler demand could be met from engine waste heat.

Recommendations

The existing engine generators are appropriate for SSWRFs electrical and thermal demands. They are sized appropriately for the facility's thermal demands and fuel availability. Gas cleaning is recommended for any DG combustion equipment as evaluated and recommended as discussed in Subtask B.5 of *Technical Memorandum 1 – Energy Review and Renewables*.

As the existing engines continue to age, it is recommended to replace them with newer engines capable of electrical efficiencies around 40%, while the existing engines have 34% nameplate electrical efficiencies.

A potential installation would be to install four Jenbacher J420 cogeneration engines to replace the CATs and WS engines. Each Jenbacher engine has a capacity of 1,400 kW. Four new engines have a total installed capacity of 5,600 kW. This maintains an N+1 configuration when the system is operated off of thermal demand, while also having enough capacity to burn all DG available and generate the maximum amount of electricity. These engines are approximately 41% efficient electrically with a potential total efficiency of 85% if all waste heat is used. Each engine is 280 x 75 x 110 inches in size and can likely be located in the existing Generator Building.

The upcoming *Planning Report* will include a District wide recommendation that discusses where and at what volume DG should be consumed. A recommendation for the resulting engine generator capacity at SSWRF to meet an N+1 installation for the DG allocation this equipment will be included.

Engineers Opinion of Probable Construction Cost

Engines costs approximately $2,970/kW per the DOE's Catalog of CHP technologies, including inflation[12]. This full project cost includes the generator, heat recovery, electrical interconnect, exhaust gas treatment system, labor, project, and construction management costs. Installing four of these engines would likely bring the cost per kW down, however a conservative estimate is four new 1,400 kW engines are estimated to cost $40,670,000.

Table 4-5: New Engine Generators Cost Summary

Description	Cost ($)
Demolition (5% of Engines)	$830,000
New Engines	$16,600,000
Electrical Modifications (10%)	$1,660,000
Installation and Labor (25%)	$4,150,000
Subtotal	$23,240,000
Description	**Cost ($)**
Overhead and Profit (20%)	$4,648,000
Contingency (40%)	$9,296,000
Design and Engineering Services (15%)	$3,486,000
Total	**$40,670,000**
AACE: -50%	$20,335,000
AACE: +100%	$81,340,000

Net Present Value Analysis of Existing CAT Engines Versus New Jenbacher Engines

New Jenbacher engine generators are approximately 7% more efficient than the existing CAT engine generators. A net present value (NPV) analysis of the existing CAT engines and new Jenbacher engines was performed to determine the 20-year present worth (PW) cost of existing engines and new engines. The O&M cost for the existing engines was sourced using plant data and was evaluated for the average

12 https://www.epa.gov/sites/default/files/2015-07/documents/catalog_of_chp_technologies_section_2._technology_characterization_-_reciprocating_internal_combustion_engines.pdf

O&M cost over the past 10 years and the past 3 years, as O&M costs have been increasing significantly for engines in recent years. **Table 4-6** summarized the NPV and PW evaluation for existing and new engines. Assumptions are listed below.

- New engines have 90% availability
- Existing CAT engines have 69% availability which was sourced from existing data
- New engine generators are 41% electrically efficient, while existing are 34%
  - Actual efficiencies observed for the CAT engine generators are between 28%-30% due to operational inefficiencies and partial loading. For this analysis, both existing and new engine generators are assumed to operate at rated full load efficiencies.
  - Existing CAT engine cut sheets show 36.2% nominal engine efficiency. The generator on the engine is 94.1% efficient, therefore the resulting electrical generation efficiency is 34% (36.2 x 94.1%).
- 975 MMBTU/day of biogas or 650 scfm @ 100% methane of fuel flow
- 0% inflation rate and a 3.375% discount rate

Table 4-6: Existing Versus New Engine NPV Analysis

	Existing CAT Engines	Existing CAT Engines	New Jenbacher Engines
	Existing O&M 10 yr avg ($368,000/Engine)	Existing O&M 3 yr avg ($706,000/Engine)	Estimated O&M
Capital Cost	$0	$0	$24,060,000
Annual O&M	$1,471,736	$2,825,668	$925,975
20 Year O&M PW Cost	$21,198,000	$40,700,000	$13,337,000
Subtotal 20 Year PW Cost	$21,198,000	$40,700,000	$37,397,000
Electricity Generated @ 650 SCFM (kWh/yr)	24,487,459	24,487,459	38,316,240
Additional Electricity Purchased (kWh/yr)	13,828,781	13,828,781	-
Additional Electricity Purchased @ $0.052/kWh	$719,097	$719,097	$0
Additional Electricity Purchased @ $0.10/kWh	$1,382,878	$1,382,878	$0

	Existing CAT Engines	Existing CAT Engines	New Jenbacher Engines
	Existing O&M 10 yr avg ($368,000/Engine)	Existing O&M 3 yr avg ($706,000/Engine)	Estimated O&M
20 Year PW Electricity Cost @ 0.052/kWh	$10,357,526	$10,357,526	$0
20 Year PW Electricity Cost @ 0.10/kWh	$19,918,319	$19,918,319	$0
Total PW Cost @ $0.052/kWh	$31,556,000	$51,058,000	$37,397,000
Total PW Cost @ $0.10/kWh	**$41,116,000**	**$60,618,000**	**$37,397,000**

The analysis shows that replacing the existing engines with new Jenbacher engines results in a PW cost of approximately $37,000,000. This is less that the PW cost of maintaining the existing CAT engines when the total value of electricity is both $0.052/kWh or $0.10/kWh and the average yearly O&M cost is $706,000/engine like it has the past 3 years. However, considering the average O&M cost of the CAT engines for the past 10 years of $368,000/engine, the PW cost for new Jenbacher engines is higher than the PW cost when considering electricity at $0.052/kWh, but is lower when considering the cost of electricity at $0.10/kWh.

Future Gas Generation after Planned Improvements
After the planned improvement projects are incorporated, SSWRF would be producing up to 473,880 MMBTU/yr of DG. This is equivalent to approximately 870 SCFM of digester gas. The resulting nominal output of electricity generated from engines by this DG is 6,350 kW. The estimated thermal output is approximately 208,650 MMBTU/yr, again exceeding the boiler's demand of 129,500 MMBTU/yr. The total installed engine capacity is 5,200 kW. Therefore, if all DG were to be beneficially utilized to generate electricity, additional generation capacity would be required. **Table 4-7** summarizes different CHP system capacities based on the available fuel flow. All numbers are DG @100% methane.

Table 4-7: CHP Capacities

DG SCFM	Electrical Output (kW)	Thermal Output (MMBTU/yr)
Existing 650	4,750	115,900
Baseline+ 870	6,350	208,650
HSW 1,180	8,600	283,000

The BAFP recommends a new drying facility at SSWRF that would be responsible for approximately 50% of MMSDs biosolids drying. If this project moves forward, it is recommended that the dryers are fueled by digester gas. This would change the future gas generation recommendation for electricity generation using digester gas. The *Draft Planning Report* will include a recommendation for process fuel optimization if a new D&D Facility is incorporated at SSWRF.

4.3.3 Digester Gas Production

The DG produced in the anaerobic digesters is being beneficially used already in the engine generators. To meet MMSD's energy goals, additional DG may need to be generated. This can be accomplished by bringing in high strength waste to utilize spare capacity in the anaerobic digesters.

4.3.3.1 High Strength Waste

SSWRF already accepts high strength waste in the anaerobic digesters, including fats, oils, and grease (FOG) and food waste. Using food waste as an example, the United States Environmental Protection Agency estimates that 220 pounds of food waste can be attributed to each person every year, including from homes, restaurants, and grocery stores. With 1.1 million people in the MMSD service area, that is equivalent to 242 million pounds of food waste annually or 660,000 pounds of food waste per day. Not all of that food waste is available, as some is being used composting programs, garbage disposals, and other beneficial reuses.

Table 4-8 provides the anaerobic digester capacity under existing and future conditions with planned improvements. The information is from the BAFP. The calculations assume that all existing anaerobic digesters and a single new acid phase digester is in operation. There is capacity in the anaerobic digesters that could be used to produce additional DG by bringing in more high strength waste.

Table 4-8 SSWRF Digester Capacity

Parameters	Unit	Existing Conditions	2045 Flow Conditions with Digester Improvements
Mesophilic Digester Capacity	MG	15.3	13.4
	CF	2,045,455	1,791,444
Acid Phase Digester Capacity	MG	N/A	0.9
	CF	N/A	120,321
JIWRF Primary Sludge	Lbs/day	72,000	N/A
SSWRF Primary Sludge	Lbs/day	111,000	N/A
Thickened WAS	Lbs/day	17,500	N/A
Total Sludge	Lbs/day	200,500	N/A
% Volatile Solids	%	77.4%	N/A
Sludge Volatile Solids	Lbs/day	155,187	286,000
Existing High Strength Waste	VS lbs/day	1,927	1,854
Total Volatile Solids	VS lbs/day	157,114	287,854
Mesophilic VS Loading Rate	Lbs VS/CF/day	0.12	0.12
Acid Phase VS Loading Rate	Lbs VS/CF/day	N/A	2.4

Based on this evaluation, there is capacity in the digesters based on the volatile solids loading. With the digester excess capacity determined, the amount of high strength waste that could be brought in was determined. The calculations evaluated bringing in food waste and FOG to determine which option has the potential to produce more DG. Both food waste and FOG could be mixed at different levels as they are available. Food waste contains protein, which when digested produces alkalinity in the digester. The same concept applies to wastewater sludge, and is the reason that digesters are well buffered at a near neutral pH. FOG is essentially composed of lipids and does not produce any alkalinity when digested. Therefore, the ratio of FOG to wastewater solids must be limited to prevent a pH drop in the digester. A fairly typical and conservative guidance on this ratio is approximately 20%. It is possible that a higher ratio of FOG to sludge may be sustainable for a digester, depending on the characteristics of the raw sludge feed, but it would likely require piloting to reliably recommend a ratio greater than 20%.

Table 4-9 and **Table 4-10** provide the potential gas production under existing and after the digester improvements have been made with future flows (Year 2045) with food waste or FOG if all available digester capacity was used.

Table 4-9 Gas Production (Existing Conditions with Primary Clarifier Improvements)

Plant Data		
Influent Flow	MGD	96.95
Digester Gas Flow	CFD	1,840,763
Sludge Feed to Digesters		
Thickened Waste Activated Sludge (TWAS)	GPD	52,458
	Lbs/Day	17,500
	Lbd VS	13,545
	%TS	4.0%
	VS/TS	77.4%
Thickened Primary Sludge (TPS)	GPD	685,701
	Lbs/Day	183,000
	Lbd VS	141,642
	%TS	3.2%
	VS/TS	77.4%
Existing High Strength Waste	GPD	6,579
	Lbs/Day	3,396
	Lbd VS/Day	1,927
	%TS	5.5%
	VS/TS	56.7%
Blended Digester Feed (TWAS + TPS + HSW)	GPD	744,739
	Lbs/Day	203,896
	Lbd VS/Day	157,114
	%TS	3.3%
	VS/TS	77.2%
Digestion System Digester Parameters		
Total Digester Volume	Ft^3	2,045,455
	Gallons	15,300,000
Design VSLR	Lbd/Ft^3	0.12
Maximum VSLR	Lbd/Ft^3	0.2
Minimum SRT	Days	15
Design VS Loading Capacity	Lbd VS/Day	245,455

Maximum VS Loading Capacity	Lbd VS/Day	409,091
Excess Digester Capacity (for Food Waste)		
Slurried Food Waste Characteristics	%TS	10
	VS/TS	0.94
Excess Volatile Solids Loading Rate Capacity (Design)	Dry Lbd VS/Day	88,341
Excess Volatile Solids Loading Rate Capacity (Maximum)	Dry Lbd VS/Day	251,977
Excess Digester Capacity (for FOG)		
FOG Characteristics	%TS	10
	VS/TS	0.95
Excess Volatile Solids Loading Rate Capacity (Design)	Dry Lbd VS/Day	88,341
Excess Volatile Solids Loading Rate Capacity (Maximum)	Dry Lbd VS/Day	251,977
Practical Volatile Solids Loading Capacity (20% of Sludge VSLR)	Dry Lbd VS/Day	31,423
Additional COD Loading and Biogas Production Potential – Food Waste		
Additional VS Loading	Lbd	88,341
Expected VSR	%	85
Volatiles Destroyed	Lbd	75,090
Specific Biogas Production Rate	Ft^3/Lb VSR	16
Excess Biogas Production	CFD	1,201,433
% Increase in Biogas Production	%	65%
Assumed Decrease Due to New Electrical Loads	%	25%
Net Excess Biogas Production	CFD	741,243
Net Increase in Biogas Production	%	40%
Additional COD Loading and Biogas Production Potential – FOG		
Additional VS Loading	Lbd	31,423
Expected VSR	%	85%
Volatiles Destroyed	Lbd	26,709
Specific Biogas Production Rate	Ft^3/Lb VSR	16
Excess Biogas Production	CFD	427,350
% Increase in Biogas Production	%	23%
Assumed Decrease Due to New Electrical Loads	%	25%
Net Excess Biogas Production	CFD	-32,841
Net Increase in Biogas Production	%	-2%

Table 4-10 Gas Production (2045 Conditions with Digester Improvements)

Plant Data		
Influent Flow	MGD	96.95
Digester Gas Flow	CFD	2,700,000
Sludge Feed to Digesters		
Existing High Strength Waste	GPD	6,503
	Lbs/Day	3,294
	Lbd VS/Day	1,854
	%TS	5.4%
	VS/TS	56.3%
Blended Digester Feed (TWAS + TPS + HSW)	GPD	899,281
	Lbs/Day	452,918
	Lbd VS/Day	287,854
	%TS	6.0%
	VS/TS	63.6%
Digestion System Digester Parameters		
Total Digester Volume (Mesophilic)	Ft^3	1,791,444
	Gallons	13,400,000
Total Digester Volume (Acid-Phase)	Ft^3	120,321
	Gallons	900,000
Design VSLR (Mesophilic)	Lbd/Ft^3	0.12
Design VSLR (Acid-Phase)	Lbd/Ft^3	2.4
Maximum VSLR	Lbd/Ft^3	0.2
Minimum SRT	Days	15
Design VS Loading Capacity	Lbd VS/Day	503,743
Maximum VS Loading Capacity	Lbd VS/Day	647,059
Excess Digester Capacity (for Food Waste)		
Slurried Food Waste Characteristics	%TS	10
	VS/TS	0.94
Excess Volatile Solids Loading Rate Capacity (Design)	Dry Lbd VS/Day	215,889
Excess Volatile Solids Loading Rate Capacity (Maximum)	Dry Lbd VS/Day	359,204

Excess Digester Capacity (for FOG)		
FOG Characteristics	%TS	10
	VS/TS	0.95
Excess Volatile Solids Loading Rate Capacity (Design)	Dry Lbd VS/Day	215,889
Excess Volatile Solids Loading Rate Capacity (Maximum)	Dry Lbd VS/Day	359,204
Practical Volatile Solids Loading Capacity (20% of Sludge VSLR)	Dry Lbd VS/Day	57,571
Additional COD Loading and Biogas Production Potential – Food Waste		
Additional VS Loading	Lbd	215,889
Expected VSR	%	85
Volatiles Destroyed	Lbd	183,506
Specific Biogas Production Rate	Ft^3/Lb VSR	16
Excess Biogas Production	CFD	2,936,089
% Increase in Biogas Production	%	109%
Assumed Decrease Due to New Electrical Loads	%	25%
Net Excess Biogas Production	CFD	2,261,089
Net Increase in Biogas Production	%	84%
Additional COD Loading and Biogas Production Potential – FOG		
Additional VS Loading	Lbd	57,571
Expected VSR	%	85%
Volatiles Destroyed	Lbd	48,935
Specific Biogas Production Rate	Ft^3/Lb VSR	16
Excess Biogas Production	CFD	782,964
% Increase in Biogas Production	%	29%
Assumed Decrease Due to New Electrical Loads	%	25%
Net Excess Biogas Production	CFD	107,964
Net Increase in Biogas Production	%	4%

Table 4-11 provides a summary comparison of the amount of DG for food waste and FOG for existing and future conditions, assuming all available digester capacity is used.

Table 4-11 Biogas Production Comparison

Parameters	Unit	Existing Conditions with Primary Clarifier Upgrade	2045 Flow Conditions with Digester Improvements
Food Waste			
Excess Biogas Production	CFD	741,243	2,261,089
Increase in Biogas Production	%	40%	84%
FOG			
Excess Biogas Production	CFD	-32,841	107,964
Increase in Biogas Production	%	-2%	4%

Additional engine generator capacity would need to be provided if the DG was to be turned into electricity or the DG could be used for the dryers in the future D&D Facility at SSWRF. In addition, a new high strength waste receiving station would be required. Typical receiving stations at other water reclamation facilities include the following at their receiving stations:

- Truck unloading and slurry tanks
- Non-potable water supply to reduce waste viscosity if needed
- Grinding system to remove larger debris
- Paddle finisher to remove grit and fibrous material
- Storage and equalization tanks
- Pumping and conveyance systems
- Odor control system

A conceptual level size of the building is approximately 40,000 square feet and conceptual costs are included in **Table 4-12** below.

Further evaluation and study would need to be completed to determine availability of high strength waste and characteristics of food waste and FOG to determine the viability in the digesters. Essential food waste characteristics include:

- Solids Content
- Nutrient Content (Nitrogen and Phosphorus)
- Organic Strength (Chemical Oxygen Demand)

- Total Sulfur
- Gross Composition (Crude Protein, Fiber, etc.)

Table 4-12 High Strength Waste Cost Estimate

Parameters	Unit
40,000 SF Building at $250/SF	$10,000,000
Equipment (Receiving and Slurry Tanks, Grinder, Paddle Finisher, Conveyance, Pumps)	$10,000,000
Site Work (20% of Building Cost)	$2,000,000
Installation and Labor	$11,000,000
Subtotal	$33,000,000
Overhead & Profit (20%)	$6,600,000
Contingency (40%)	$13,200,000
Design and Engineering Services (15%)	$4,950,000
Total	**$57,750,000**
AACE: -50%	$28,875,000
AACE: +100%	$115,500,000

4.3.3.2 Thermal Hydrolysis

The thermal hydrolysis process (THP) is the process of exposing sludge or other organic material to high pressures and temperatures. The process has been used successfully to increase digester gas production, dewaterability of digested sludge, and increase digester capacity. THP was evaluated as part of the BAFP but was not recommended.

THP was evaluated as part of this report to determine if additional DG could be generated to produce more energy. THP was evaluated in coordination with Cambi, a THP manufacturer. It was determined that a THP system at SSWRF would not increase DG significantly because most of the solids entering the digesters are from primary sludge, which already digests easily. THP is beneficial in increasing DG production when WAS is used. With the energy required to operate THP, it is not recommended.

While a THP system at SSWRF does not increase DG production significantly, the ability to improve biosolids dewaterability prior to drying could decrease overall energy usage for the D&D Facility, either at JIWRF or SSWRF. This will be evaluated further as part of the *Planning Report*.

4.3.4 Future Energy Generation

Future Gas Energy Generation after Recommended Alternatives

As Section 4.3.3.1 shows, an additional 741,243 cf/d can be generated by incorporating a food waste program. After assuming a 60% methane content, this equates to 310 SCFM or 168,420 MMBTU/yr of additional digester gas. The new total 1,180 SCFM of DG equates to an engine nominal output of 8,600 kW, and a thermal output of 283,000 MMBTU/yr.

4.3.5 Excess Scum

Scum is collected from the primary and secondary clarifiers at SSWRF and concentrated before being disposed off-site. Most water reclamation facilities send their collected scum to landfills or pump it to the digesters for removal. Research is ongoing for different processes to capture the potential energy in scum. The most promising research is from the University of Minnesota, where pilot testing showed about 70% of the collected scum could be converted to a biodiesel.[13] The system, while showing promise, has not been tested at a large scale or commercialized yet. It is recommended to monitor this research further but no assumption will be made for new energy generated.

4.3.6 Pyrolysis of Digested Sludge to Produce Synthetic Gas and Biochar

Pyrolysis is an alternative for disposal of digested sludge that is not sent to the JIWRF D&D Facility. Approximately 11,000 lbs/day of digested sludge are dewatered to produce about 2,000 lbs/day of cake at 25% solids. Pyrolysis has been evaluated and recommended in the BAFP as means of disposal for biosolids during Phase 5 as part of the adaptive implementation pathway in the event that regulatory changes prohibit the production of Milorganite™. It is recommended that a detailed review and pilot study be completed if pyrolysis is going to be installed. Considerations to be evaluated further include:

- The effects of pyrolysis on energy, including the production of excess heat
- Confirmation that all regulatory requirements will be met
- Understanding the feed material and cake being fed into pyrolysis
- Dewatering upstream of pyrolysis
- Characteristics of biochar
- Potential uses of biochar
- Air pollution emissions and potential control strategies

[13] https://www.cleanenergyresourceteams.org/u-m-researchers-turning-wastewater-scum-profitable-biofuels

- Optimizing excess energy
- If drying facilities are still in use, will the excess heat and energy generated from pyrolysis be compatible with drying facilities?

Pyrolysis can be defined as the thermal decomposition of biosolids with the use of heat and without any addition of extra oxygen. This process produces synthetic gas (syngas) and biochar. Syngas is a fuel gas mixture which is combustible and can be used as an energy source of internal combustion engines. The pyrolysis system can utilize the heat generated by the syngas oxidation to sustain its own process without any external energy. Pyrolysis of biosolids is in the early stages of development for water reclamation facilities.

The evaluation of pyrolysis at SSWRF included coordination with two manufacturers of pyrolysis systems, Kore Infrastructure and Bioforcetech.

- Kore has a full-scale facility in operation in Los Angeles County that accepts organic waste, including biosolids.
    - Kore’s smallest unit is 25 tons per day. As SSWRF produces only about 1 ton per day of excess biosolids, this unit is not feasible.
    - Per Kore, at 25 tons per day, up to one megawatt of energy could be produced, minus about 30% to operate the pyrolysis process. This is depending on the type of organic material being fed into the system.
- Bioforcetech is another manufacturer of pyrolysis equipment. They have implemented pyrolysis systems in the United States in California (Silicon Valley Clean Water and City of Redding) and Pennsylvania (Ephrata Borough Authority). They do offer equipment sized for the excess biosolids at SSWRF. The pyrolysis system would be self-sufficient from an energy standpoint once startup is complete. The process would generate waste heat that could be used elsewhere. The system would not generate excess amounts of syngas that could be used.
    - The addition of ash from sludge incineration would not increase the syngas amount.

There are benefits to utilizing a pyrolysis process to dispose of biosolids, including the biochar end product and carbon sequestration. Thermal energy through waste heat can be used for other processes. For a system this size, syngas production that could be used as a fuel source for engines is not feasible.

4.3.7 Algae and Biofuel

Algae can be used during the wastewater treatment process to remove nutrients from plant effluent, specifically nitrogen and phosphorus. Typical algae systems can include a raceway pond or a photobioreactor, which is a system that can be used to cultivate algae using light, in which algae in suspension is pumped through pipes. In addition to treating effluent water, the algae can be harvested to produce algal biodiesel.

Laboratory experiments have proved that the oil content per ton of dry biomass of algae (*Chlorella vulgaris*) grown in ideal conditions are 46%, even higher than the rapeseed oil content of 40%.[14] This type of system would require artificial lighting in the winter months and would not produce sufficient amounts of algal biodiesel to be energy positive.

An alternative system that was evaluated is a revolving algae biofilm (RAB) system developed by Gross-Wen Technologies (GWT). In this process, sidestream flows (centrate and filtrate) instead of final effluent would be used. This technology would be used in lieu of other sidestream treatment discussed in **Section 4.4.1.2.1**.

Algae is grown on a vertical belt, rotating through the wastewater and removing nitrogen and phosphorus. Carbon dioxide is consumed by the algae and oxygen is generated by the algae. The RAB system has a low energy input, utilizing a single 5 HP motor to turn the belt. There is a prime opportunity here to reduce the carbon footprint. The nature of algae itself is beneficial for reducing carbon emissions, as algae takes in carbon dioxide and produces oxygen. The algae acts as a carbon sequester and for every one ton of algae produced, approximately two tons of carbon dioxide are removed from the atmosphere. Nitrous oxide emissions are avoided by removing nitrogen through assimilation. GWT has facilities in Iowa with similar latitudes as Milwaukee that operate successfully.

Algae can be harvested and sold as a fertilizer, with characteristics similar to Milorganite™, or pumped to the digesters to increase DG production. There is potential to generate biodiesel, but the process is still being researched and commercialized.

GWT provided a conceptual size and cost. The RAB system is modular and has flexibility to be constructed into the space that is available. The RAB system to treat 0.25 MGD with an ammonia concentration of 800 mg/L would be sized for approximately 10,000 square feet. **Table 4-13** shows the PV cost summary.

Table 4-13: RAB Cost Summary

Description	Cost ($)
RAB Capital Cost	$6,019,000
Site Work and Piping (25%)	$1,505,000
Electrical (5%)	$301,000

[14] Stuart A Scott, Matthew P Davey, John S Dennis, Irmtraud Horst, Christopher J Howe, David J Lea-Smith, Alison G Smith, **Biodiesel from algae: challenges and prospects**, Current Opinion in Biotechnology, Volume 21, Issue 3, 2010, Pages 277-286, ISSN 0958-1669, https://doi.org/10.1016/j.copbio.2010.03.005.

Description	Cost ($)
Overhead and Profit (20%)	$1,204,000
Contingency (40%)	$2,408,000
Design and Engineering Services (15%)	$903,000
Total	**$12,340,000**
AACE: -50%	$6,170,000
AACE: +100%	$24,680,000

4.3.8 Photovoltaics

Solar photovoltaic (PV) panels can directly generate renewable electricity for consumption. The larger the area, the more electricity that can be generated.

To maximize PV electricity generation, all potential areas at SSWRF were evaluated. These include the area above buildings, primary and secondary clarifiers, aeration basins, chlorine contact basins, digesters, sludge lagoon, and vacant areas. The potential areas included for evaluation are shown in **Figure 4-3** and **Figure 4-4** and the available area for each is summarized in **Table 4-14** below.

Table 4-14: PV Area Summary

Location	Area (ft^2)	kWh/yr
Primary Clarifiers	108,800	2,052,000
Secondary Clarifiers	317,400	5,987,000
Aeration Basins	320,400	6,042,000
Chlorine Contact Basin	71,250	1,344,000
Sludge Lagoon	263,500	4,970,000
Anaerobic Digesters	148,000	2,791,000
Buildings	107,300	2,022,000
Vacant Areas	1,174,350	22,147,000
Total	2,511,000	47,355,000

Figure 4-3: Potential PV Locations (North)

Figure 4-4: Potential PV Locations (South)

Utilizing PV Watts for this available land area results in a 35,086 kW sized PV system, producing 47,335,000 kWh/yr (161,500 MMBTU/yr).[15] Note that this number does not take into account shadows or obstructions and is an estimate of the total generation capacity.

Engineers Opinion of Probable Construction Cost

The cost of PV panels has continued to decrease as they become more prevalent. Using a cost of $2.1/W, the cost to install a system of this size is approximately $110 million. This cost includes all hardware, labor, interconnect, and soft costs. Due to the complexity of installing the panels at the locations evaluated, including building support structures for them, it is estimated to increase the cost to $132.5 million[16]. **Table 4-15** shows the PV cost summary.

Table 4-15: PV Cost Summary

Description	Cost ($)
Capital Cost	$98,000,000
Overhead and Profit (20%)	$19,600,000
Contingency (40%)	$39,200,000
Design and Engineering Services (15%)	$14,700,000
Total	**$171,500,000**
AACE: -50%	$85,750,000
AACE: +100%	$343,000,000

The yearly O&M cost for a 35,086 kW PV system is estimated to be $17/kW according to an NREL report "PV O&M Cost Model and Cost Reduction"[17]. Considering a 35,086 KW system, this results in a yearly O&M cost of $596,500.

The electricity savings totals $2,462,460/yr considering a cost of electricity of $0.052/kWh. The resulting years to pay off the system is 49 years, which would exceed the life expectancy of the system.

The electricity savings totals $4,735,500/yr considering a cost of electricity of $0.10/kWh. The resulting years to pay off the system is 22 years, which is about the life expectancy of the system.

[15] https://pvwatts.nrel.gov/pvwatts.php
[16] https://www.nrel.gov/docs/fy19osti/72399.pdf
[17] https://www.nrel.gov/docs/fy17osti/68023.pdf

Battery storage was not included in the analysis, however they cost approximately $350/kWh of installed battery[18]. Required durations for power discharge that size battery systems will have to be a part of a specific PV design and study.

Simplified LCOE Analysis

Table 4-16: PV sLCOE Analysis

Variable	Value
Analysis Period	20 years
Discount Rate	3.375%
Capital Recovery Factor	7%
Overnight Capital Cost	$2,100/kW
Fixed O&M Cost	$20/kW-yr
Capacity Factor	15.4%
Fuel Cost	$0/MMBTU
Heat Rate	0 Btu/kWh
Variable O&M Cost	$0/kWh
sLCOE	**$0.123/kWh**

Table 4-16 summarizes the sLCOE analysis and variables for a PV system, which is approximately $0.123/kWh. This results in a utility electricity price breakeven point of $0.123/kWh. This means that if the average total electricity cost from the utility is above 12.3 cents/kWh including electricity consumption and demand charges, it is more cost effective to install PVs to generate electricity. If the average total utility electricity cost is below 12.3 cents/kWh, then it is more cost effective to purchase from the utility. This is an important factor when considering installation of photovoltaics.

Recommendations

The number, size, and potential locations of PV panels will be evaluated further in the *Planning Report* as a MMSD-wide review of energy usage and energy generation capacity to meet MMSD's goals.

[18] https://www.nrel.gov/docs/fy21osti/79236.pdf

4.3.8.1 Electricity Consumption and Generation Analysis for PV Sizing

An analysis was performed reviewing CHP energy generation, digester gas availability, and utility purchased energy, to visualize points where all available digester gas would be utilized to generate electricity and SSWRF still purchases electricity from the utility. **Figure 4-5** plots purchased electricity (Orange) against generated electricity (x-axis). The goal is to replace this purchased electricity with renewable energy, such a photovoltaics. Also overlayed the flared gas kilowatt equivalent (kWe) (Blue) against generated electricity (x-axis) when it was flared. Additional assumptions are listed below.

- No electricity exporting (actual total consumption confines the max)
- Perfect consumption of DG, with the same CHP efficiency
- No limit on CHP capacity of reliability
- No electricity production from NG

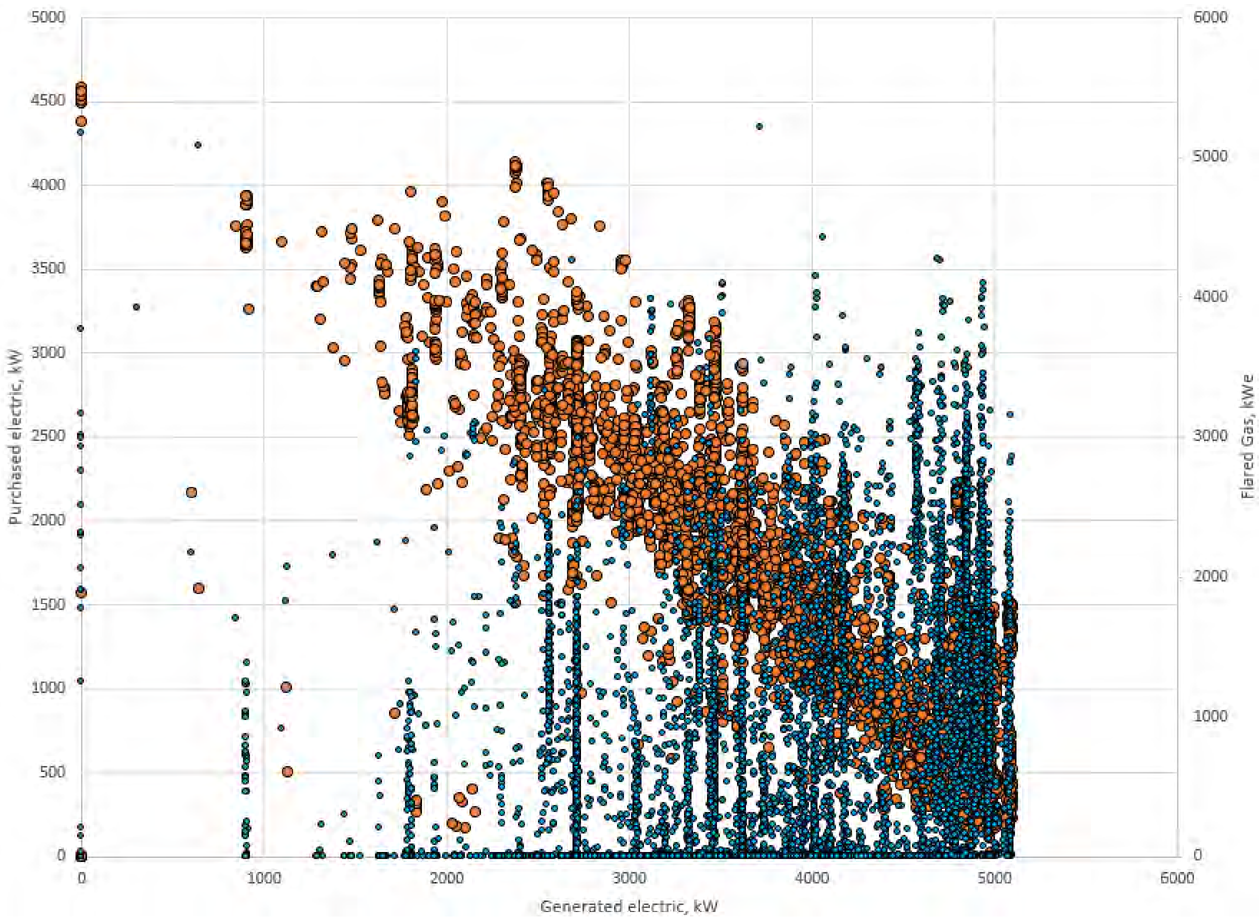

Figure 4-5: SSWRF Electricity Consumption and Generation Analysis

The blue dots represent 181,407 kWh/yr of flared gas, which would be a 97% reduction from the 2021 value of 7,883,723 kWh/yr under the assumptions listed. The orange dots represent 15,059,751 kWh of purchased electricity that can be generated by another renewable source. The peak estimated purchased electricity was 4,832 kW, with an average of 1,800 kW.

A 11,500 kW PV system would generate 15,522,824 kWh per year, or 1,772 kW average. Utilizing the same \$2.1/W, an 11,500 kW PV system would cost \$24,150,000. Installation area of 6.875 m^2 per kW rated results in an area requirement of 79,000 m^2 (850,000 SF or 20 acres). For reference, **Figure 4-6** shows what this area looks like at SSWRF.

Figure 4-6: 11,500 kW PV System Size

4.3.9 Wind

A wind energy site assessment was prepared for MMSD by Kettle View Renewable Energy in 2008. The study considered 4 small wind turbines of approximately 0.1 MW each. Wind turbines this size would not significantly affect SSWRFs electrical energy consumption. Due to the increasing prevalence and decreasing cost of wind turbine installation, this Memo evaluated installing larger 2.4 MW turbines at SSWRF.

Each 2.4 MW turbine would require approximately 3.7 acres of land for installation.[19] The GE 2 MW-127 turbine was used as a representative size for the footprint for this analysis.[20] This turbine is approximately 300 feet tall with a rotor diameter of 380 feet (190 feet radius), that results in the lowest blade tip being about 100 feet above ground while rotating. **Figure 4-7** and **Figure 4-8** and show potential turbine locations at SSWRF. It should be noted that these are conceptual preliminary planning locations evaluated for best possible electricity generation at SSWRF. All locations would have to be reviewed, including by structural and geotechnical engineers for feasibility.

Assuming a capacity factor of 41%[21], twelve (12) 2.4 MW turbines would generate an average of 11.8 MW of electricity. Extrapolating the average generation over a year result in 103,438,080 kWh/yr (352,950 MMBTU/yr) of electricity.

Engineers Opinion of Probable Construction Cost

A typical wind turbine installation of this size would cost around $1470/kW rated[22]. This is the installed project cost including equipment, electrical, and labor. Twelve installations at this rate amounts to approximately $45,000,000. However, due to the complexity and deep foundational requirements, the capital cost is estimated to be about double that at $85,000,000. **Table 4-17** shows the cost breakdown for wind turbines.

Table 4-17: Wind Cost Summary

Description	Cost ($)
Capital Cost	$85,000,000
Overhead and Profit (20%)	$17,000,000
Contingency (40%)	$34,000,000
Design and Engineering Services (15%)	$12,750,000
Total	**$148,750,000**
AACE: -50%	$74,375,000
AACE: +100%	$297,500,000

[19] https://www.nrel.gov/docs/fy09osti/45834.pdf
[20] https://www.ge.com/renewableenergy/sites/default/files/related_documents/ge-2mw-onshore-wind-turbine-platform.pdf
[21] https://css.umich.edu/publications/factsheets/energy/wind-energy-factsheet
[22] https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Wind%20Technologies%20Market%20Report%20FINAL.pdf

The yearly O&M cost for a wind system is anticipated to be between $33/kW and $59/kW due to a large number of variables that impact the system. The yearly cost will be estimated to be $44/kW based on a recommendation from the U.S. Department of Energy report "Wind Technologies Market Report"[23]. Considering a 35,086 KW system, this results in a yearly O&M cost of $1,267,200.

At $0.052/kWh, the value of electricity generated is $5,378,780/yr. The resulting simple payback not including O&M costs is 27.7 years.

At $0.10/kWh, the value of electricity generated is $10,343,808/yr. The resulting simple payback not including O&M costs is 14.4 years.

Figure 4-7: Potential Wind Turbine Locations (North)

23 https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Wind%20Technologies%20Market%20Report%20FINAL.pdf

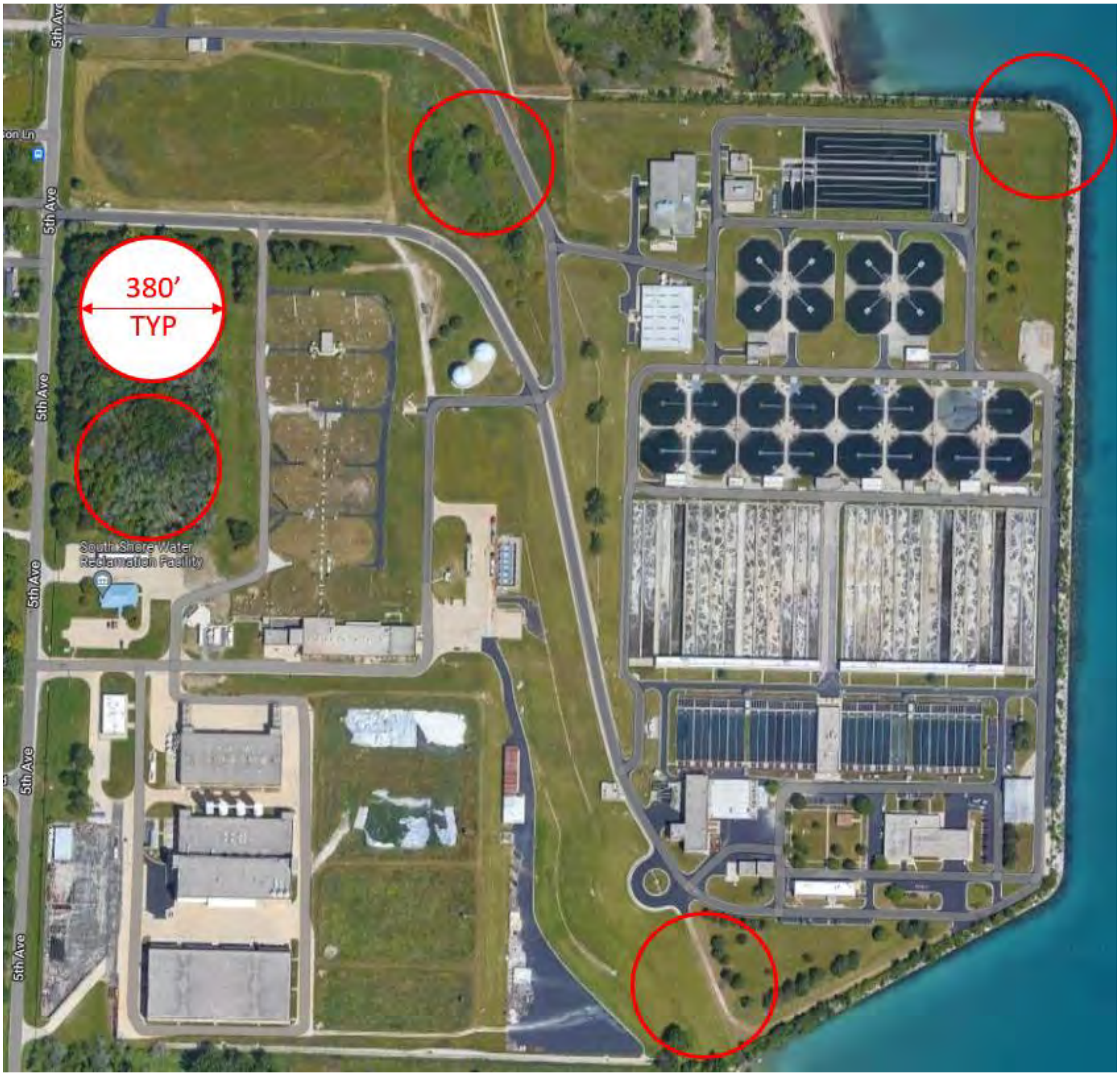

Figure 4-8: Potential Wind Turbine Locations (South)

Simplified LCOE Analysis

Table 4-18: Wind sLCOE Analysis

Variable	Value
Analysis Period	20 years
Discount Rate	3.375%
Capital Recovery Factor	7%
Overnight Capital Cost	$1,470/kW
Fixed O&M Cost	$29/kW-yr
Capacity Factor	36.0%
Fuel Cost	$0/MMBTU
Heat Rate	0 Btu/kWh
Variable O&M Cost	$0/kWh
sLCOE	**$0.042/kWh**

Table 4-18 summarizes the sLCOE analysis and variables for wind turbines, which is approximately $0.042/kWh. This results in a cost breakeven point of generating electricity versus purchasing electricity of $0.042/kWh. This means that if the average total electricity cost from the utility is above 4.2 cents/kWh including electricity consumption and demand charges, it is more cost effective to install wind turbines to generate electricity. If the average total utility electricity cost is below 4.2 cents/kWh, then it is more cost effective to purchase from the utility. This is an important factor when considering installation of wind turbines.

Recommendations
The number, size, and potential locations of wind turbines will be evaluated in the *Planning Report* as a MMSD-wide review of energy usage and energy generation capacity to meet MMSD's goals.

4.3.9.1 Wind Turbine Local Ordinances, Regulations, and Codes

Wind turbine installations are referenced by the Wisconsin State Legislature Public Service Commission (PSC), Chapter PSC 128.[24] The chapter states that installations with a maximum generating capacity less than 100 MW, regulatory authority resides with the local governmental unit where the project is located. PSC 128 establishes the formal process that all local governments must abide by when reviewing permit applications for wind energy projects under 100 MW. The rule also set standards that local governments may apply to the placement of wind turbines as well as their construction and operation. Local governmental units have the option of adopting, for example, setback distances that are less stringent than the baseline standards in PSC 128. However, they may not impose standards that are more stringent than those specified in that rule.[25]

Under the current rules, a local government may require a large wind turbine to be set back to 1,250 feet from a neighboring residence, if that neighbor is not also a wind turbine host. For sound, the maximum thresholds that a local government may set are 50 decibels (dBA) during the day and 45 dBA at night. For shadow flicker, a local government may prohibit a large wind turbine from producing shadow flicker more than 30 hours per year and may require a wind turbine owner to mitigate shadow flicker that occurs more than 20 hours per year. Neighbors are allowed to waive these standards under a written contract. If a wind farm developer has filed an application to build a wind project, a local governmental unit has 90 days from the date of the application to adopt a wind energy ordinance and an additional 90 days to review and approve the proposed project. [26]

Finally, the Federal Aviation Administration (FAA) also requires a notice to be submitted at least 45 days before the start of the proposed construction for an obstruction evaluation or an airports airspace analysis be performed. The Code of Federal Regulations (CFR) CFR 14 Part 77.9 defines the rules for filing a structure in the National Airspace.[27]

4.3.10 Effluent Heat Recovery

Heat can be recovered from the plant effluent water by utilizing water source heat pumps. The heat pump withdrawal would take the water from the Effluent Channel and heat a circulating water loop that could serve for heating the anaerobic digesters. Effluent temperatures at SSWRF are above 60 degrees Fahrenheit throughout the year, presenting adequate temperatures for heat pump operation for water-to-water type.

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[24] https://docs.legis.wisconsin.gov/code/admin_code/psc/128
[25] https://www.renewwisconsin.org/wind-farms/
[26] https://www.renewwisconsin.org/wind-farms/
[27] https://oeaaa.faa.gov/oeaaa/oe3a/main/#/noticePrescreen

The hot water loop at SSWRF is designed for 160 F to 170 F water. A water-to-water heat exchanger water temperature is limited to about 110 F greater than the effluent water temperature. This means that the heat recovery system in conjunction with a heat pump would be able to generate approximately 170 F to 180 F for the hot water temperature, which would meet the existing design conditions.

Modifications to the existing infrastructure are required and summarized below:

- Heat exchanger and heat pumps to be installed at the final effluent conduit.
- A water pump to circulate the water taken from the final effluent conduit is required, along with insulated pipe to convey the hot water to a connection to the existing hot water system connection or another desired location.

Heat Recovery

The Hot Water System provides cooling water for the generator engine jacket water recovery heat exchangers. The hot water system transfer heat generated in these areas to the sludge in the anaerobic digesters through the spiral sludge heat exchangers and to several buildings through forced air heating units or convection fin-tube devices.

Each heat exchanger is in the digester gallery next to each respective recirculation pump. The heat exchanger is designed to raise the inlet temperature of the sludge (90° F) to an outlet temperature of 100° F at a rate of 210 gpm for Digesters 1 and 2,550 gpm for Digesters 3 through 8, and 600 gpm for Digesters 9 through 12. In transferring this amount of heat through the sludge, the heat exchanger will utilize hot water with an inlet temperature of 140° F. The heat exchangers have a capacity of 2,500,000 Btu per hour for Digesters 1 through 8 and 2,800,000 Btu per hour per heat exchanger for Digesters 9 through 12.

Boiler system

The total boiler loop energy consumption is approximately 129,500 MMBTU per year. The boiler's NG consumption accounts for 13,500 MMBTU of this consumption, while DG accounts for 62,000. The boiler loop also receives waste heat from the engines, which is accounts for 54,000 MMBTUs of energy annually. A large SHARC System is designed to generate 11,000 MBH (each unit) and can be installed in series.

Large water source heat pumps systems are more common in Europe than the U.S. currently. There are examples of large heat pumps being utilized for large facility heating and cooling, which would reduce the boiler energy consumption, and could reduce other electric loads from building air conditioning if a chilled water loop was incorporated.

Manufacturers and representatives have been contacted to size equipment specific to SSWRF. Based on these discussions and the examples of realized projects in Europe, we consider this to be a feasible energy efficient heating system[28]. Preliminary estimates are the total heating energy consumption would be reduced by 20%, and all energy required would be electric. This would reduce SSWRF's natural gas dependence and reduce overall energy consumption. A 20% savings on the existing 129,500 MMBTU results in a new boiler energy consumption of 103,600 MMBTU/yr.

Recommendations

SSWRFs major gas consumers are the engines and boilers. Since SSWRF generates enough thermal waste heat from the engines to satisfy the thermal demands of the boiler loop year-round, transitioning the existing boiler loop to a water source heat pump system is not recommended. The waste heat from the engines when operating on DG is considered renewable, and the boiler loop is currently the only process where this energy can be beneficially utilized.

If a new dewatering and drying facility were to be installed in the future as discussed by the BAFP, it is recommended that the thermal demands of that facility be evaluated to determine if there is enough additional thermal demand to warrant installing a water source heat pump for the boiler loop. This will be further evaluated in the forthcoming *Planning Report* as part of this project's scope.

4.4 Energy Efficiency

This section focuses on the energy efficiency improvements for the major energy users at SSWRF. This includes the Secondary Treatment Process, Pumps, Lighting and Electrification.

4.4.1 Secondary Treatment Improvements

Secondary treatment for the conventional activated sludge treatment process is typically the largest energy user at a water reclamation facility. A number of projects to improve the secondary treatment system at SSWRF are in various phases of design and construction, including new diffusers, process modifications, and aeration control. Below are additional improvements:

4.4.1.1 Blower Improvements

Existing Blowers Background

SSWRF has four blowers equipped with 1,500 HP motors and Benshaw medium voltage Reduced Voltage Solid-State Starters (RVSS). The feeders to all 4 blowers are 4,160V and comes from the RVSS starters located in the Powerhouse Building 326. Each of the RVSS/blower systems receive 4,160V

[28] https://www.ehpa.org/fileadmin/red/03._Media/03.02_Studies_and_reports/Large_heat_pumps_in_Europe_MDN_II_final4_small.pdf

power from a switchgear lineup which is also in the powerhouse. It is the same switchgear which receives power from the five on-site Digester/Natural Gas engine generator systems, located in the same building.

The blower manufacturer is Siemens/Turblex, and the Siemens motor has a nameplate rating of 1,500 HP. The blowers always run at full speed and are not able to be turned down by reducing operating speed.

Based on assumptions provided by MMSD, the blower starting amps are assumed to be 1,100 A. This is based on the main motor having an amperage rating of 179A and an assumed factor for inrush of 6. CAT's SpecSizer generator software was used to determine the capacity required to start a single 1,500 HP blower motor with the RVSS[29]. It was assumed that the value for maximum permitted frequency and voltage dips is 30% and a current limit of 300%. The results indicate that two CAT G3512 engine generators rated for 750 ekW/937 kVA are sufficient to start a blower motor or a total of 1,500 ekW is required to startup a blower. The 1,500 kW WS engine generator, or two CAT engine generators (925 kW on DG and 773 kW on NG each) are sufficient to startup a blower.

Existing System Energy Analysis

The Siemens/Turblex Blowers are much more efficient than standard centrifugal multistage blowers. With standard centrifugal multistage blowers, adding a variable frequency drive (VFD) can provide a 25-30% gain in blower efficiency. The Siemens/Turblex Blowers incorporate both inlet guide vanes and outlet diffuser vanes to control header pressure. A realistic efficiency gain with VFDs would be 10-20%. VFDs would allow the Inlet and Outlet vanes to be run in a more open position which would allow more overall efficient operation of the Blowers.

Three blowers are in operation most of the time. At full load, the blowers draw a shaft HP of about 1,100 each. Using three blowers' operation as a conservative estimation of load, 3,300 HP x 749W/HP = 2,472,000W = 2,472 kW. This equates to 2,472 kW x 8,760HR/Year = 21,652,000 kWh/Year. A 10% efficiency gain would equate to savings of 21,652,000 kWh/Year x 0.10 = 2,165,000 kWh/Year savings.

- Annual cost savings using $0.10/kWh would be 2,165,000 kWh/Year x 0.10 = $216,000.
- Annual cost savings using $0.052/kWh would be 2,165,000 kWh/Year x 0.052 = $113,000.

Turbo Blower Evaluation

To further decrease energy usage, a different style of blower could be used that is more efficient. High efficiency turbo blowers incorporate technology used in the turbo jet engine industry that has evolved to produce low pressure aeration blowers for wastewater treatment plants. High efficiency turbo blowers are a single stage centrifugal type blower with the impeller mounted directly to the high-speed motor shaft. These units use permanent magnet motors due to their high energy efficiency and power factor, especially

[29] https://specsizer.cat.com/

at high speeds and temperatures. The permanent magnet motor is directly coupled to the drive allowing it to operate at high speeds of 20,000 to 40,000 revolutions per minute (RPM). Turbo blowers use special low-friction bearings to support the rotating shaft and require no lubrication. Shaft bearings or supports can be magnetic or air foil.

Turbo blowers are supplied in ready to plug and install packages with a variable frequency drive and internal control panels. As they do not have bearings, this equipment requires less maintenance because they do not require lubrication, they produce less noise, they have a high efficiency in energy consumption and their capacity to work at minimum air flows is high compared to the other technologies.

The largest high efficiency turbo blower unit in the market is a 1,100-kW turbo blower that can provide an air flow close to 40,000 SCFM at 8 PSIG. Analyzing past data from 2018 through 2022, SSWRF utilized on average 87,000 SCFM. As summarized in Section 3, SSWRF has projects that will reduce airflow demand to approximately 62,000 SCFM.

To make a comparison with the planned blower flow rates, the assumption was made to achieve a total airflow of 62,000 SCFM. For this, two turbo blower units are needed with an estimated power consumption of 1,650 kW.

Using the plant data obtained from 2018-2022, the energy usage of the existing running two blowers was estimated and compared to two new turbo blowers. This comparison is shown in **Table 4-19**.

Table 4-19 Comparison of Energy Usage per Blower Unit

Type of Blower	Number of units	Air flow rate SCFM	Pressure PSIG	Energy usage kW
High Efficiency Turbo Blower	2	62,000	8	1,650
Blower 1 and 2	2	62,000	8	1,983

The turbo blower would have an estimated 330 kW less load than Blower 1 and Blower 2 at 62,000 SCFM. Over a hypothetical period of one year running, the difference in power consumption and cost between the units is shown in **Table 4-20**.

Table 4-20 Energy Consumption Potential Savings

Type of Blower	No. of Units	Energy Consumption in One Year of Operation (kWh)	Energy Consumption Difference (kWh)	Energy Consumption Cost Difference from Turbo Blowers ($0.052/kWh)	Energy Consumption Cost Difference from Turbo Blowers ($0.10/kWh)
High Efficiency Turbo Blower	2	14,454,000	--	--	--
Blower 1 and 2	2	17,368,000	2,914,000	$151,433	$291,433

Utilizing turbo blowers instead of Blower 1 and Blower 2 saves approximately 17% in electricity usage. Utilizing turbo blowers instead of Blower 1 and Blower 2 would result in 2,914,000 kWh/yr (9,950 MMBTU/yr) in electricity savings.

Engineers Opinion of Probable Construction Cost

The conceptual opinion of capital cost for installing high efficiency blowers are estimated to be $7,525,000.

Table 4-21: Blower Cost Summary

Description	Cost ($)
Equipment Costs (Assume 4 New Blowers)	$2,000,000
Demolition (10%)	$200,000
Electrical Upgrades (25%)	$500,000
Piping Modifications (30%)	$600,000
Labor (50%)	$1,000,000
Subtotal	$4,300,000
Overhead and Profit (20%)	$860,000
Contingency (40%)	$1,720,000
Design and Engineering Services (15%)	$645,000
Total	**$7,525,000**
AACE: -50%	$3,762,500
AACE: +100%	$15,050,000

4.4.1.2 Process Modifications

4.4.1.2.1 Ammonia Sidestream Treatment

Due to the high levels of ammonia present in the filtrate and centrate at SSWRF, ammonia sidestream treatment was evaluated to determine potential energy savings. In addition to energy advantages, the introduction of side stream treatment on concentrated side streams offers significant capacity enhancement in the system. Data was shared with Ovivo, who analyzed and reported back a recommendation of their anammox system, which is a deammonification process utilizing granular bacteria.

The deammonification process can significantly reduce energy in the system by reducing the recycling of ammonia back to the aeration tanks. Typically, ammonia must be converted to NO_2^- and then NO_3^- through nitrification before the conversion to nitrogen. Anammox is able to take NO_2^- and convert it directly to nitrogen, essentially reducing the energy needed for this process by 50 percent. The bacteria take the nitrite converted by oxidizing ammonia and then take the leftover ammonia and convert it to nitrogen. Additionally, there is no carbon needed to achieve any nitrogen removal.

The Annamox bacteria themselves are slow growing, hence it is important to retain as many bacteria as possible. Fortunately, since these bacteria are significant in size (about 1.5 mm in diameter) they can be easily retained. The granular biomass only needs ammonia and nitrite to survive. The biomass, combined with fine bubble aeration, allow for treatment of ammonia of about 90%, with the potential of achieving up to 95% treatment in the system.

This system offers some major advantages in terms of energy reduction. The utilization of a sidestream process uses approximately 67% less energy than treating it in the aeration tanks. The footprint and biosolids used are also much more favorable compared to the conventional system. Carbon is not required at all in the operation of the system, it represents a major decrease in carbon footprint from a conventional system.

The equipment required for the system will depend on the concentrations of total suspended solids and biochemical oxygen demand. If there is too much TSS in the sidestream flow, then a lamella separator may be needed in front of the Anammox separator to remove solids. A worst-case scenario for equipment needed would yield this list:

- Lamella system
- Pre-aeration system with coarse bubble diffuser
- Pumps for transferring liquid throughout the system
- Anammox system

- Fine bubble diffuser
- Biomass
- Biomass separator

- Blowers
- Instrumentation

One item of note regarding the effectiveness of the Anammox sidestream treatment is MMSD's plan to implement acid-phase digestion at SSWRF as a means of increasing capacity compared to traditional mesophilic digestion. Certain constituents of the acid-phase digestion system could impact the bacteria performance in the Anammox system. To find out what this impact is and how severe it could be would require a good handle on the concentrations and compositions of the sidestream flow once acid-phase digestion is implemented.

Pilot Study

A pilot study of the ANITA Mox™ MBBR system was performed by Veolia at SSWRF from October 2020 through February 2021. The study was focused on the sidestream from the gravity belt thickeners (GBTs) to determine the effectiveness of an ANITA Mox™ system. The study was not focused on the associated energy savings. This pilot test yielded the following results:

1. The ANITA Mox™ process continuously provided nitrogen removal by deammonification with minimal production of NO_3. The reactor effluent NH_4-N concentration remained stable and in the typical range for the duration of the test.
2. The pilot test demonstrated 80-85% ammonia removal at influent ammonia-N levels greater than 800 mg/L.
3. The process performed despite numerous interruptions in flow, extended periods of low-influent NH_4-N concentrations, periods of high influent TSS (as evidenced by black-colored filtrate), and high polymer and defoamer concentrations that required operation at reactor DO concentrations much higher than normal. (High DO has the potential to inhibit the annamox reaction).
4. The average applied loads were reduced during periods of dilute concentrations and GBT upsets.
5. The ANITA Mox™ process consistently demonstrated recovery from a variety of abnormal conditions. This attribute is an operating advantage of the media-based biomass.

These results indicate that an ammonia sidestream process at SSWRF could be successful and reduce energy usage.

Energy Usage

The introduction of the Anammox sidestream treatment would decrease energy usage. These energy savings estimates are shown in **Table 4-22** below.

Table 4-22 Anammox Energy Savings

Parameter	Without Sidestream		With Sidestream	
Total Flow	97.0	MGD	97.0	MGD
Total Ammonia	20.69	Mg/L	20.22	Mg/L
	16,734	Lb/day	16,359	Lb/day
Blower Energy Needed	19,618,320	kWh/yr	19,323,529	kWh/yr
Energy Savings due to Sidestream Treatment:			**294,791**	**kWh/yr**
Percent Reduction in Ammonia Loading			**2.24**	**%**

4.4.1.3 Secondary Treatment Improvements Summary

Table 4-23 below summarizes the energy savings for the aeration basins in addition to the planned improvements.

Table 4-23: Secondary Treatment Energy Reduction Summary

Process	Reduction (MMBTU/yr)
High Efficiency Turbo-Blowers	9,950
Ammonia Side Stream Treatment	1,000
Total	10,950

4.4.2 Pump Efficiency Improvements

4.4.2.1 Install VFDs for Pumps, Fans, and other Equipment

VFD Background

VFDs control the amount of voltage and frequency supplied to a motor and can be used to reduce energy usage compared to constant speed motors. Equipment like pumps, blowers and fans represent the most potential for cost savings from the application of VFDs by operating the equipment at more efficient operating points.

VFDs have more energy due to inefficiencies losses than an across the line starter because the semiconductors which change the frequency of the power sent to the motor to change speed cause voltage drop which leaves the VFD as waste heat. Harmonic mitigation devices and motor protection output filters are often required to keep the VFD from sending potentially harmful noise back into the electrical system and protect inverter duty motors. Harmonic filters typically consume about 1.5 % of the energy being sent into the drive system. Output filters typically consume about 1% of the energy being sent to the motor.

Background Energy/Cost Saving Applications using VFDs
The torque requirements of the driven equipment are the main factor affecting potential energy savings. Examples of Constant Torque (CT), Linear Torque (LT) and Variable Torque (VT) motor loads are listed below:

Equipment	Torque
Belt Conveyor	CT
Screw Compressor	LT
Centrifugal Pump	VT
Centrifugal Blower	VT

Both CT and LT applications both have less energy savings potential than VT. Both CT and LT applications have linear torque requirements that motor energy will be proportion to speed of driven equipment. At 80% driven speed, energy requirement will be at least 80% of the full speed. With VT applications, torque requirements increase in proportion of to the square of the driven equipment speed and reach full torque requirement around or at full speed. This translates into the cube law relation between speed and power. At 80% driven speed, energy requirements will be about 50% of full speed depending on the pumps or blowers design curve.

VT loads can yield power savings proportional to the speed reduction cubed. (Power is the product of torque and speed, and variable torque load requirements decrease in proportion to the square of the speed.)

MMSD Energy/Cost Saving Applications using VFDs

SSWRF equipment that was reviewed to determine energy saving potential with the use of VFDs are listed below:

1. 1,500 HP Centrifugal Blowers (4 total)
2. 150 HP RAS Pumps (10 total)
3. 200 HP Plant Effluent Pumps (5 total)
4. 200 HP Interplant Sludge Pumps (6 total)
5. 60 HP Upper Flushing Water Pumps (2 total)
6. 60 HP Primary Sludge Pumps (4 total)

7. 60 HP Aeration Basin Drain Pumps (4 total)
8. 50 HP Return/Waste Activated Sludge Pumps (6 total)
9. 30 HP Waste Activated Sludge Transfer Pumps (4 total)
10. 25 HP Digester Building Sludge Transfer Pump (1 total)
11. 25 HP Sludge Thickening Thickened Sludge Pumps (3 total)
12. 25 HP Phase 1 Dewatering Centrifuge Feed Pump (3 total)
13. 25 HP Phase 1 Dewatering Thickened Sludge Pumps (3 total)
14. 50 HP Phase 2 Dewatering Lime Slurry Pumps (6 total)
15. 20 HP Primary Basin Drain Pumps (2 total)
16. 75 HP Secondary Basin Cleaning Pump (1 total)
17. 100 HP Generator Building Gas Compressors (3 total)
18. 125 HP Digester Building Gas Storage Compressor (2 total)
19. 100 HP Digester Building Primary Cooling Water Pump (2 total)
20. 50 HP Digester Building AgriLife Transfer Pump (2 total)
21. 25 HP Digester Building Gas Mixing Compressor (1 total)
22. 100 HP Sludge Thickening Air Supply Unit (1 total)
23. 40 HP Sludge Thickening Air Supply Unit (1 total)
24. 25 HP Sludge Thickening Air Compressor (2 total)
25. 40 HP Phase 1 Dewatering Operational Storage Pump (4 total)
26. 250 HP Phase 2 Dewatering Precoat Pumps (3 total)
27. 125 HP Phase 2 Dewatering Wash Pumps (2 total)
28. 125 HP Phase 2 Dewatering Sludge Transfer Pumps (6 total)
29. 75 HP Phase 2 Dewatering Sludge Feed Pumps (8 total)
30. 20 HP Primary Scum Pumps (4 total)
31. 100 HP Lower Flushing Water Pumps (4 total)
32. 125 HP Generator Building Primary Heat Recovery Pumps (2 total)
33. 75 HP Sludge Thickening Recycle Pump (6 total)

Item 1 is one of the major power uses at South Shore. The four blowers each have a 1,500 HP motor with a Benshaw RVSS (soft start). The blowers are centrifugal so some power saving could be gained by changing the RVSS to Variable Frequency Drives.

Items 2 through 14 above are presently being driven by VFDs.

Items 15 through 29 were compiled by reviewing the MMSD One-Line and P&ID record drawings. Some of these pumps are CT or LT type loads which would not benefit from a VFD upgrade. Some of these pumps are not operated regularly (such and Phase 2 Dewatering, Drain Pumps, Cleaning Pump) so a conversion to VFD powered would likely not be a benefit.

Items 30 through 33 were also compiled by reviewing the MMSD One-Line and P&ID record drawings. These pumps are Centrifugal and are Variable Torque so it may be beneficial to upgrade with a VFD, but process input is needed to determine if conversion to VFD powered would be a benefit.

<u>*Engineers Opinion of Probable Construction Cost*</u>
An alternative to new turbo blowers is to install VFDs on the existing blowers. The Aeration Blowers currently have RVSS starters. The cost of VFDs for each of these blowers would be about $400,000 per blower to replace RVSS with VFD. This cost includes equipment, engineering, and labor. Note: Lead times for VFDs like this are 40 to 50 weeks. The remaining equipment (Items 30 to 33) could be evaluated further to determine if VFDs are applicable.

4.4.2.2 Install High-Efficiency Motors for Pumps, Fans, and other Equipment at SSWRF

Background
Most motors at SSWRF are National Electrical Manufacturers Association (NEMA) Design B Motors. The minimum required full load efficiencies are shown below:

HP Range	Minimum Eff.
1-4	78.8
5-9	84.0
10-19	85.5
20-49	88.5
50-99	90.2
100-124	91.7
>125	92.4

High efficiency motors have been available and have been specified and installed on most recent projects at MMSD. The efficiencies for high efficiency motors are defined by tables in NEMA standard MG-1-1998. Some examples for typical enclosed 1800 RPM high efficiency motors are shown below:

HP	Nominal Eff.
1	82.5
5	87.5
10	89.5
20	91.0
50	93.0
100	94.5
125	94.5
150-500	95 – 95.8

Energy Analysis
The typical energy efficiency improvements from standard motors to high efficiency motors is approximately 3%. Section 2.8 shows the baseline electricity consumption by process. A 3% efficiency improvement for all process pump motors is shown in **Table 4-24**.

Table 4-24: Process Pumps Energy Reduction (MMBTU/yr)

Process	Baseline	Reduction	New
RAS/WAS Transfer	4,400	130	4,270
RAS	16,700	500	16,200
WAS	1,300	40	1,260
IPS	4,400	130	4,270
Effluent Pumps	8,900	270	8,630
Primary Sludge Pumps	900	30	870
Process Pumps Total	36,600	1,100	35,500

Engineers Opinion of Probable Construction Cost

Motors smaller than 50 HP were assumed to cost $500/HP, while motors larger than 50 HP were assumed to cost $300/HP. The conceptual opinion of capital cost for installing high efficiency motors are estimated to be $1,250,000. The 1,100 MMBTU/yr is equivalent to 322,375 kWh/yr. This results in a yearly savings of $16,500 using $0.052/kWh and $32,200 using $0.10/kWh. There is no positive return on investment if these motors are replaced prior to the existing equipment's end of useful life.

Table 4-25: High Efficiency Motors Cost Summary

Description	Cost
Capital Cost	$1,250,000
Installation and Labor	$625,000
Subtotal	$1,875,000
Overhead and Profit (20%)	$375,000
Contingency (40%)	$750,000
Design and Engineering Services (15%)	$281,000
Total	**$3,281,000**
Description	**Cost**
AACE: -50%	$1,641,000
AACE: +100%	$6,563,000

Recommendation
When motors are scheduled to be replaced due to age, specify that the new motors are replaced with high efficiency motors. It is recommended MMSD incorporate language into their MCRR process to allow for high efficiency motor replacement.

4.4.3 Anaerobic Digester Mixing

Mixing within the anaerobic digesters is important to maintain an even temperature, prevent solids from settling, and optimize the anaerobic digester. SSWRF has twelve anaerobic digesters, with six of the digesters used as storage tanks and six active tanks used for digestion. MMSD has been implementing upgrades to the mixing systems in the anaerobic digesters due to equipment reaching the end of its useful life, to improve mixing, and reduce energy usage. Anaerobic Digester 10 uses linear motion mixers and Anaerobic Digesters 6, 8, and 9 are planned to have the existing mixing systems replaced with new linear motion mixers.

The mixing system for Anaerobic Digester 12 includes two chopper pumps to recirculate flow through a nozzle system in the digester. The two 100 HP pumps run continuously and use significantly more energy than the linear motion mixers that are being installed. It is recommended to upgrade the mixing system for Anaerobic Digester 12 to new linear motion mixers. The anticipated energy usage and savings is provided in **Table 4-26** and **Table 4-27** below.

Table 4-26: AD12 Mixers Evaluation

Digester Mixing Equipment	Number of Units	Motor HP	Total Energy usage, kW
Existing Pump and Nozzle Mixing System	2	100	149
New Linear Motion Mixers	3	15	34

Table 4-27: AD12 Mixing System Energy Savings

Digester Mixing Equipment	Number of Units	Annual Energy Consumption, MWH	Annual Energy Consumption Difference, MWH	Energy Consumption Cost Difference at $0.052/kWh	Energy Consumption Cost Difference at $0.1/kWh
Existing Pump and Nozzle Mixing System	2	1,306	1,103	57,356	$110,300
New Linear Motion Mixers	3	294	0		0

4.4.4 Lighting

The purpose of this section is to quantify the energy reduction expected from past projects and future efforts replacing all High-Pressure Sodium (HPS) and fluorescent lights with light emitting diodes (LEDs).

MMSD has completed three contracts that have upgraded almost all the lighting at SSWRF. These contracts and their substantial completion dates are included in **Table 4-28** below.

Table 4-28: MMSD Lighting Project Summary

Contract	Substantial Completion Date
S06010C01	1/2022
S06010C02	11/2019

The substantial completion dates are mostly after the 2018-2020 energy evaluation range this report utilizes. Therefore, it was assumed the electricity consumption included, does not include most LED lighting upgrades. This section estimates this electricity demand reduction and future lighting electricity consumption for planning purposes.

The average energy use for an industrial facility lighting is 8%, which includes the use of fluorescence lamps.[30] LED lights are an energy efficient lighting source that are replacing the older fluorescent lighting sources and are actively being installed throughout SSWRF to reduce energy usage. This analysis quantifies the energy reductions expected from these efforts. In addition to saving energy, the lighting quality and performance improves. LED lighting operates for decades without replacement or maintenance.

The SSWRF Dewatering Building 360 was used as a representative basis for this analysis. All previous HPS and wall pack fixtures have been replaced with LED fixtures and all fluorescent T8 lamps with LED retrofit lamps. The Dewatering Building had approximately 161 industrial grade 2'x4' 64 W fluorescent fixtures, 81 HPS lights, 250W Low-Bay fixtures, and 37 HPS 400W Low-Bay fixtures.

Modifications to the infrastructure are summarized below:

- Replacement of fluorescent T8 lamps with LED lamps
- Replacement of 250W High-Pressure Sodium fixtures with LED fixtures
- Replacement of 400W High-Pressure Sodium (HPS) Low-Bay fixtures with LED fixtures

By replacing the fixtures and lamps with LEDs, a decrease of 32.9 kW is expected, see **Table 4-29**. This reduction is equivalent to 72.6% of the building's total lighting electricity consumption.

Table 4-29: Dewatering Building 360 LED Lighting Comparison

Dewatering Facility Light Fixtures	Count	kW/ Fixture	Total kW		LED Equivalent	kW/ Fixture	Total kW
Fluorescent, 2x4, 64W	161	0.064	10.30		LED Lamps, 2x4, 36W	0.036	5.80
Low-Bay HPS, 250W	81	0.25	20.25		Low-Bay LED, 48W	0.048	3.89
Low-Bay HPS, 400W	37	0.4	14.8		Low-Bay LED, 74W	0.074	2.74
			45.35				**12.42**

[30] Quadrennial Technology Review. September 2015. "Assessment of Energy Technologies and Research Opportunities", U.S. Department of Energy. **Figure 5.10**.
https://www.energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf

Energy Savings (compared to 2018-2020)
MMSD's annual average electricity consumption was 155,000 MMBTU/yr or 45,490,000 kWh/yr. Assuming 8% of this total represents the lighting energy usage, this equates to 3,340,000 kWh/yr (12,400 MMBTU/yr). Utilizing the 72.6% energy savings with the retrofit projects results in a total SSWRF savings in lighting electricity consumption of 2,425,000 kWh/yr (72.6% x 3,340,000 kWh/yr)).

Utilizing the SSWRF blended energy rate of $0.052/kWh, the retrofit projects have an annual savings of $126,000 (2,425,000 kWh x $0.052/kWh). Utilizing an electricity rate of $0.10/kWh, the annual savings is $242,500.

Engineers Opinion of Probable Construction Cost
The equipment and installation cost to upgrade the lighting is $134,000. This cost was found by assuming 2,000 fixtures were replaced which was approximated by dividing the total lighting electric consumption by the average kW/fixture. The total number of fixtures was then multiplied by $67/fixture.[31] This value includes installation cost.

Table 4-30: LED Lighting Cost Summary

Description	Cost ($)
Capital Cost	$134,000
Overhead and Profit (20%)	$26,800
Contingency (40%)	$53,600
Design and Engineering Services (15%)	$20,100
Total	**$234,500**
AACE: -50%	$117,250
AACE: +100%	$469,000

Recommendations
Installing LED high-efficiency lighting to reduce energy consumption is recommended to be continued throughout SSWRF future lighting installations.

[31] RS Means: 265119107040

Section 5 Summary of Alternatives

5.1 Summary of Alternatives

This section summarizes the recommendations from the various alternatives discussed in the Section 3 as shown in the **Table 5-1** below. These are all recommended projects beyond what is included in the Baseline+. The total reductions summarized equate to approximately 24,000 MMBTU/yr. This is approximately an 8.4% reduction from the Baseline+.

Table 5-1: Energy Reduction Summary

Alternatives	Description	kWh/yr	MMBTU/ yr	% Reduction
Energy Generation Improvements				
Digester Gas Production	Discussion of future potential increased in Digester Gas production from Food Waste.	--	168,420 Generation	--
Digester Gas Energy Generation	Gas cleaning for digester gas combustion equipment and replacement of existing engines at end of useful life with new, higher-efficiency engines is recommended.	--		
Excess Solids	Further evaluation of Pyrolysis as an alternative method for disposal of excess digested sludge is recommended.	--		
Excess Scum	It is recommended to continue hauling excess scum offsite for disposal or sending it to the anaerobic digesters.			

	Alternatives	Description	kWh/yr	MMBTU/yr	% Reduction
	Algae and Biofuel	Further evaluation of energy impacts of a revolving algae biofilm (RAB) (nitrogen/phosphorous removal and carbon dioxide capture) is recommended.	--		
	Photovoltaics	Discussion of possible locations for PV installations at SSWRF and associated payback periods; further evaluation to be performed in TM-5.	47,335,000 Generation	161,500 Generation	--
	Wind	Discussion of electricity generation and associated payback period of (2) 2.4 MW wind turbines at SSWRF.	103,438,080 Generation	352,950 Generation	--
	Effluent Heat Recovery	Transitioning existing boiler loop to water source heat pump system is not recommended.	--		
	Grid Renewable Energy Markup	Consideration of We Energies' current grid power mix (share of renewable energy) is recommended when planning future energy projects and performing accounting of renewable energy consumption.			
Energy Efficiency Improvements					
Secondary Treatment Efficiency Improvements					
	Blower Improvements	This alternative recommends using a High Efficiency Turbo Blower which can produce an energy saving of 17% over the existing blowers.	2,914,000 Reduction	9,950 Reduction	17%

Alternatives		Description	kWh/yr	MMBTU/ yr	% Reduction
	Ammonia Sidestream Treatment	This alternative recommends the introduction of side stream treatment on concentrated side streams which offers significant capacity enhancement in the system.	293,070 Reduction	1,000 Reduction	1.2%
Pump Efficiency Improvements					
	VFDs	This alternative recommends reducing energy loss in existing VFD systems by specifying inverter duty, high efficiency motors; Active front end VFDs; setting drives to dynamic voltage to frequency settings when motors are at low load conditions, etc.	--		
	High Efficiency Motors	This alternative recommends installing high efficiency motors.	33,600 Reduction	1,100 Reduction	3%
Other Efficiency Improvements					
	Anaerobic Digester Mixing	This alternative recommends upgrading the existing 100 HP pumps on digester 12 to new linear motion mixers.	1,103,000 Reduction	3,764 Reduction	84%
	Lighting	This alternative quantifies the energy savings expected from MMSD's efforts to upgrade all lighting to LEDs.	2,425,000 Reduction	8,275 Reduction	72.6%
Optimization of Energy Operating Strategy					
Electrification		This alternative recommends natural gas fired equipment to be transitioned to be fully electric when equipment is at the end of its useful life and up for replacement. DG fired equipment is another option, depending on where and how DG is used for other users.	--		

Alternatives	Description	kWh/yr	MMBTU/ yr	% Reduction
Grid Renewable Energy Markup	Consideration of We Energies' current grid power mix (share of renewable energy) is recommended when planning future energy projects and performing accounting of renewable energy consumption.	--		

Section 6 Conclusion

6.1 Summary

This *TM-4* breaks down the energy consumption baseline at SSWRF, potential energy reductions, renewable energy generation opportunities, and the resulting energy breakdown after the recommendations are implemented.

6.2 Renewable Energy Generation Summary

Table 6-1 summarizes the potential yearly energy generation achievable from the analysis included in **Section 4**.

Table 6-1: Renewable Energy Generation Summary

Source	Electricity (MMBTU/yr)	Gas (MMBTU/yr)	Total (MMBTU/yr)
Photovoltaic	161,500	0	161,500
Wind	352,950	0	352,950
Pyrolysis	0	0	0
Algae Bioreactor	0	0	0
DG	0	642,300	642,300
Total	514,450	642,300	1,156,750

6.3 Energy Reduction Summary

Table 6-2 summarizes the yearly energy reductions achievable from the analysis included in **Section 4**.

Table 6-2: Energy Reduction Summary

Consumer	Baseline+ (MMBTU/yr)	Reduction (MMBTU/yr)	New (MMBTU/yr)
AERATION	59,219	10,950	48,269
UV IMPROVEMENTS	3,839	0	3,839
OTHER (HVAC, MISC PROCESS)	21,450	3,764	17,674
RAS	16,700	500	16,200
LIGHTING	12,400	8,275	4,125
EFFLUENT PUMPS	8,633	260	8,373
IPS	3,916	120	3,796
RAS/WAS TRANSFER PUMPS	4,400	130	4,270
WAS	1,300	40	1,260
PRIMARY SLUDGE PUMPS	900	30	870
BOILER	129,500	0	129,500
OTHER NATURAL GAS	23,916	0	23,916
Total	286,161	24,069	262,092

Using $0.052/kWh the 24,069 MMBTU (7,053,902 kWh) is equivalent to $366,803/yr or savings. Using $0.10/kWh, the savings is $705,390.

The cost of transitioning the 24,000 MMBTU of NG to electricity results in increased utility costs ranging between $125,000 and $580,000 using $5/MMBTU and $10/MMBTU for the price of NG, and $0.052/kWh and $0.10/kWh for the cost of electricity.

6.3.1 Greenhouse Gas Reduction

Reducing non-renewable energy consumption including grid purchased electricity, NG, and electricity generated from NG on-site directly reduces overall GHG emissions. Therefore an 8% reduction in non-renewable energy consumption is an 8% reduction in GHG emissions. A 20% reduction in a processes non-renewable energy consumption results in a 20% reduction in that processes GHG emissions. As MMSD's renewable energy generation increases and non-renewable energy consumption decreases, MMSD's GHG emissions will consequently also be reduced. GHG emissions will be further quantified, with an established baseline in the Carbon Free portion of this project's scope.

6.4 Combined Energy Breakdown

Assuming the previous recommendations are incorporated, the new annual SSWRF energy breakdown is summarized in **Table 6-3** as follows:

Table 6-3: Energy Source by Consumer

Consumer	NG (MMBTU/yr)	Electricity (MMBTU/yr)	Waste Heat (MMBTU/yr)	Total (MMBTU/yr)
AERATION	0	48,269	0	48,269
UV IMPROVEMENTS	0	3,839	0	3,839
OTHER (HVAC, MISC PROCESS)	0	17,674	0	17,674
RAS	0	16,200	0	16,200
LIGHTING	0	4,125	0	4,125
EFFLUENT PUMPS	0	8,373	0	8,373
IPS	0	3,796	0	3,796
RAS/WAS TRANSFER PUMPS	0	4,270	0	4,270
WAS	0	1,260	0	1,260
PRIMARY SLUDGE PUMPS	0	870	0	870
BOILER	0	0	129,500	129,500
OTHER NATURAL GAS	0	23,916	0	23,916
Total	0	132,592	129,500	262,092

The purpose of **Table 6-3** is to show what the energy profile of the end using consumption equipment would look like after the energy recommendations and improvements are incorporated. The other NG loads column has the energy demand allocated under electricity because the recommendation is to transition those loads to electric fuel sources. The end goal would be to have renewable electricity fuel the electricity loads at SSWRF. It is recommended that non-renewable NG consumption be phased out to achieve MMSDs goals.

Other electric loads refer to various electrical energy consuming equipment otherwise not tabulated in the table. Other natural gas loads refer to purchased natural gas that various equipment consumes at the facility.
The total end user energy consumption is 262,092 MMBTU. This value is lower than the value shown in **Section 2.1** (543,000 MMBTU) because it doesn't include energy from the inefficiencies of the engines for power generation discounting waste heat utilized (161,500 MMBTU) or energy lost due to flaring (73,000 MMBTU). It includes the efficiencies realized by incorporating the alternatives evaluated in **Section 4** (24,069 MMBTU) and the difference in energy from the original baseline to the planned improvements summarized in **Section 3** (22,339 MMBTU)[32]. The energy reduction this report details is primarily due to process improvements from the Baseline+ energy consumption. This report shows energy reductions from the Baseline+ consumption of 286,000 MMBTU/yr to the new 262,000 MMBTU/yr resulting in a reduction of about 24,000 MMBTU/yr.

[32] 543,000 - 161,500 - 73,000 – 24,069 - 22,339 - = 262,092 MMBTU/yr

6.4.1 Sankey Diagram

Figure 6-1 shows the energy breakdown after all recommendations in **Section 4** are incorporated.

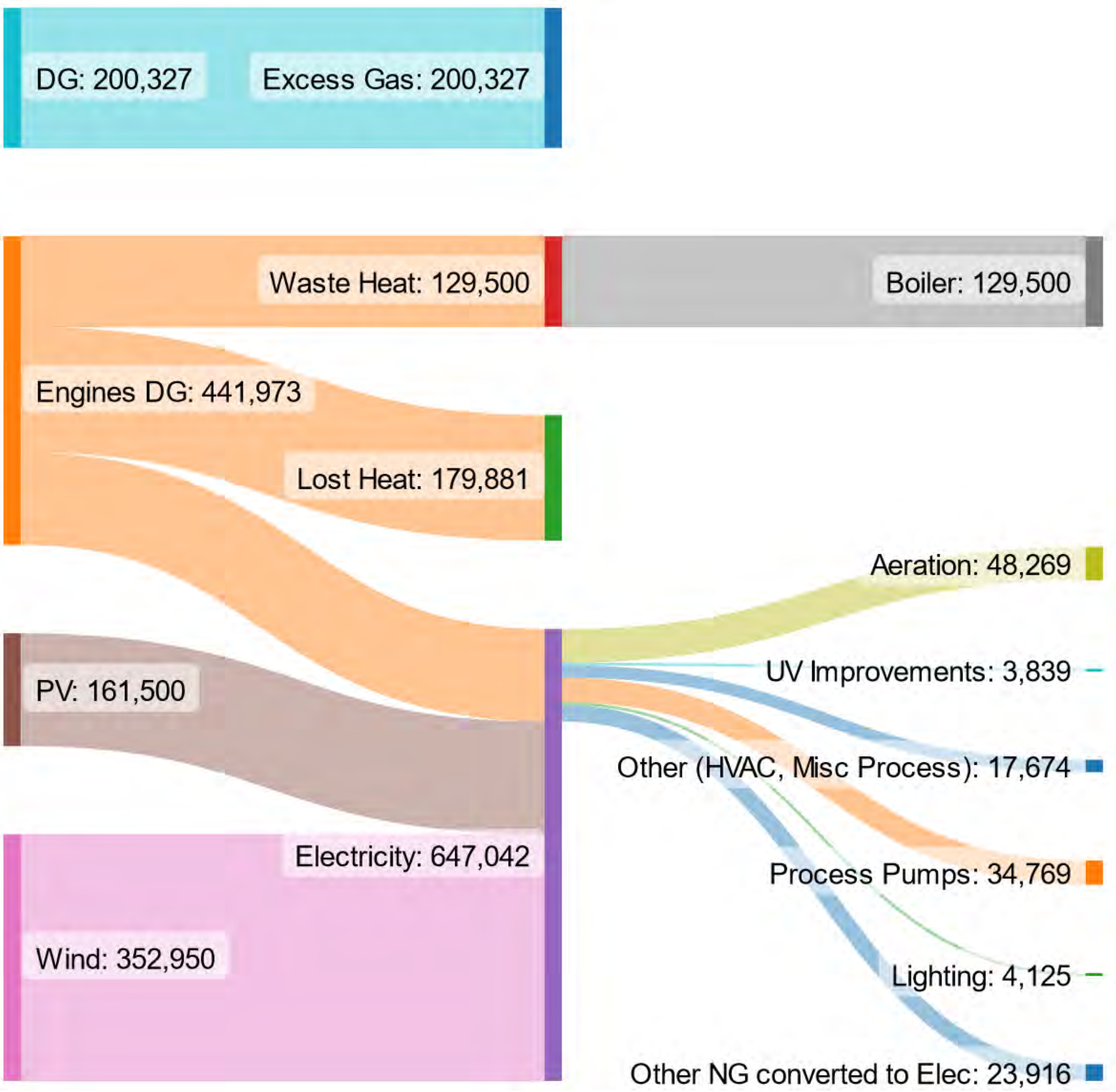

Figure 6-1: Sourced Energy by Consumer (MMBTU)

Figure 6-1 shows the energy summaries presented in **Table 6-1** and **Table 6-3**. Renewable energy comprises 100% of the total energy consumption shown in the Sankey Diagram. The excess energy (714,777 MMBTU/yr) could be used to offset with non-renewable energy consumption at other MMSD assets such as JIWRF, Administration Facilities, or the Conveyance System.

As part of this project, additional technical memorandums are being prepared and be submitted at a later date.

- The *Planning Report* will be a MMSD-wide document to meet the MMSD energy goals. The *Planning Report* will include a plan to offset all non-renewable energy consumption. Non-renewable energy consumption at JIWRF may be offset through excess renewable energy generation at SSWRF, energy generation at other MMSD properties, or a combination of them.
- *Technical Memorandum 5 – Carbon Free Needs Assessment*

Appendix A

sLCOE

Engine sLCOE for DG @ $2.11/MMBTU		
Years	20	
Discount Rate	3.375%	
Capital Recovery Factor	6.96%	
Overnight Capital Cost	2800.632	$/kW
Fixed O&M Cost	0	$/kW-yr
Capacity Factor	69%	
Fuel Cost	2.110421	$/MMBtu
Heat Rate	9896	Btu/kWh
Variable O&M Cost	0.02709	$/kWh
sLCOE	**0.080039**	**$/kWh**

Engine sLCOE for NG @ $5/MMBTU		
Years	20	
Discount Rate	3.375%	
Capital Recovery Factor	6.96%	
Overnight Capital Cost	2800.632	$/kW
Fixed O&M Cost	0	$/kW-yr
Capacity Factor	69%	
Fuel Cost	5	$/MMBtu
Heat Rate	9896	Btu/kWh
Variable O&M Cost	0.02709	$/kWh
sLCOE	**0.108634**	**$/kWh**

Engine sLCOE for NG @ $10/MMBTU		
Years	20	
Discount Rate	3.375%	
Capital Recovery Factor	6.96%	
Overnight Capital Cost	2800.632	$/kW
Fixed O&M Cost	0	$/kW-yr
Capacity Factor	69%	
Fuel Cost	10	$/MMBtu
Heat Rate	9896	Btu/kWh
Variable O&M Cost	0.02709	$/kWh
sLCOE	**0.158114**	**$/kWh**

PV sLCOE		
Years	20	
Discount Rate	3.375%	
Capital Recovery Factor	6.96%	
Overnight Capital Cost	2100	$/kW
Fixed O&M Cost	20	$/kW-yr
Capacity Factor	15.4%	
Fuel Cost	0	$/MMBtu
Heat Rate	0	Btu/kWh
Variable O&M Cost	0	$/kWh
sLCOE	**0.123119**	**$/kWh**

Wind sLCOE		
Years	20	
Discount Rate	3.375%	
Capital Recovery Factor	6.96%	
Overnight Capital Cost	1470	$/kW
Fixed O&M Cost	29	$/kW-yr
Capacity Factor	36.0%	
Fuel Cost	0	$/MMBtu
Heat Rate	0	Btu/kWh
Variable O&M Cost	0	$/kWh
sLCOE	**0.041624**	**$/kWh**

Engine Capacity Factor							
	SSWRF CAT Power		Number of Engines	Capacity	Max Operation		Capacity Factor
	MMBTU	kWh		kW	Hrs	kWh	
2018	67060.17	19653324	4	773	8760	27085920	0.725592
2019	59634.55	17477097	4	773	8760	27085920	0.645247
2020	65626.88	19233269	4	773	8760	27085920	0.710084
						AVG	**0.693641**

Cost References

Engine Cost	2310	$/kW	from epa 2013	1 x 633 kW Engine
Engine O&M	0.02709	$/kWh		

Gas Compression, treatment and condensate management Capital Cost	1610	$/scfm	from EPA	for a 1,000 SCFM syste
	490.6319	$/kW		
O&M Cost	207	$/scfm	from EPA	yearly
	0.007201	$/kWh		hourly
	2.110421	$/MMBTU		

Table 4-6. LFG Medium-Btu Direct-Use Project Components — Estimated Cost Summary[5]

Component	Typical Capital Costs*	Typical Annual O&M Costs*
Gas compression, treatment and condensate management	$730 to $1,400/scfm	$130 to $180/scfm
Gas pipeline	$689,700 to $880,700/mile	Negligible

scfm: standard cubic feet per minute
*2020 dollars. Ranges compare a 1,000-scfm to 3,000-scfm system. Economies of scale are achieved for gas compression and treatment at larger flow rates, however, pipeline costs increase as a result of larger diameter pipe.

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Appendix E

Planned Improvements List

Administration Planned Improvements

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
M01044	HQ and Lab Building Remodel	2026	Yes	-87,150	-917	-10.0%	No	-	Estimated 10% reduction in HVAC energy

JIWRF Planned Improvements

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
J01013	Preliminary Facility Electrical Upgrade	2023	Yes	-4,540,827	0	-54.0%	No	-	The project will replace all building lighting with light emitting diode (LED) technology to save energy.
J01019	JI Force Main Assessment	2026	No	-	-	-	-	-	
J01021	Grit Basin Equipment Replacement	2021	No	-	-	-	-	-	
J01024	Harbor Siphon Structures & Adjacent Asset Modifications	2021	No	-	-	-	-	-	
J01025	High & Low Level Screw Pump Replacement	2022	No	-	-	-	-	-	
J01030	Odor Control Preliminary Treatment Facility	2028	No	-	-	-	-	-	
J06089	Flow Meter Replacement	2023	No	-	-	-	-	-	
J01027	Primary Clarification, Sludge and Scum Pumping		No	-	-	-	-	-	
J01028	Primary Clarifier Drive Improvements	2024	No	-	-	-	-	-	
J06090	Clarifier Cathodic Protection Upgrades at JI WRF	2025	No	-	-	-	-	-	
J02012	Aeration System Diffusers Replacement	2025	Yes						This project has potential to reduce JIWRF process air supply from approximately 90,000 scfm to 70,000 scfm.
J02015	Aeration Basin Concrete Rehabilitation	2023	No	-	-	-	-	-	
J02016	Process Air Compressor Replacement	2026	Yes						1. Mitigate risk R0376 related to the operational reliability, economic efficiency, and energy impacts from the age, condition, and serviceability of the PACs.
J02013	East Plant RAS Header and Pump Replacement	2018	No	-	-	-	-	-	
J03006	Disinfection Process Improvements	2027	No	-	-	-	-	-	Potentially adds UV electric demand
J04037	Thickened Sludge Improvements	2024	?						Project purpose - Identify and implement cost effective sludge thickening improvements to achieve 4% total solids blended sludge feed to the belt filter presses (BFP) in the JIWRF Dewatering and Drying (D&D) Facility.
J04077	Odor Control Equalization & Blend Facility and D&D Baghouse	2026	No	-	-	-	-	-	

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
J04075	Dewatering & Drying Belt Filter Press Overhauls at JI WRF	2026	No	-	-	-	-	-	
J04038	D&D Dryers Guillotine Gate Replacement	2024	Yes?						The purpose of this project is to restore the dryer waste heat guillotine gates and control valves in the Dewatering and Drying (D&D) Facility to their original operating condition.
J04057	Dryer Exhaust Duct Header Replacement	2022	No	-	-	-	-	-	
J04060	Sludge Cake Transport & Feed Conveyors Replacement	2022	No	-	-	-	-	-	
J04061	D&D PLC 5 Upgrades	2026	No	-	-	-	-	-	
J04079	Dryer Train Overhaul & Upgrades	2029	No	-	-	-	-	-	Could possibly include LFG burners on some dryers.
J04080	Phase 2 MCC Replacement D&D	2028	No	-	-	-	-	-	
J04081	D&D HVAC Upgrade	2028	Yes	-877,041	-	-10.0%			Ensure the heating, ventilation and air conditioning (HVAC) systems included in this project adequately and efficiently heat, condition, and ventilate the areas they serve
J06061	Dryer Conversion for Additional LFG	2022	No	-	-	-	-	-	Past
J04035	Greens Grade Train Replacement and Redundant Train Evaluation	2022	No	-	-	-	-	-	
J04064	Chaff System Improvements	2028	No	-	-	-	-	-	
J04065	D&D First Stage Classification Equipment Replacement	2023	No	-	-	-	-	-	
J04066	Milorganite Dust Suppressant System Upgrades	2021	Yes?	-225,342	-	-10.0%			Reduce energy consumption by relocating the system indoors. Past project
J04067	D&D South Cake Loadout System	2021	No	-	-	-	-	-	
J04070	Milorganite Facilities Improvements Phase V		No	-	-	-	-	-	
J04072	Milo Transport and Silo Storage Equipment Replacement	2025							include 10% reduction?
J04074	Milorganite Packaging Facility	2026							Increases energy use
J04073	D&D Dust Collection System		No	-	-	-	-	-	
J06056	Turbine Extended Service Agreement		No	-	-	-	-	-	
J06066	Power System Improvements	2022	No	-	-	-	-	-	
J06076	Turbine Waste Heat Expansion Joint 12 & 13 Replacement	2019	Yes?						The purpose of this project is to restore the integrity and reliability of the waste heat system between the JIWRF gas turbines and the Milorganite dryer
J06081	Replace MCCs and LCUS-P Phase 1	2026	No	-	-	-	-	-	

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
J06092	GE Turbine Generator 2 Recommissioning		No	-	-	-	-	-	
J06093	GE Frame 5 Gas Turbine No. 1 Major Overhaul	2023	No	-	-	-	-	-	
P02003	LFG Pipeline Pigging Station	2020	No	-	-	-	-	-	
P02004	Landfill Gas System - Metro Landfill		Yes?	-	-	-	Yes	700,000	Waste Management projects Metro Landfill can provide between 700,000 and 850,000 MMBtu/year of LFG
J04076	Compressed Air System Upgrade	2026	Yes	-680	-	-10.0%	-	-	To restore the reliability of the plant air system, increase system efficiency, and reduce energy consumption
J06083	HVAC System Improvements - Bldgs 234, 235, 243, & 256	2025	Yes	-61,433	-83	-10.0%	-	-	Improved HVAC equipment in certain areas of JIWRF buildings, with better controls. The new units should provide good climate control with more energy-efficient operation
J06084	W3 &W4 System Modifications	2023	No	-	-	-	-	-	
J06050	JI I&C Improvements	2018	No	-	-	-	-	-	
J06068	JI & SS Network Optimizations	2019	No	-	-	-	-	-	
P01005	Interplant Pipeline Improvements - Phase II	2025	TBD						Has potential,Replace key system components such as pumps, motors, variable frequency drives, magnetic flow meters, valves, and piping at the Jones Island IPS Pump Station, the South Shore IPS Pump Station and the IPS valve vaults located between the two facilities
P01006	Replace IPS Pipes within South Shore WRF Property	2021	No	-	-	-	-	-	
J06032	JI Geotechnical Structural Analysis	2032	No	-	-	-	-	-	
J06073	Harbor Siphons Area Settlement Mitigation	2025	No	-	-	-	-	-	
J06075	2018 JI Capital Equipment Rehabilitation/Replacement	2024	No	-	-	-	-	-	10% rule applies, but difficult to quantify
J06078	JI WRF Odor Assessment		No	-	-	-	-	-	
J06082	Flood Resiliency Improvements	2024	No	-	-	-	-	-	Minor increase to electric
J06085	Administrative/Maintenance Space Planning Analysis		No	-	-	-	-	-	Results in a CIP, some ideas reduce energy
J06086	Building Roof Replacement Phase 4	2025	No	-	-	-	-	-	
J06087	2025-2029 JI Capital Equipment Replacement	2032	No	-	-	-	-	-	
J99001	Allowance for Plant Rehabilitation		No	-	-	-	-	-	
J99003	Operator Contribution to CIP		No	-	-	-	-	-	
J99004	Allowance for D&D Rehabilitation		No	-	-	-	-	-	

SSWRF Planned Improvements

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
S01009	Scum System Improvements	2023	No	-	-	-	No	-	
S01013	Primary Clarification System Improvements	2028	Yes	-	-	-	Yes	-	Preliminary values from the project used. Increase in digester gas (27%), decrease in aeration energy (4.2%), decrease in solids (11%). Energy decrease at JIWRF is not included in the energy total.
	Aeration System		Yes	-1,025,000	-	-4.2%	No	-	
	IPS		Yes	-141,852	-	-11.1%	No	-	
	D&D Facility at JIWRF (not included in energy savings at SSWRF)		Yes		-95,654	-11.1%	No	-	
	Digesters		Yes				Yes	27.3%	
S01015	Grit Equipment Replacement	2027	No	-	-	-	No	-	
S02008	SS Capacity Improvements	2025	No	-	-	-	No	-	
S02013	Aeration Galleries RAS Header Piping Rehab	2023	No	-	-	-	No	-	
S02014	Secondary Clarifier Idling Control	2022	No	-	-	-	No	-	
S02015	Aeration System Upgrade	2028	Yes	-4,920,000	-	-20.0%	No	-	Improvements include tapered membrane diffusers, aerobic/anaerobic swing zone, and DO control. Assumed 20% reduction in aeration energy usage.
S02017	Process Air Header Improvements	2027	Yes	-1,230,000	-	-5.0%	No	-	Assumed 5% energy decrease of aeration system due to a decrease in leaks.
S02018	RAS Pumps Replacement	2026	No	-	-	-	No	-	
S03003	Post-Secondary Capacity Improvements	2023	No	-	-	-	No	-	
S03004	Effluent Pump MCC and VFD Upgrade	2023	Yes	-78,253	-	-3.0%	No	-	Assumed 3% energy savings based on new electrical equipment and VFD.
S03005	Disinfection Process Improvements	2028	Yes	+1,125,000	-	New Load	No	-	Assumed new hybrid UV/chemical disinfection system.
S04010	Thickening Process Capacity Enhancements	2026	No	-	-	-	No	-	
S04012	Plate and Frame Press Upgrade	2023	No	-	-	-	No	-	
S04029	Digester Mixing II	2026	Yes	-	-	Negligible	Yes		New linear motion mixers (3 per digester at 15HP/ea) for AD9 and 11.
S04034	High Strength Waste Mixing Improvements	2028	Yes	-	-	Negligible	No	-	
S04035	Digester 6 & 8 Mixer Replacement	2023	Yes	-	-	Negligible	No	-	The existing mechanical draft tube mixers will be replaced with new linear motion mixers. The draft tube mixers were not operational during 2018-2020 and not included in the energy data. The four 10 HP mechanical draft tubes will be replaced with four 7.5 HP linear motion mixers.
S04036	Bldg. 383 HVAC Replacement	2023	Yes	-1,167	-28	-10.0%	No	-	Assumed 10% energy savings for new HVAC equipment.

Project Number	Project Name	Construction Substantial Completion	Energy Impact (Yes/No)	Estimated Change Electricity (kWh)	Estimated Change Natural Gas (MMBTU)	Estimated Change % to Equipment or Process	Energy Generation (Yes/No)	Estimated Renewable Generation Increase %	Notes
S04037	Pyearolysis Evaluation	2025	No	-	-	-	No	-	
S04038	Digester Capacity Restoration	N/A	No	-	-	-	No	-	Digester cleaning project will restore capacity. Assumed no impact to energy.
S04039	Gravity Thickening & Acid Phase Digestion	2028	Yes	+490,000	-	New Load	Yes	5%	New energy loads for gravity thickeners and pumps. Assumed 5% increase in digester gas production rate per BAFP.
S04040	Dewatering and Drying Facility	2032	Yes	+6,300,000	+430,500	New Load	No	-	
S06019	Replace W3 Flushing Water Pumps	2023	Yes	-249,000	-	-	No	-	Lower site has a proposed savings of 36,000 kWh/year. Upper site has a proposed savings of 213,000 kWh/year. This project was recently completed, energy effects not included in the original baseline calculations.
S06027	Tunnels Concrete Rehabilitation	2023	No	-	-	-	No	-	
S06038	2018 SS Capital Equipment Rehabilitation/Replacement	N/A	No	-	-	-	No	-	
S06040	SS Network Optimization	N/A	No	-	-	-	No	-	
S06042	SS WRF Odor Assessment	N/A	No	-	-	-	No	-	
S06047	Protective Relay Synchronization	N/A	No	-	-	-	No	-	
S06048	Building Roof Replacement Phase 5	Completed	No	-	-	-	No	-	
S06049	2025-2029 SS Capital Equipment Replacement	N/A	No	-	-	-	No	-	
S06050	Bldg. 378 HVAC System Upgrade	2027	Yes	-2,333	-55	-10.0%	No	-	Assumed 10% energy savings for new HVAC equipment. Also touches Building B380.
S06053	W3 Flushing Water System Fire Flow	2028	Yes	-	-	Negligible	No	-	
S06054	SSWRF Feeder, LCUS, and MCC Replacements	N/A	No	-	-	-	No	-	
S06055	Secondary Clarifier Batteries 1, 2, 3, 4 Walkways Replacement	N/A	No	-	-	-	No	-	
S99001	Allowance for Plant Rehabilitation	N/A	No	-	-	-	No	-	
S99003	Operator Contribution to CIP	N/A	No	-	-	-	No	-	

Appendix F

Planned Improvements and

Recommended Improvements

Impact Summary

JIWRF Summary Table

				PI							RI					
CONSUMER	Baseline			Change (+/-)		Baseline + Planned Improvements			Reduction		Change (+/-)			Baseline + PI + RI		
	MMBTU/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	MMBTU/yr	MMBTU/yr		MMBTU/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	MMBTU/yr
Dryers	861,000	861,000	0			861,000	0	861,000	0		0	0	0	861,000	0	861,000
Aeration and Blowers	107,500	0	31,510,000			0	31,510,000	107,500	0		31,700	0	9,290,000	0	22,220,000	75,800
Process Pumps	80,800	0	23,680,000			0	23,680,000	80,800	0		2,400	0	700,000	0	22,980,000	78,400
Lighting	29,000	0	8,500,000			0	8,500,000	29,000	0		15,500	0	4,540,000	0	3,960,000	13,500
Boiler	61,000	0	17,880,000			0	17,880,000	61,000	0		12,200	0	3,580,000	0	14,300,000	48,800
ISS Pumps	52,000	0	15,240,000			0	15,240,000	52,000	0		0	0	0	0	15,240,000	52,000
D&D Dust System and HVAC	37,700	0	11,050,000			0	9,940,000	33,900	3,800		1,100	0	320,000	0	9,620,000	32,800
D&D HVAC Upgrade	--	--	--	0	-880,000	--	--	--	--		--	--	--	--	--	--
Milorganite Dust Suppressant System Upgrades	--	--	--	0	-230,000	--	--	--	--		--	--	--	--	--	--
Other Electric Loads	53,000	0	15,530,000			0	15,469,320	52,800	200		0	0	0	0	15,470,000	52,800
Compressed Air System Upgrade	--	--	--	0	-680	--	--	--	--		--	--	--	--	--	--
HVAC System Improvements - Bldgs 234, 235, 243, & 256	--	--	--	0	-60,000	--	--	--	--		--	--	--	--	--	--
Other Natural Gas Loads	153,000	153,000	0			152,920	0	152,900	100		0	0	0	152,920	0	152,900
HVAC System Improvements - Bldgs 234, 235, 243, & 256	--	--	--	-80	0	--	--	--	--		--	--	--	--	--	--
Total	1,435,000	1,014,000	123,390,000	-80	-1,170,680	1,013,920	122,219,320	1,430,900	4,100		62,900	0	18,430,000	1,013,920	103,790,000	1,368,000

SSWRF Summary Table

				PI							RI					
CONSUMER	Baseline			Change (+/-)		Baseline + Planned Improvements			PI Reduction		Change (+/-)			Baseline + PI + RI		
	MMBTU/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	MMBTU/yr	MMBTU/yr		MMBTU/yr	dth/yr	kWh/yr	dth/yr	kWh/yr	MMBTU/yr
Aeration	83,700	0	24,600,000			0	17,420,000	59,400	-24,500		-10,950	0	-3,210,000	0	14,210,000	48,500
Primary Clarifier Improvements	--	--	--	0	-1,030,000	--	--	--			--	--	--	--	--	--
Aeration System Upgrade	--	--	--	0	-4,920,000	--	--	--			--	--	--	--	--	--
Process Air Header Improvements	--	--	--	0	-1,230,000	--	--	--			--	--	--	--	--	--
UV Disinfection Improvements	0	0	0	0	1,130,000	0	1,130,000	3,900	3,860		0	0	0	0	1,130,000	3,900
Other (HVAC, Misc Process)	22,300	0	6,510,000			0	6,256,500	21,300	-860		-3,764	0	-1,100,000	0	5,156,500	17,600
Replace W3 Flushing Water Pumps	--	--	--	0	-250,000	--	--	--			--	--	--	--	--	--
Bldg. 378 HVAC Improvements	--	--	--	0	-2,300	--	--	--			--	--	--	--	--	--
Bldg. 383 HVAC Improvements	--	--	--	0	-1,200	--	--	--			--	--	--	--	--	--
RAS	16,700	0	4,890,000			0	4,890,000	16,700	0		-500	0	-150,000	0	4,740,000	16,200
Lighting	12,400	0	3,630,000			0	3,630,000	12,400	0		-8,275	0	-2,430,000	0	1,200,000	4,100
Effluent Pumps	8,900	0	2,610,000			0	2,531,700	8,600	-270		-260	0	-80,000	0	2,451,700	8,400
Effluent Pump MCC and VFD Upgrade	--	--	--	0	-78,300	--	--	--			--	--	--	--	--	--
IPS	4,400	0	1,300,000			0	1,160,000	4,000	-480		-120	0	-40,000	0	1,120,000	3,800
Primary Clarifier Improvements	--	--	--	0	-140,000	--	--	--			--	--	--	--	--	--
RAS/WAS Transfer Pumps	4,400	0	1,300,000			0	1,300,000	4,400	0		-130	0	-40,000	0	1,260,000	4,300
WAS	1,300	0	390,000			0	390,000	1,300	0		-40	0	-10,000	0	380,000	1,300
Primary Sludge Pumps	900	0	260,000			0	260,000	900	0		-30	0	-10,000	0	250,000	900
Boiler	129,500	129,500	0			129,500	0	129,500	0		0	0	0	129,500	0	129,500
Other Natural Gas	24,000	24,000	0			23,910	0	23,910	-90		0	0	0	23,910	0	23,910
Bldg. 378 HVAC Improvements	--	--	--	-60	0	--	--	--			--	--	--	--	--	--
Bldg. 383 HVAC Improvements	--	--	--	-30	0	--	--	--			--	--	--	--	--	--
Total	308,500	153,500	45,490,000	-90	-6,521,800	153,410	38,968,200	286,310	-22,340		-24,069	0	-7,070,000	153,410	31,898,200	262,410

Appendix G

Greenseams® Renewable Energy Potential Summary

Property Name	Municipality	County	Area (acres)	Hydric Area (acres)	Property % Hydric Soil	Non-Hydric Area (acres)	Property Acquired via WDNR Grant?	Feasible for Renewable Energy (Y/N)?	Notes
Kohlwey	Mequon	Ozaukee	32.5	11.6	36%	20.9	None	Yes	
Ernst	Germantown	Washington	34.5	13.0	38%	21.5	None	Yes	
Grall	Oak Creek	Milwaukee	22.1	12.8	58%	9.3	None	Yes	
Joerres	Kewaskum	Washington	117.4	78.0	66%	39.4	None	Yes	
New Testament Church	Milwaukee	Milwaukee	35.9	24.0	67%	11.9	None	Yes	
Kaiser	Milwaukee	Milwaukee	85.0	57.4	67%	27.7	None	Yes	
Burant	Mequon	Ozaukee	9.6	3.6	37%	6.0	None	No	Not feasible due to property being heavily forested.
Dobberfuhl	Germantown	Washington	10.3	7.7	75%	2.6	None	No	Not feasible due to property having greater than 75% hydric soil.
DeAngelis/Toriano LLC	Germantown	Washington	23.0	17.5	76%	5.5	None	No	Not feasible due to property having greater than 75% hydric soil.
Stauffacher	Germantown	Washington	40.4	31.2	77%	9.3	None	No	Not feasible due to property having greater than 75% hydric soil.
Anderson	Germantown	Washington	23.1	17.9	77%	5.2	None	No	Not feasible due to property having greater than 75% hydric soil.
Conley	Germantown	Washington	6.5	5.5	85%	1.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Grundy	Oak Creek	Milwaukee	16.5	14.0	85%	2.5	None	No	Not feasible due to property having greater than 75% hydric soil.
Gray	Germantown	Washington	20.1	18.0	90%	2.1	None	No	Not feasible due to property having greater than 75% hydric soil.
Weiss Mequon	Mequon	Ozaukee	84.7	77.7	92%	7.1	None	No	Not feasible due to property having greater than 75% hydric soil.
La Londe	Germantown	Washington	4.4	4.0	92%	0.4	None	No	Not feasible due to property having greater than 75% hydric soil.
Cannon	Oak Creek	Milwaukee	15.4	14.2	93%	1.1	None	No	Not feasible due to property having greater than 75% hydric soil.
Hubacek	Kewaskum	Washington	33.5	32.0	96%	1.5	None	No	Not feasible due to property having greater than 75% hydric soil.
Quesnell	Germantown	Washington	30.3	29.0	96%	1.3	None	No	Not feasible due to property having greater than 75% hydric soil.
Ludwig	Oak Creek	Milwaukee	13.3	13.0	98%	0.3	None	No	Not feasible due to property having greater than 75% hydric soil.
Schmidt	Trenton	Washington	14.3	14.0	98%	0.3	None	No	Not feasible due to property having greater than 75% hydric soil.
Ramthun	Farmington	Washington	20.4	20.0	98%	0.4	None	No	Not feasible due to property having greater than 75% hydric soil.
Elger	Germantown	Washington	11.2	11.1	99%	0.1	None	No	Not feasible due to property having greater than 75% hydric soil.
Watson	Oak Creek	Milwaukee	39.3	39.1	99%	0.2	None	No	Not feasible due to property having greater than 75% hydric soil.
Dyer	Germantown	Washington	32.5	32.3	99%	0.2	None	No	Not feasible due to property having greater than 75% hydric soil.
Kosterman	Germantown	Washington	15.1	15.0	100%	0.1	None	No	Not feasible due to property having greater than 75% hydric soil.
Holl	Germantown	Washington	20.0	20.0	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Schloemer	Germantown	Washington	24.5	24.5	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Polzer	Germantown	Washington	39.1	39.1	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Rowan	Oak Creek	Milwaukee	33.1	33.1	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Huiras	Fredonia	Ozaukee	20.0	20.0	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Hendrickson	Mequon	Ozaukee	19.7	19.7	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.

Property Name	Municipality	County	Area (acres)	Hydric Area (acres)	Property % Hydric Soil	Non-Hydric Area (acres)	Property Acquired via WDNR Grant?	Feasible for Renewable Energy (Y/N)?	Notes
Meyer	Fredonia	Ozaukee	15.1	15.1	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Oak Creek Investment	Oak Creek	Milwaukee	9.8	9.8	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Luft	Mequon	Ozaukee	8.0	8.0	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Larsen	Germantown	Washington	7.0	7.0	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Domoe	Oak Creek	Milwaukee	6.0	6.0	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Pettit	Mequon	Ozaukee	2.0	2.0	100%	0.0	None	No	Not feasible due to property having greater than 75% hydric soil.
Reinders	Germantown	Washington	25.7	32.6	127%	-6.9	None	No	Not feasible due to property having greater than 75% hydric soil.
Minor	Germantown	Washington	15.4	27.9	182%	-12.5	None	No	Not feasible due to property having greater than 75% hydric soil.
Radicevich	Franklin	Milwaukee	15.6	3.9	25%	11.8	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Dix	Fredonia	Ozaukee	80.1	28.0	35%	52.1	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Marti (Steffel)	Mequon	Ozaukee	54.7	19.5	36%	35.2	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Stauss	Germantown	Washington	167.4	88.4	53%	79.0	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Kons	Germantown	Washington	44.2	24.0	54%	20.2	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Swartz	Germantown	Washington	13.0	8.7	67%	4.3	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
MLG	Germantown	Washington	52.0	37.0	71%	15.0	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
St. Nikola	Franklin	Milwaukee	17.3	12.5	72%	4.8	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Griffiths	Mequon	Ozaukee	17.9	13.0	72%	4.9	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Franklin DC East	Franklin	Milwaukee	45.0	33.0	73%	12.0	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Baravella	Germantown	Washington	17.8	13.4	75%	4.4	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Hoerig	Mequon	Ozaukee	72.9	63.2	87%	9.7	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Boehlke	Germantown	Washington	21.2	18.8	89%	2.4	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Wiskerchen	Fredonia	Ozaukee	40.0	36.2	91%	3.8	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
St. Sava	Franklin	Milwaukee	24.2	22.4	93%	1.7	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Schubert	Cedarburg	Ozaukee	74.0	70.5	95%	3.5	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Babiasz	Mequon	Ozaukee	30.2	29.0	96%	1.2	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.
Schwefel	Germantown	Washington	16.4	41.1	251%	-24.7	DNR Stewardship	No	Not feasible due to property acquired through WDNR Stewardship.

Appendix H
Fee Simple Renewable Energy Potential Summary

FID	Property #	Property Address	Area (acres)	Grantor Name	Feasible for Renewable Energy (Y/N)?	Notes
53	722	4926 W Green Tree Rd	45.1	Towne Realty, Inc.	Yes	
397	1152	4343 S 6th St	15.2	Central Steel & Wire	Yes	
408	3468	1436 E Forest Hill Ave	11.8	Camio Barbian-Gayan, Personal Representative of the Estate of James N. Barbian, Deceased	Yes	
63	72	4900 W State St	3.5	Central Ready Mixed Concrete, Inc.	Yes	
284	70	1016 N Hawley Rd	3.3	City of Milwaukee	Yes	
379	3138	4330 N 35th St	2.4	Pittman, James Dba Bee Bus Lines, Inc.	Yes	
42	3092	900 N 43rd St	2.4	W.R. Grace & Co.	Yes	
380	3139	4320 N 35th St	2.2	Pittman, James Dba Bee Bus Lines, Inc.	Yes	
378	3137	4350 N 35th St	2.0	Multiple	Yes	
383	3142	4250 N 35th St	1.9	City of Milwaukee, Redevelopment Authority	Yes	
214	76	4200 W Monarch Pl	1.1	Illing Family Limited Partnership	Yes	
381	3140	4260-4300 N 35th St	1.0	Pittman, James Dba Bee Bus Lines, Inc.	Yes	
76	2800	8600 S 5th Ave	63.1	Home Real Estate and Investment Co.	No	This property is included with the SSWRF evaluation.
384	3153	8600 S 5th Ave	49.6	None	No	This property is included with the SSWRF evaluation.
330	551	9800 N Swan Blvd	48.8	County of Milwaukee	No	This property is a recreation area. Renewable energy not feasible.
14	553	10602 Underwood Creek Pkwy	40.7	County of Milwaukee	No	This property is a recreation area. Renewable energy not feasible.
116	1883	700 E Jones St	33.6	City of Milwaukee	No	This property is included with the JIWRF evaluation.
75	2794	8400 S 5th Ave	31.2	Marie B. Gottschalk, Ida Yunker and Marie Y. Schwarting	No	This property is included with the SSWRF evaluation
82	2801	8415 S 5th Ave	30.9	B & G Land Development Inc.	No	This property is heavily forested. Renewable energy not feasible.
60	1879	700 E Jones St	21.5	City of Milwaukee	No	This property is included with the JIWRF evaluation.
19	745	3353 W Glendale Ave	19.1	County of Milwaukee	No	This property is located over water. Renewable energy not feasible.
225	3046	4357 N 37th St	10.8	County of Milwaukee	No	This property is located over water. Renewable energy not feasible.
416	3517	2425 S 35th St	9.4	Wisconsin Gas LLC Doing Business as We Energies	No	This property is a We Energies building. Renewable energy not feasible.
269	1885	700 E Jones St	9.3	City of Milwaukee	No	This property is included with the JIWRF evaluation.
412	1884	700 E Jones St	9.1	State of Wisconsin	No	This property is included with the JIWRF evaluation.
209	1758	164 N 44th St	8.5	Chicago, Milwaukee, St. Paul & Pacific Railroad Co.	No	This property is located over a highway and has a shape that is not conducive to renewable energy.
43	2864	260 W Seeboth St	7.5	Chicago, Milwaukee, St. Paul & Pacific Railroad Co.	No	This property is MMSD's corporate office. Renewable energy not feasible.
288	349	W Fisher Pkwy	6.8	County of Milwaukee	No	This property is located over water. Renewable energy not feasible.
389	344	N Mayfair Rd	6.6	County of Milwaukee	No	This property is located over water. Renewable energy not feasible.
310	723	5100 W Green Tree Rd	6.1	County of Milwaukee	No	This property has a shape that is not conducive to renewable energy.
167	2556	5074 W Mill Rd	6.1	Roland J. Teske Co., Inc	No	This property is located over a highway and has a shape that is not conducive to renewable energy.
339	2844	3102 W Morgan Ave	5.4	James L. Callan and Robert G. Dela Hunt	No	This property has a shape that is not conducive to renewable energy.
415	3528	W Bradley Rd	5.3	Village of Brown Deer	No	This property is located over water. Renewable energy not feasible.

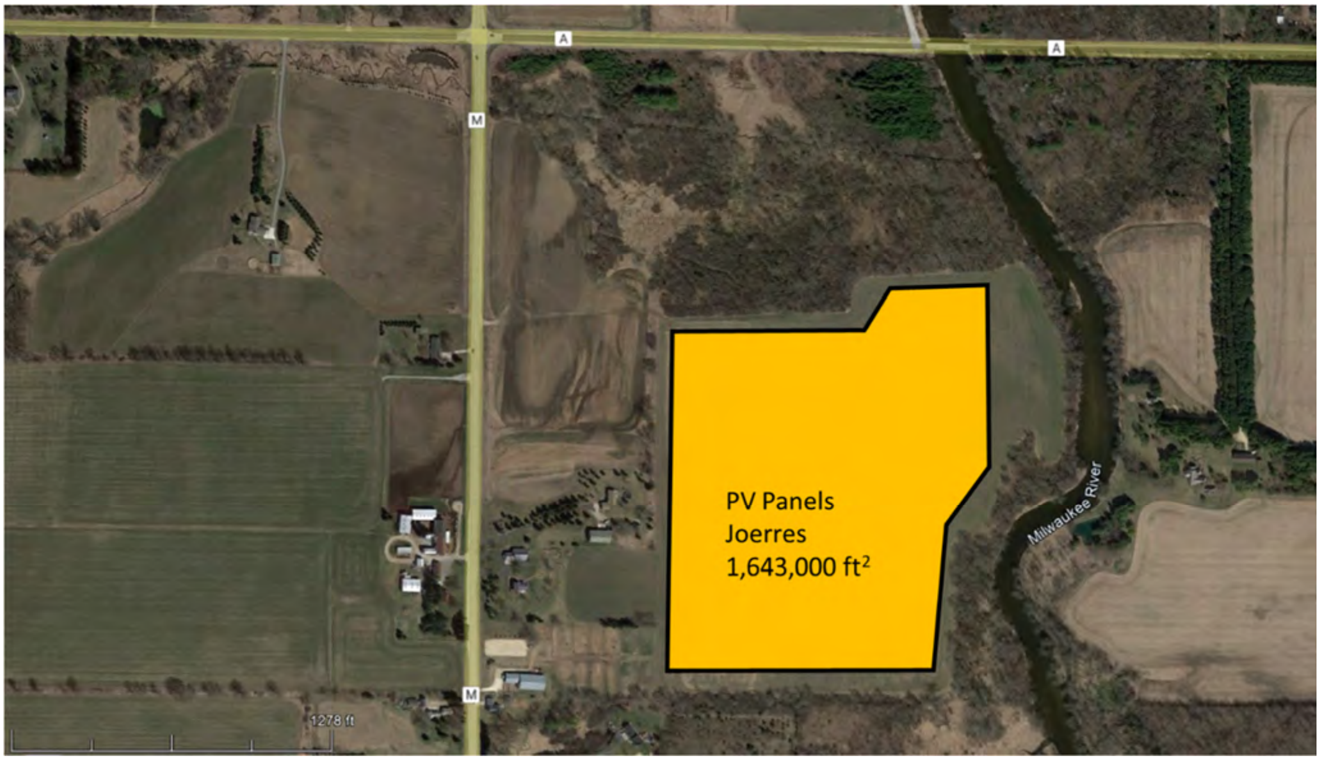
FID	Property #	Property Address	Area (acres)	Grantor Name	Feasible for Renewable Energy (Y/N)?	Notes
421	1318	3600 S 27th St	5.1	Alexander Weiler	No	This property is located over water. Renewable energy not feasible.
413	1891	700 E Jones St	5.1	City of Milwaukee	No	This property is included with the JIWRF evaluation.
418	3146	4235 N 30th St	5.0	Drs Power & Technologies, Inc.	No	This property is a recreation area and a CNG fueling station. Renewable energy not feasible.
417	3518	3460 W Leeds Place	5.0	Dion-Simon Investments LLC	No	This property has a building on it and is somewhat forested. Renewable energy not feasible.
398	67	6001 W State St	4.2	Sears, Roebuck & Co.	No	This property contains multiple buildings. Renewable energy not feasible.
22	1660	3600 S 27th St	4.0	Arthur J. Stenz & Caroline A. Stenz, et al	No	This property is located over water and has a shape that is not conducive to renewable energy.
12	752	3323 W Glendale Ave	3.8	CMC Heartland Partners	No	This property has a shape that is not conducive to renewable energy.
74	2845	3102 W Morgan Ave	3.4	S.D. Realty Co.	No	This property is located over water and a channel and has a shape that is not conducive to renewable energy.
394	3266	3410 W Hopkins St	3.2	Hopkins Development Group	No	This property primarily consists of a building. Renewable energy not feasible.
69	87	2702 S 6th St	3.2	County of Milwaukee	No	This property is located over water and a road. Renewable energy not feasible.
23	2846	3545 S 27th St	3.1	Multiple	No	This property primarily consists of a parking lot. Renewable energy not feasible.
356	541	8301 N Port Washington Rd	3.0	Patricia Ann Donohue	No	This property primarily consists of ponded water. Renewable energy not feasible.
59	3056	6044 S 13th St	3.0	City of Milwaukee	No	This property primarily consists of a parking lot. Renewable energy not feasible.
385	3262	3353 W Glendale Ave	2.9	City of Milwaukee	No	This property has a shape that is not conducive to renewable energy.
84	2998	4431 S 6th St	2.9	Wegener Greenhouses, Inc.	No	This property is located over water and has a shape that is not conducive to renewable energy.
406	68	1033 N Hawley Rd	2.9	Ashland, Inc.	No	This property has remnants of buildings on it. Renewable energy not feasible.
224	2400	6985 N River Rd	2.7	Multiple	No	This property appears to be a residential property. Renewable energy not feasible.
390	346	N Mayfair Rd	2.3	County of Milwaukee	No	This property is located over water. Renewable energy not feasible.
81	2986	4431 S 6th St	2.2	Central Steel & Wire	No	This property is located over water. Renewable energy not feasible.
291	71	1016R N Hawley Rd	2.1	Eco-Tech of Milwaukee, Inc.	No	This property is located over water. Renewable energy not feasible.
400	462	1225 S Carferry Dr	2.0	City of Milwaukee	No	This property is included with the JIWRF evaluation.
391	2560	N Mayfair Rd	2.0	County of Milwaukee	No	This property is located over water. Renewable energy not feasible.
361	2876	4710 S Root River Pkwy	2.0	Angeline C. Gunther	No	This property appears to be a wetland and possibly a residential area. Renewable energy not feasible.
342	2971	4247 S 13th St	2.0	Anton and Anna Hartl	No	This property is located over water. Renewable energy not feasible.
72	2795	8600 S 5th Ave	1.9	Marie B. Gottschalk, Ida Yunker and Marie Y. Schwarting	No	This property is included with the SSWRF evaluation.
71	2771	6555 W Dodge Pl	1.7	Trend Builders, Inc.	No	This property is located over water. Renewable energy not feasible.
268	228	Channel	1.6	County of Milwaukee	No	This property is located over water and has a shape that is not conducive to renewable energy.
329	424	2901 Root River Pkwy	1.6	Jack G. Mueller	No	This property is located in a residential area. Renewable energy not feasible.

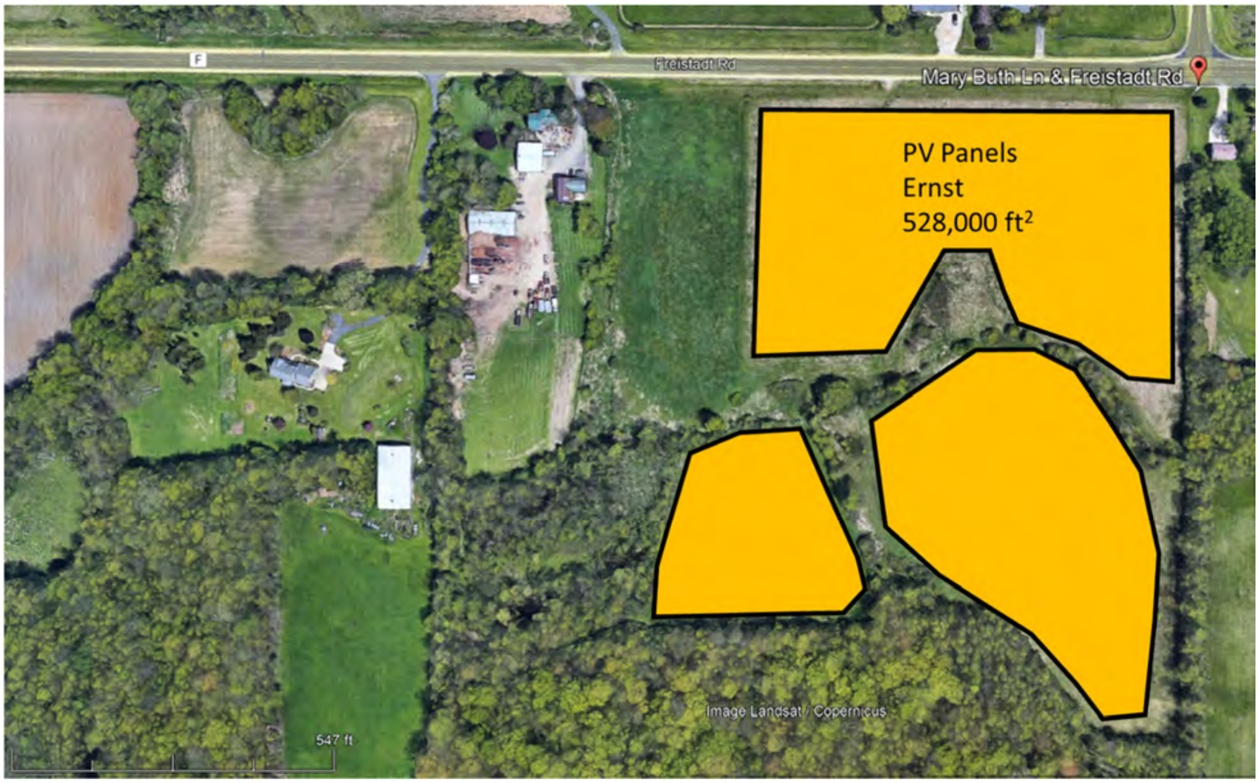
FID	Property #	Property Address	Area (acres)	Grantor Name	Feasible for Renewable Energy (Y/N)?	Notes
20	1869	1314 E Chambers St	1.6	City of Milwaukee	No	This property has a building on it and has a shape that is not conducive to renewable energy.
61	1422	2851 S 16th St	1.6	Howe Sound Company	No	This property is located over water. Renewable energy not feasible.
15	1042	7415 W Bennett Ave	1.6	August and Irene Urbanek	No	This property is located over water. Renewable energy not feasible.
334	425	2939 Root River Pkwy	1.5	Richard and Jeri Beres	No	This property is adjacent to a creek/stream and appears to be a wetland. Renewable energy not feasible.
347	2156	300 N 40th St	1.5	Wisconsin Electric Power Co	No	This property appears to be a recreational area. Renewable energy not feasible.
327	427	2951 Root River Pkwy	1.5	Peter D & Angela K Ragen	No	This property is adjacent to a creek/stream and appears to be a wetland. Renewable energy not feasible.
407	991	1029 N Hawley Rd	1.5	Badger Alloys, Inc.	No	This property has remnants of buildings on it. Renewable energy not feasible.
301	2991	4300 S 13th St	1.5	Consolidated Concrete & Materials Corp.	No	This property is located over water and a road. Renewable energy not feasible.
420	3497	South of 4900 W James St	1.5	Central Ready Mixed Concrete, Inc.	No	This property has a shape that is not conducive to renewable energy.
27	2494	2122 S 4th St	1.5	Vilter Manufacturing Corp.	No	This property has a building on it and is adjacent to the Kinnickinnic River. Renewable energy not feasible.
24	2764	6500 W Howard Ave	1.4	Leonore Butt	No	This property is located over water and over a channel. Renewable energy not feasible.
403	3404	4044 N 31st St	1.4	G&D Properties, LLC	No	This property has a building on it. Renewable energy not feasible.
414	3488	4427 S 6th St	1.4	Todd C. & Claire M. Raasch	No	This property has houses and parking on it. Renewable energy not feasible.
245	2203	1701 N Lincoln Memorial Dr	1.4	City of Milwaukee	No	This property has a shape that is not conducive to renewable energy.
386	3154	2820 S 124th St	1.3	Lawrence & Dorothy Riley	No	This property appears to be a residential property. Renewable energy not feasible.
425	3726	3102 W Hampton Ave	1.3	Amanda M, David J & John A Hanser	No	This property has a building on it. Renewable energy not feasible.
348	1974	W Fisher Pkwy	1.3	Badger Mutual Insurance Co.	No	This property is located over a channel. Renewable energy not feasible.
302	2749	2201 W Van Beck Ave	1.2	Leonard R. & Augusta Pietrasik	No	This property is residential and next to a channel. Renewable energy not feasible.
300	2993	602 W Armour Ave	1.2	Marion & Anna R. Rishel	No	This property is residential, next to a channel and over a road. Renewable energy not feasible.
142	2207	2644 S Chase Ave	1.2	City of Milwaukee	No	This property has buildings on it and is adjacent to the Kinnickinnic River. Renewable energy not feasible.
3	536	160 E Dean Rd	1.2	Evelyn L. Werwath	No	This property is adjacent to a creek/stream and appears to be a wetland. Renewable energy not feasible.
405	3430	5421 W Thurston Ave	1.2	City of Milwaukee	No	This property is located over water. Renewable energy not feasible.
17	2370	11575 W Forest Home Ave	1.1	Sacred Heart Monastery of Franklin	No	This property has a building on it. Renewable energy not feasible.
422	3568	602R W Armour Ave	1.1	Joseph & Irene Kotarak	No	This property is located over water. Renewable energy not feasible.
64	2503	2702R S 6th St	1.1	County of Milwaukee	No	This property is located over the Kinnickinnic River. Renewable energy not feasible.
359	2833	1005 E Reservoir Ave	1.0	CMC Real Estate Corp.	No	This property has residential and recreational uses. Renewable energy not feasible.

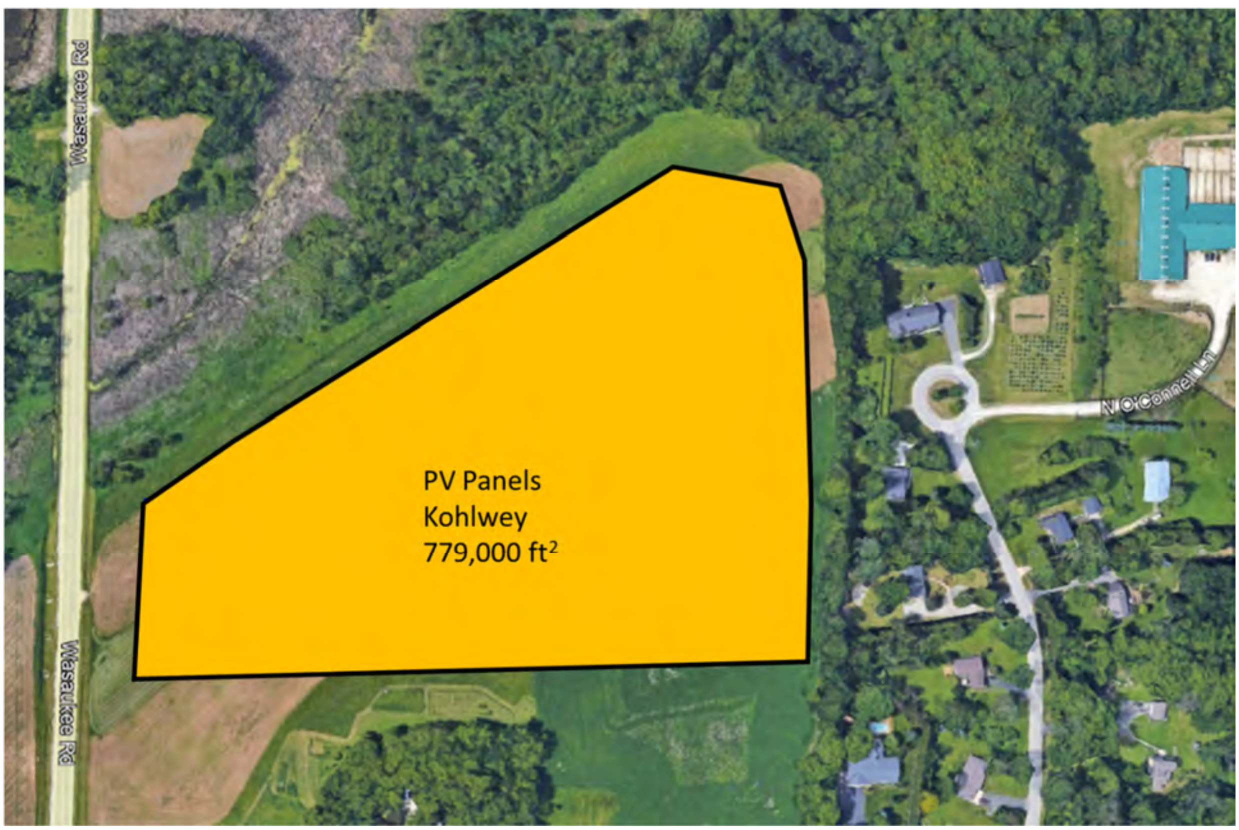
Appendix I

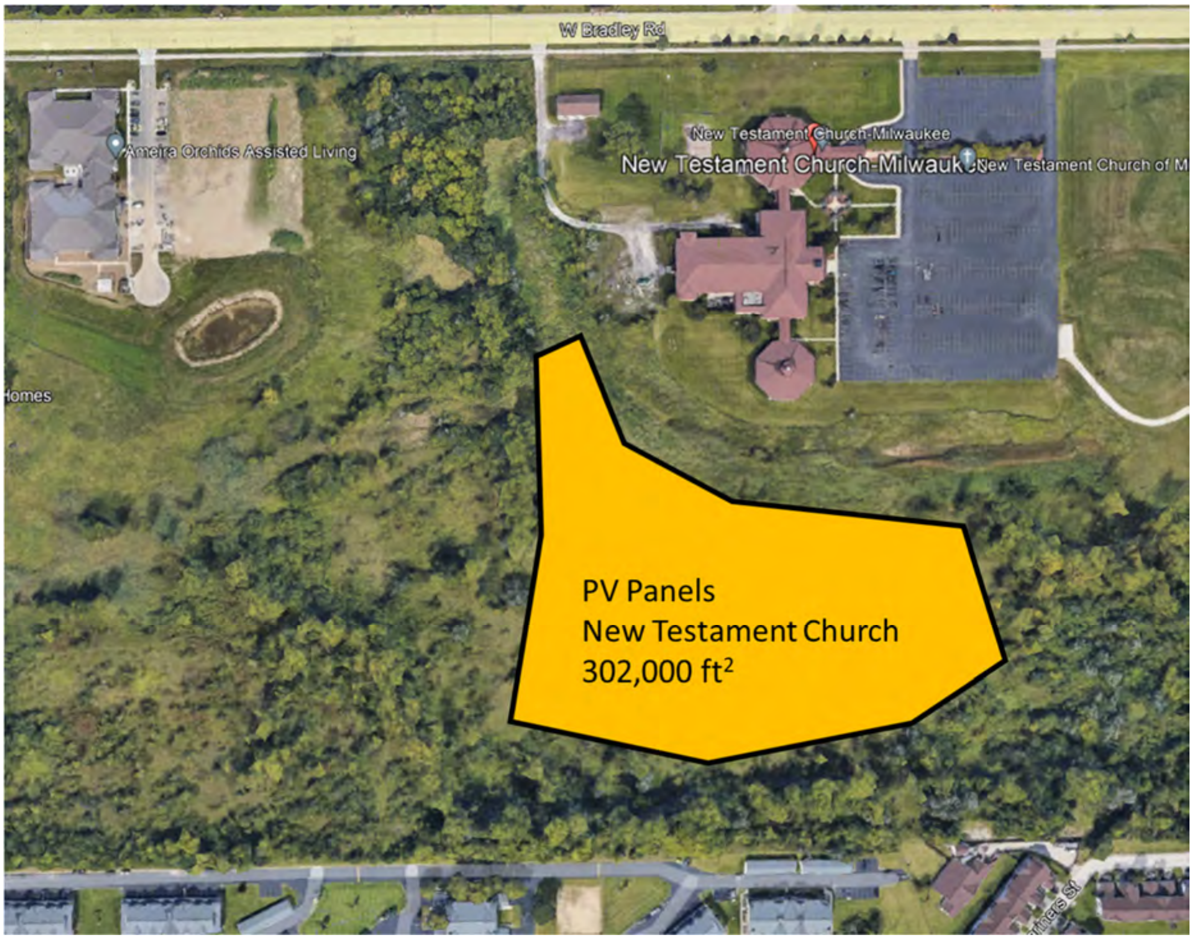
Alternative 2 - Fee Simple Electricity Generation Analysis

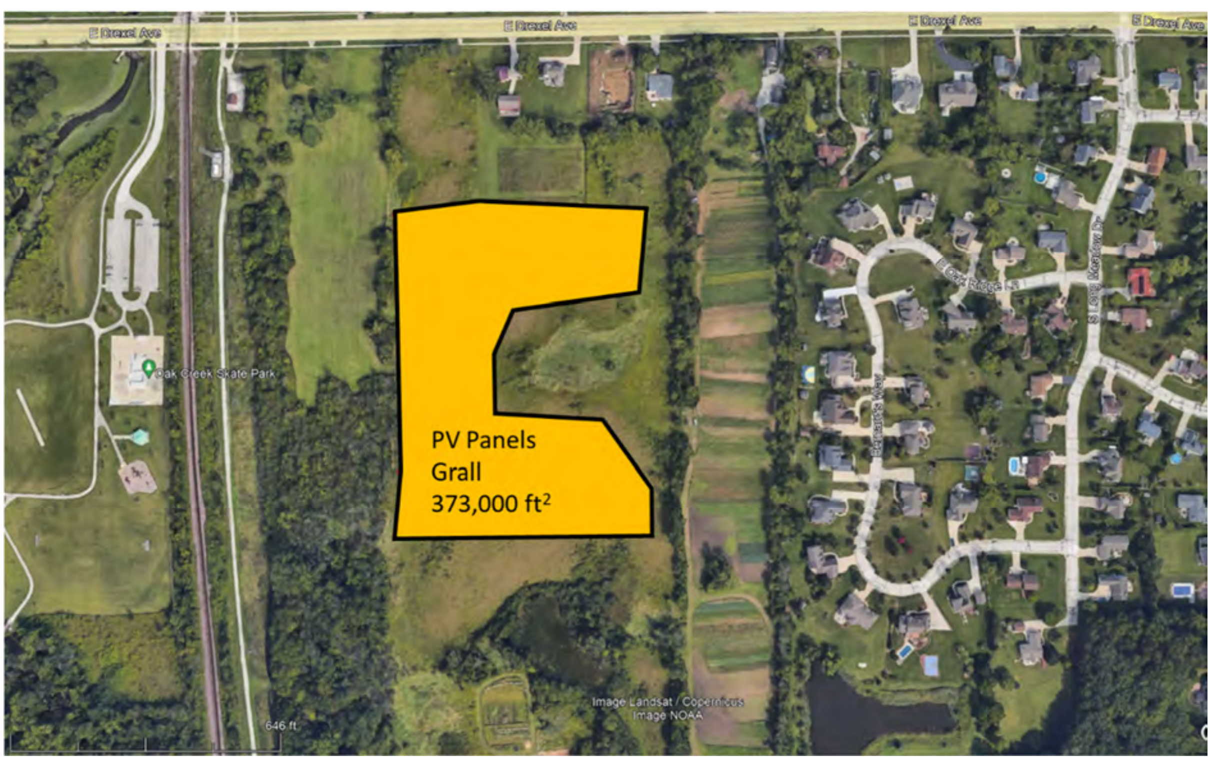
GREENSEAMS PROPERTIES




Freistadt Rd
Mary Buth Ln & Freistadt Rd
PV Panels
Ernst
528,000 ft²
Image Landsat / Copernicus
547 ft

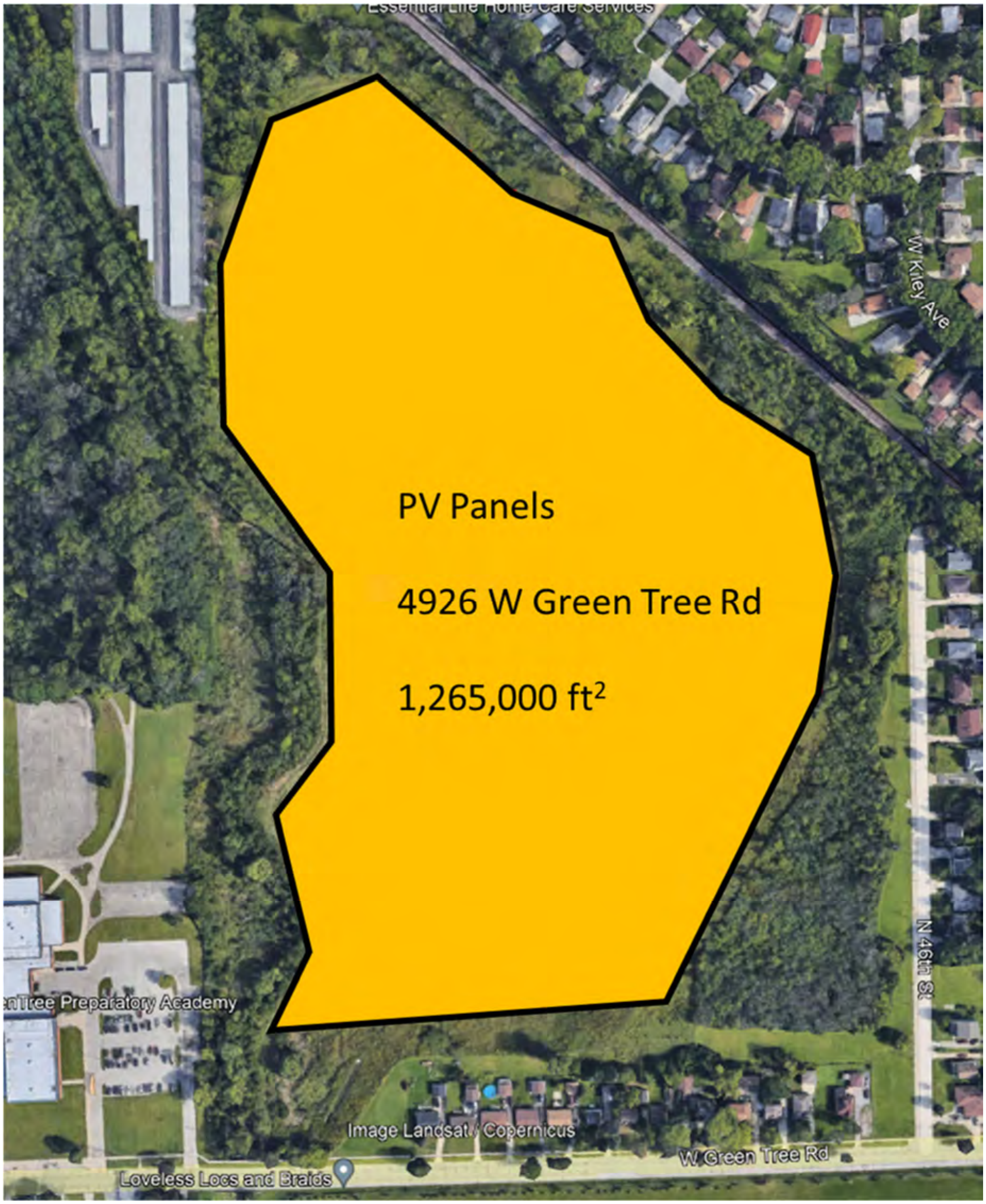

Wasaukee Rd
PV Panels
Kohlwey
779,000 ft²
N O'Connell Ln
Wasaukee Rd

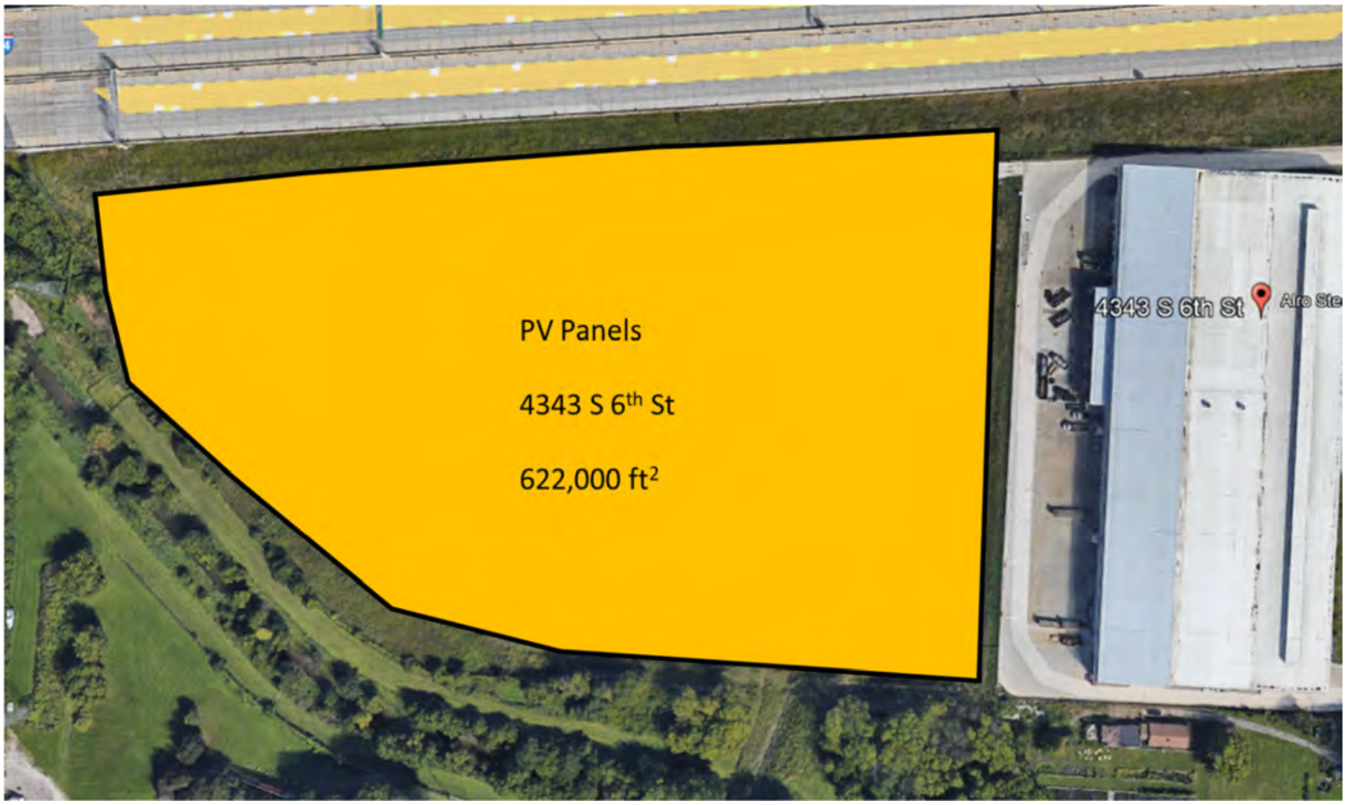

W Bradley Rd
New Testament Church-Milwaukee
Ameira Orchids Assisted Living
PV Panels
New Testament Church
302,000 ft²

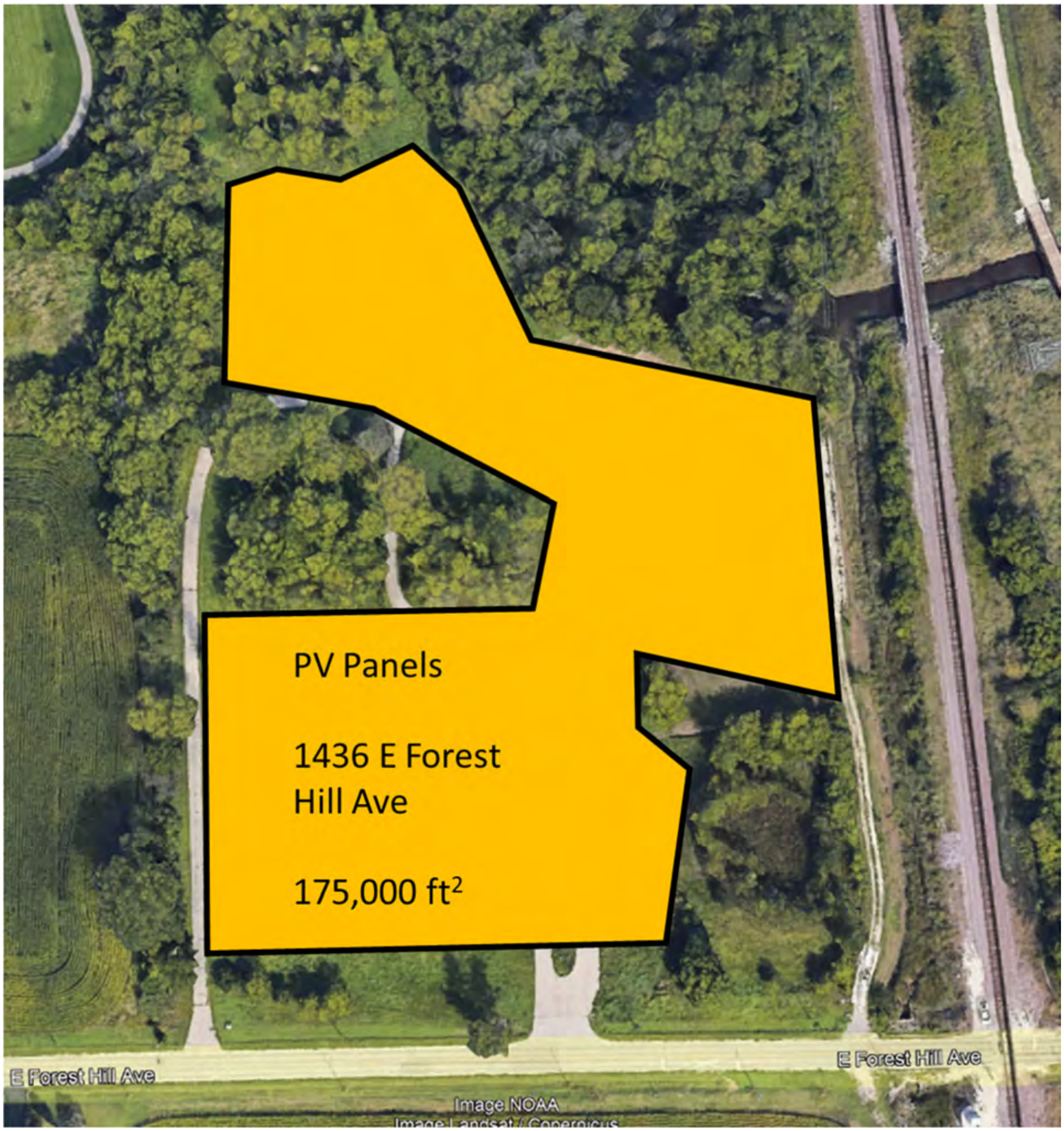

E Drexel Ave
Oak Creek Skate Park
PV Panels
Grall
373,000 ft²

FEE SIMPLE PROPERTIES


W Congress St
W Congress St
N 35th St
Bug's Life Learning Center 2 Llc
N 37th St
N 36th St
W Marion St
Wind Turbine (380')
4250-4350 N 35th St
Clemens Public School
Heaven's Playground CC & Learning Center
Quality Electric Service

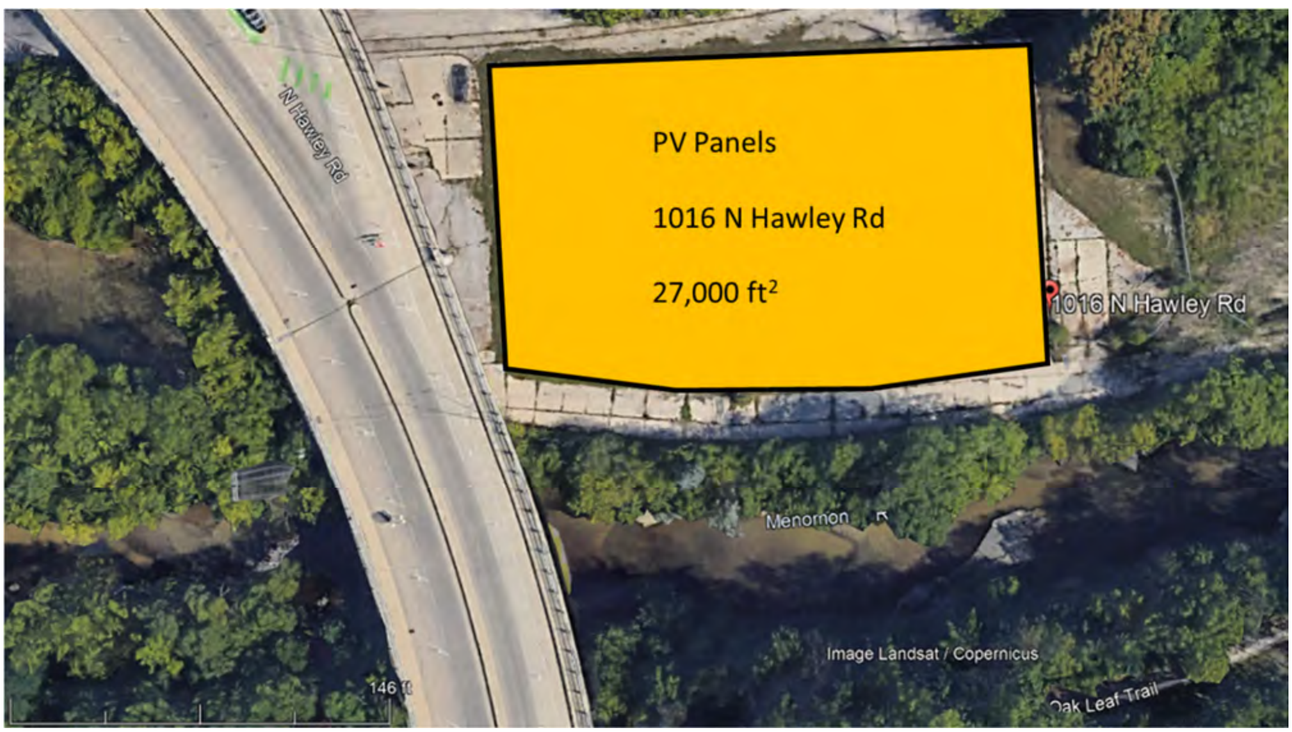

Essential Life Home Care Services
PV Panels
4926 W Green Tree Rd
1,265,000 ft²
W Kiley Ave
N 46th St
enTree Preparatory Academy
Image Landsat / Copernicus
W Green Tree Rd
Loveless Locs and Braids


PV Panels
4343 S 6th St
622,000 ft2
4343 S 6th St


PV Panels
1436 E Forest Hill Ave
175,000 ft²
E Forest Hill Ave
E Forest Hill Ave
Image NOAA


rning Center 2,Llc
PV Panels
4250-4350 N 35th St
268,000 ft2

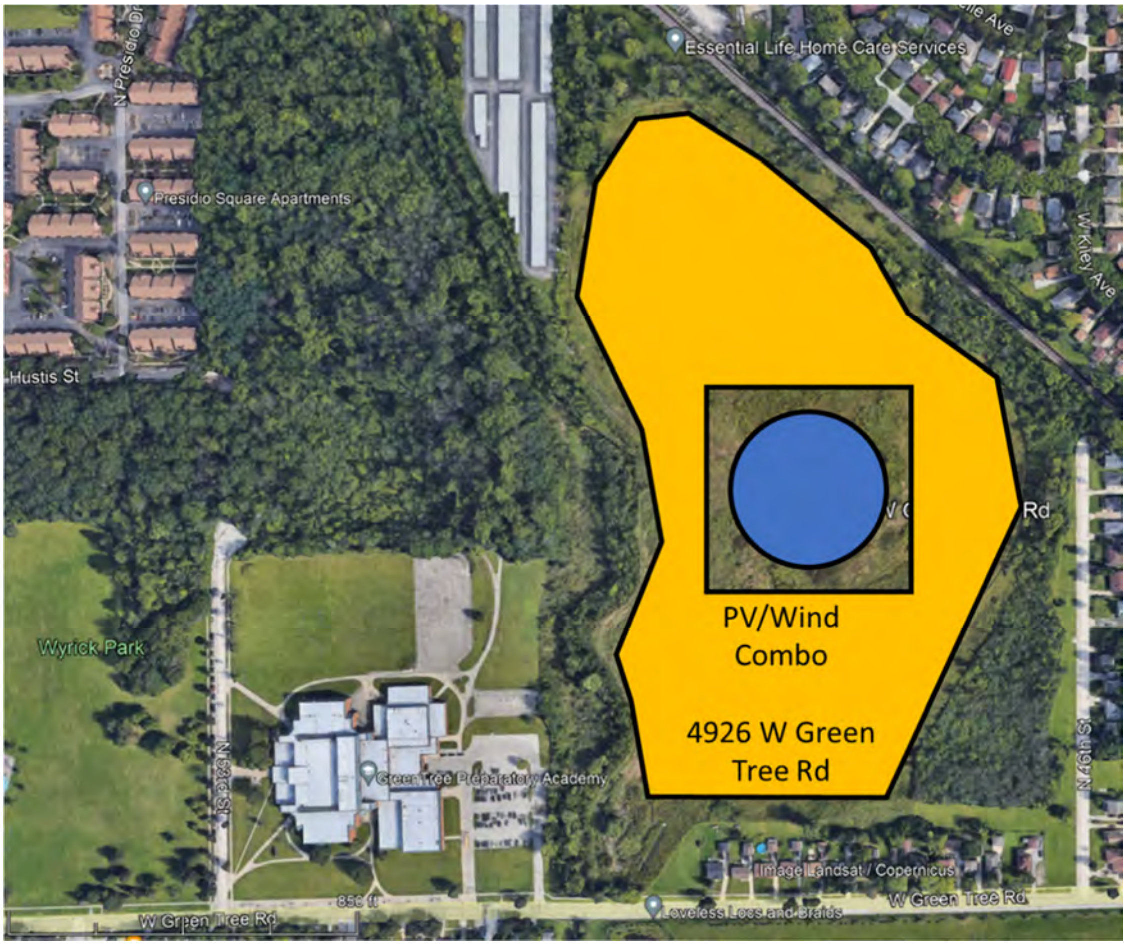
Menomonee River
PV Panels
4900 W State St
51,000 ft²
Image Landsat / Copernicus
255 ft



N Hawley Rd
PV Panels
1016 N Hawley Rd
27,000 ft²
1016 N Hawley Rd
Image Landsat / Copernicus
146 ft
Oak Leaf Trail

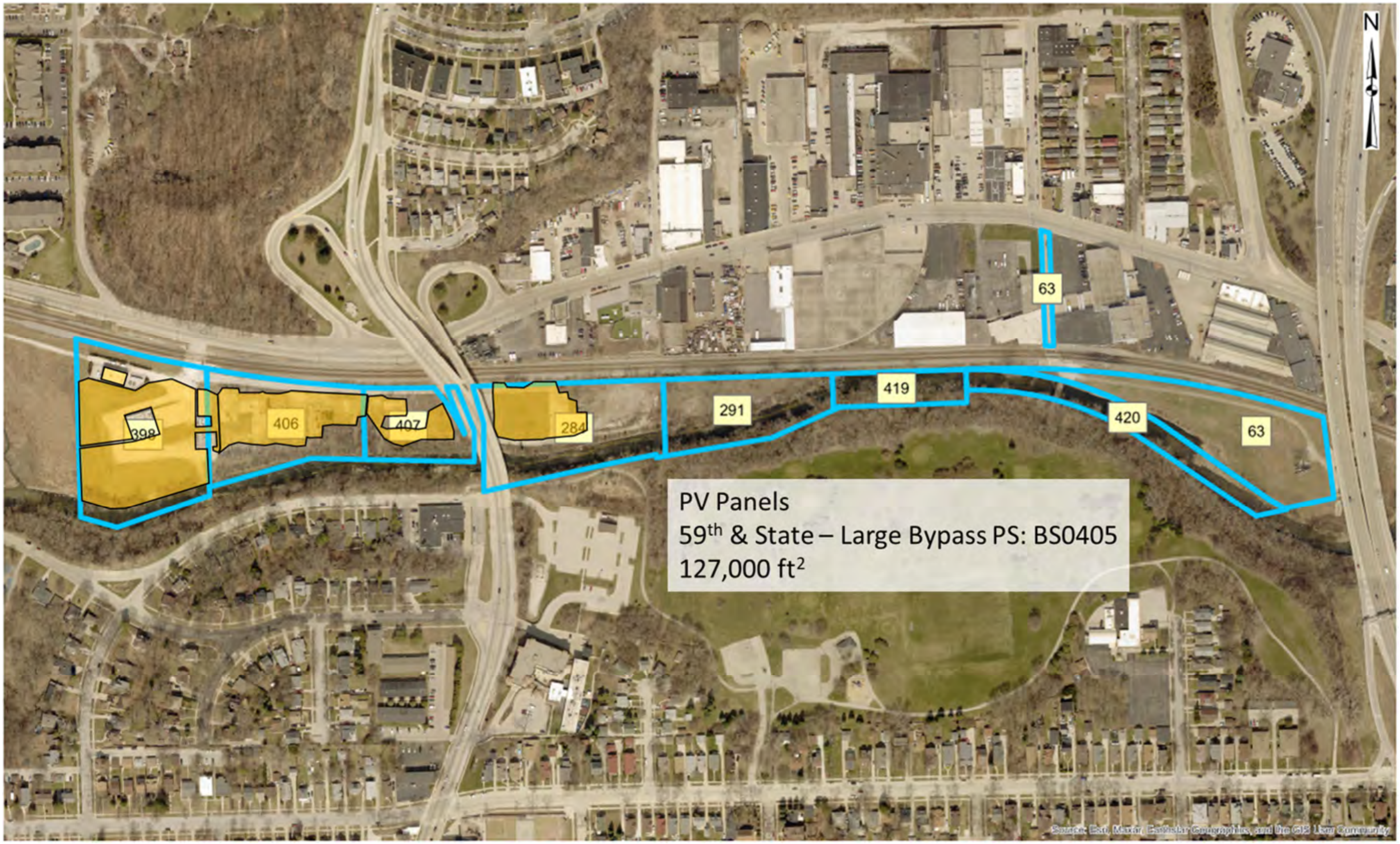

Leon Pallets
W Monarch Pl
Braden Plumbing
PV Panels
900 N 43rd St
65,000 ft2
Image Landsat / Copernicus
201 ft

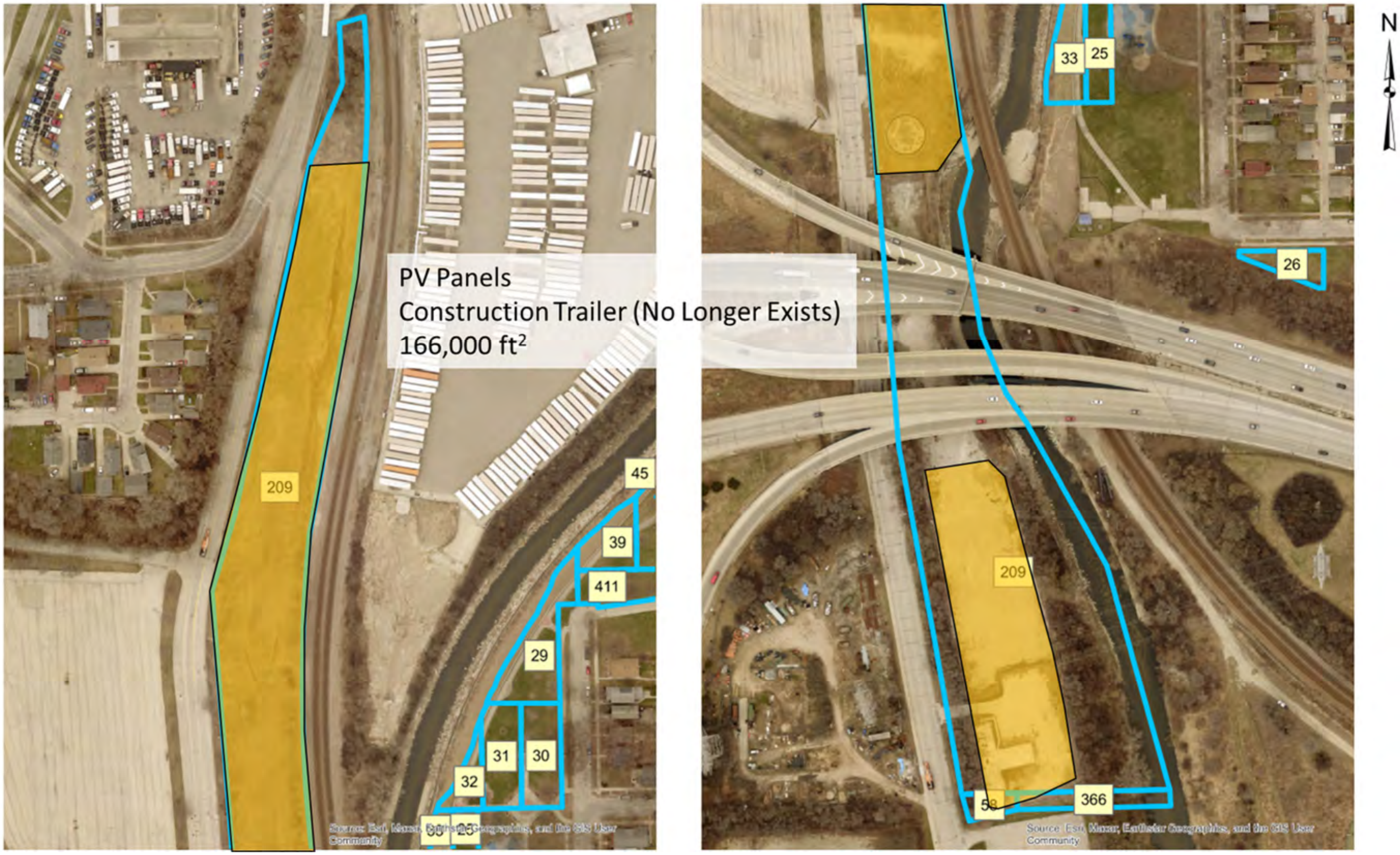

PV Panels
4200 W Monarch Pl
28,000 ft2
Image Landsat / Copernicus
200 ft


Essential Life Home Care Services
Presidio Square Apartments
N Presidio Dr
Hustis St
Wyrick Park
Green Tree Preparatory Academy
PV/Wind
Combo
4926 W Green
Tree Rd
W Kiley Ave
Image Landsat / Copernicus
W Green Tree Rd
Loveless Locs and Braids
850 ft


PV/Wind
Combo
4343 S 6th St
4343 S 6th St
Alro St
760 ft

CONVEYANCE PROPERITES





GREELEY AND HANSEN

Example Panel Configuration

Address	Area (ft^3)
4926 W Green Tree Rd	1,265,000
4343 S 6th St	622,000
1436 E Forest Hill Ave	175,000
4250-4350 N 35th St	289,000
TOTAL	**2,351,000**

Appendix J

High Strength Waste Calculations

ALTERNATIVE 1			
FOOD WASTE - Existing Conditions with Planned Improvements			
Parameter	**Quantity**	**Units**	**Notes and References**

User Inputs in BLUE

Constants			
Design VSLR	0.12	lbd/ft^3	BAFP Pg. 70
Minimum SRT	15	days	BAFP Pg. 70
Slurried Food Waste Characteristics	10%	%TS	Typical of Slurried Food Waste (GPSD January 2016)
	0.94	VS/TS	Typical of Slurried Food Waste (GPSD January 2016)
Expected VSR	85%	%	Typical of Food Waste (GPSD January 2016)
Specific Biogas Production Rate	16	ft^3/lb VSR	

Digester Gas Parameters			
Digester Gas Needed After Planned Improvements	87,500	MMBTU/yr	
	87,479	dTh/yr	
	87,480,000	CF/yr	
	166	SCFM	100% Methane
	277	SCFM of DG	Assumes digester gas has 60% methane

Biogas Production Potential			
Biogas Production Needed	400,000	SCFD	
Volatiles Destroyed	25,000	lb/day	
VS Loading Needed	29,500	lb/day	
	14.8	tons/day	
TS Loading Needed	31,400	lb/day	
	15.7	tons/day	
Additional Biosolids for Disposal	6,400	lb/day	

Digester Size (VS Loading Design Basis)			
Digester Volume Needed (Design)	246,000	ft^3	Volume needed based solely on design VSLR
	1,841,000	gal	

Digester Size (SRT Design Basis)			
Digester Hydraulic Capacity	37,650	gpd	
Digester Volume Needed (SRT Basis)	75,501	ft^3	Volume needed based on solids retention time
	564,748	gal	

Digester Volume			
Digester Volume Needed	**246,000**	**ft^3**	The greater of the two calculated digester volumes is used
	1,841,000	**gal**	

Existing Digester Volume			
Existing Digester Volume	2,045,455	ft^3	
Existing Design VS Loading Capacity	245,455	lbd VS/day	Only mesophilic digester space was considered due to unknowns surrounding food waste in thermophilic digesters
Current Sludge Feed	157,114	lbd VS/day	
Remaining VS Loading	88,341	lbd VS/day	
Remaining Available Volume	736,172	ft^3	
% of Remaining Volume Available for Food Waste	20%	%	
Digester Volume Available for Food Waste	147,234	ft^3	
Remaining Digester Volume Needed for Food Waste	98,766	ft^3	
Desired Buffer	20,000	ft^3	
Remaining Digester Volume Needed	120,000	ft^3	

New Digester Volume			
Digester Volume Needed	120,000	ft^3	
	897,600	gal	
	0.90	MG	
Desired Digester Size	0.50	MG	
Quantity of Digesters Needed	2		
Digester Volume	66,845	ft^3	
Digester Diameter	58	ft	
Digester Sidewater Depth	25.0	ft	

Food Waste Summary Table - Current Flow and Loadings (with Primary Clarifier Improvements)			
Digester Gas Needed After Planned Improvements	87,500	MMBTU/yr	
	277	SCFM of DG	
Quantity of Food Waste Needed	15.7	tons/day	
Digester Volume Needed	246,000	ft^3	
Volume to Existing Digesters	126,000	ft^3	
Volume to New Digesters	120,000	ft^3	
New Digester Size	0.50	MG	
Quantity of New Digesters Needed	2		
Digester Diameter	58	ft	
Digester Sidewater Depth	25.0	ft	

Energy for Heating Incoming Sludge			
Flow	37,650	gal/day	Based on total slurried food waste flow, assuming 10% TS
Digester Temperature	95	F	Assumed value
Inlet Sludge Temp, min	53	F	Assumed value
Inlet Sludge Temp, max	75	F	Assumed value
BTU Required to Heat Sludge, winter	549,061	BTU/hr	BTU/hr = GPM X (ΔT X 500)
BTU Required to Heat Sludge, summer	261,458	BTU/hr	BTU/hr = GPM X (ΔT X 500)

Digester Heat Losses			
Digester Cover Heat Transfer Coefficient	0.825	BTU/(ft^2*F*h)	
Ambient Temp, Min	20	F	Average daily low for December, January, February (https://www.weather.gov/mkx/monthly_climate_table)
Ambient Temp, Max	80	F	Average daily high for June, July, August (https://www.weather.gov/mkx/monthly_climate_table)
Digester Dome Height	25	ft	Assumed value
Digester Cover Dome Area	4,583	ft^2	
Digester Cover Heat Losses, Min	56,709	BTU/hr	
Digester Cover Heat Losses, Max	283,547	BTU/hr	
Digester Wall to Air Area	917	ft^2	Assumes 80% of digester is underground
Wall to Air Heat Transfer Coefficient	0.27	BTU/(ft^2*F*h)	Concrete wall / 1" air space / Brick
Digester Wall to Air Heat Losses, Min	3,712	BTU/hr	
Digester Wall to Air Heat Losses, Max	18,559	BTU/hr	
Cone Depth	10.0	ft	
Digester to Earth Area	6,493	ft^2	Assumes 80% of digester is underground
Earth Heat Transfer Coefficient	0.11	BTU/(ft^2*F*h)	Concrete floor exposed to earth
Digester to Earth Heat Losses, Min	10,713	BTU/hr	
Digester to Earth Heat Losses, Max	53,564	BTU/hr	
Total Heat Losses, winter	355,670	BTU/hr	
Total Heat Losses, summer	71,134	BTU/hr	

Total Heating Requirements			
Winter Conditions	1,260,400	BTU/hr	
Summer Conditions	403,725	BTU/hr	
Total	1,664,125	BTU/hr	
	14,578	MMBTU/yr	

HSW Energy Needed			
Total Flow Needed	**250**	**GPM**	System is comparable to EBMUD, which has 250 GPM flow rate. https://www.biocycle.net/green-energy-from-food-wastes-at-wastewater-treatment-plant/
Slurry Tank Mixers	3	Quantity	Assumed 3 mixers needed at 20 hp per mixer
	20	hp	
	60	Total hp	
Paddle Finisher (Brown 202)	3	Quantity	Capacity is 40-125 GPM. Quantity of 3 assumed for buffer. https://www.loebequipment.com/inventory/20-hp-ss-paddle-type-brown-mdl-202-pulper-finisher-paddle-type-w-2-blades-electrica/
	20	hp	
	60	Total hp	
Grinder (10K Open Channel Muffin Monster)	1	Quantity	Used for flow rate up to 550 GPM. https://www.jwce.com/products/10k-in-line-muffin-monster/
	5	hp	
	5	Total hp	
Peristaltic Pump (Bredel 2100)	1	Quantity	Provides flow rates up to 475 GPM. https://www.wmfts.com/en-us/bredel/hose-pumps/bredel-hose-pumps-65-2100/
	27	hp	
	27	Total hp	
Total Equipment Energy Needed	152	Total hP	
	114	Total kW Needed	
	389,000	BTU/hr Needed	
	3,500	MMBTU/yr	
Total Heating Energy Needed	15,000	MMBTU/yr	
Building Energy Needed	1,500	MMBTU/yr	Assuming a 40,000 SF building
Total HSW Energy Needed	**20,000**	**MMBTU/yr**	

ALTERNATIVE 1

FOOD WASTE - Existing Conditions with Primary Clarifier Improvements and Digester Improvements

User Inputs in BLUE

Parameter	Quantity	Units	Notes and References
Constants			
Design VSLR (Mesophilic)	0.12	lbd/ft^3	BAFP Pg. 70
Design VSLR (Acid-Phase)	2.4	lbd/ft^3	BAFP Pg. 70
Minimum SRT	15	days	BAFP Pg. 70
Slurried Food Waste Characteristics	10%	%TS	Typical of Slurried Food Waste (GPSD January 2016)
	0.94	VS/TS	Typical of Slurried Food Waste (GPSD January 2016)
Expected VSR	85%	%	Typical of Food Waste (GPSD January 2016)
Specific Biogas Production Rate	16	ft^3/lb VSR	
Digester Gas Parameters			
Digester Gas Needed After Planned Improvements	87,500	MMBTU/yr	
	87,479	dTh/yr	
	87,480,000	CF/yr	
	166	SCFM	100% Methane
	277	SCFM of DG	Assumes digester gas has 60% methane
Biogas Production Potential			
Biogas Production Needed	400,000	SCFD	
Volatiles Destroyed	25,000	lb/day	
VS Loading Needed	29,500	lb/day	
	14.8	tons/day	
TS Loading Needed	31,400	lb/day	
	15.7	tons/day	
Additional Biosolids for Disposal	6,400	lb/day	
Digester Size (Design Basis)			
Digester Volume Needed (Design)	246,000	ft^3	Volume needed based solely on design VSLR
	1,841,000	gal	
Digester Size (SRT Basis)			
Digester Hydraulic Capacity	37,650	gpd	
Digester Volume Needed (SRT Basis)	75,501	ft^3	Volume needed based on solids retention time
	564,748	gal	
Digester Volume			
Digester Volume Needed	**246,000**	**ft^3**	The greater of the two calculated digester volumes is used
	1,841,000	**gal**	
Existing Digester Volume			
Existing Mesophilic Digester Volume	1,791,444	ft^3	
Existing Mesophilic Design VS Loading Capacity	214,973	lbd VS/day	Only mesophilic digester space was considered due to unknowns surrounding food waste in thermophilic digesters
Current Sludge Feed	157,041	lbd VS/day	
Remaining VS Loading	57,932	lbd VS/day	
Remaining Available Volume	482,765	ft^3	
% of Remaining Volume Available for Food Waste	20%	%	
Digester Volume Available for Food Waste	96,553	ft^3	
Remaining Digester Volume Needed for Food Waste	149,447	ft^3	
Desired Buffer	20,000	ft^3	
Remaining Digester Volume Needed	170,000	ft^3	
New Digester Volume			
Digester Volume Needed	170,000	ft^3	
	1,271,600	gal	
	1.27	MG	
Desired Digester Size	0.75	MG	
Quantity of Digesters Needed	2		
Digester Volume	100,267	ft^3	
Digester Diameter	71	ft	
Digester Sidewater Depth	25.0	ft	
Food Waste Summary Table - 2045 Capacity with Current Loading Rates			
Digester Gas Needed After Planned Improvements	87,500	MMBTU/yr	
	277	SCFM of DG	
Quantity of Food Waste Needed	15.7	tons/day	
Digester Volume Needed	246,000	ft^3	
Volume to Existing Digesters	76,000	ft^3	
Volume to New Digesters	170,000	ft^3	
New Digester Size	0.75	MG	
Quantity of New Digesters Needed	2		
Digester Diameter	71	ft	
Digester Sidewater Depth	25.0	ft	
Energy for Heating Incoming Sludge			
Flow	37,650	gal/day	Based on total slurried food waste flow, assuming 10% TS
Digester Temperature	95	F	Assumed value
Inlet Sludge Temp, min	53	F	Assumed value
Inlet Sludge Temp, max	75	F	Assumed value
BTU Required to Heat Sludge, winter	549,061	BTU/hr	BTU/hr = GPM X (ΔT X 500)
BTU Required to Heat Sludge, summer	261,458	BTU/hr	BTU/hr = GPM X (ΔT X 500)
Digester Heat Losses			
Digester Cover Heat Transfer Coefficient	0.825	BTU/(ft^2*F*h)	
Ambient Temp, Min	20	F	Average daily low for December, January, February (https://www.weather.gov/mkx/monthly_climate_table)
Ambient Temp, Max	80	F	Average daily high for June, July, August (https://www.weather.gov/mkx/monthly_climate_table)
Digester Dome Height	25	ft	Assumed value
Digester Cover Dome Area	5,612	ft^2	
Digester Cover Heat Losses, Min	69,454	BTU/hr	
Digester Cover Heat Losses, Max	347,272	BTU/hr	
Digester Wall to Air Area	1,122	ft^2	Assumes 80% of digester is underground
Wall to Air Heat Transfer Coefficient	0.27	BTU/(ft^2*F*h)	Concrete wall / 1" air space / Brick
Digester Wall to Air Heat Losses, Min	4,546	BTU/hr	
Digester Wall to Air Heat Losses, Max	22,731	BTU/hr	
Cone Depth	10.0	ft	
Digester to Earth Area	8,655	ft^2	Assumes 80% of digester is underground
Earth Heat Transfer Coefficient	0.11	BTU/(ft^2*F*h)	Concrete floor exposed to earth
Digester to Earth Heat Losses, Min	14,280	BTU/hr	
Digester to Earth Heat Losses, Max	71,402	BTU/hr	
Total Heat Losses, winter	441,405	BTU/hr	
Total Heat Losses, summer	88,281	BTU/hr	
Total Heating Requirements			
Winter Conditions	1,431,870	BTU/hr	
Summer Conditions	438,019	BTU/hr	
Total	1,869,890	BTU/hr	
	16,380	MMBTU/yr	
HSW Energy Needed			
Total Flow Needed	**250**	**GPM**	System is comparable to EBMUD, which has 250 GPM flow rate. https://www.biocycle.net/green-energy-from-food-wastes-at-wastewater-treatment-plant/
Slurry Tank Mixers	3	Quantity	Assumed 3 mixers needed at 20 hp per mixer
	20	hp	
	60	Total hp	
Paddle Finisher (Brown 202)	3	Quantity	Capacity is 40-125 GPM. Quantity of 3 assumed for buffer. https://www.loebequipment.com/inventory/20-hp-ss-paddle-type-brown-mdl-202-pulper-finisher-paddle-type-w-2-blades-electrica/
	20	hp	
	60	Total hp	
Grinder (10K Open Channel Muffin Monster)	1	Quantity	Used for flow rate up to 550 GPM. https://www.jwce.com/products/10k-in-line-muffin-monster/
	5	hp	
	5	Total hp	
Peristaltic Pump (Bredel 2100)	1	Quantity	Provides flow rates up to 475 GPM. https://www.wmfts.com/en-us/bredel/hose-pumps/bredel-hose-pumps-65-2100/
	27	hp	
	27	Total hp	
Total Equipment Energy Needed	152	Total hP	
	114	Total kW Needed	
	389,000	BTU/hr Needed	
	3,500	MMBTU/yr	
Total Heating Energy Needed	17,000	MMBTU/yr	
Building Energy Needed	1,500	MMBTU/yr	Assuming a 40,000 SF building
Total HSW Energy Needed	**22,000**	**MMBTU/yr**	

ALTERNATIVE 1

FOOD WASTE - 2045 Flow Conditions with Digester Improvements

Parameter	Quantity	Units	Notes and References
User Inputs in BLUE			
Constants			
Design VSLR (Mesophilic)	0.12	lbd/ft^3	BAFP Pg. 70
Design VSLR (Acid-Phase)	2.4	lbd/ft^3	BAFP Pg. 70
Minimum SRT	15	days	BAFP Pg. 70
Slurried Food Waste Characteristics	10%	%TS	Typical of Slurried Food Waste (GPSD January 2016)
	0.94	VS/TS	Typical of Slurried Food Waste (GPSD January 2016)
Expected VSR	85%	%	Typical of Food Waste (GPSD January 2016)
Specific Biogas Production Rate	16	ft^3/lb VSR	
Digester Gas Parameters			
Digester Gas Needed After Planned Improvements	87,500	MMBTU/yr	
	87,479	dTh/yr	
	87,480,000	CF/yr	
	166	SCFM	100% Methane
	277	SCFM of DG	Assumes digester gas has 60% methane
Biogas Production Potential			
Biogas Production Needed	400,000	SCFD	
Volatiles Destroyed	25,000	lb/day	
VS Loading Needed	29,500	lb/day	
	14.8	tons/day	
TS Loading Needed	31,400	lb/day	
	15.7	tons/day	
Additional Biosolids for Disposal	6,400	lb/day	
Digester Size (Design Basis)			
Digester Volume Needed (Design)	246,000	ft^3	Volume needed based solely on design VSLR
	1,841,000	gal	
Digester Size (SRT Basis)			
Digester Hydraulic Capacity	37,650	gpd	
Digester Volume Needed (SRT Basis)	75,501	ft^3	Volume needed based on solids retention time
	564,748	gal	
Digester Volume			
Digester Volume Needed	**246,000**	**ft^3**	The greater of the two calculated digester volumes is used
	1,841,000	**gal**	
Existing Digester Volume			
Existing Mesophilic Digester Volume	1,791,444	ft^3	
Existing Mesophilic Design VS Loading Capacity	214,973	lbd VS/day	Only mesophilic digester space was considered due to unknowns
Current Sludge Feed	287,854	lbd VS/day	surrounding food waste in thermophilic digesters
Remaining VS Loading	0	lbd VS/day	
Remaining Available Volume	0	ft^3	
% of Remaining Volume Available for Food Waste	20%	%	
Digester Volume Available for Food Waste	0	ft^3	
Remaining Digester Volume Needed for Food Waste	246,000	ft^3	
Desired Buffer	20,000	ft^3	
Remaining Digester Volume Needed	270,000	ft^3	
New Digester Volume			
Digester Volume Needed	270,000	ft^3	
	2,019,600	gal	
	2.02	MG	
Desired Digester Size	1.25	MG	
Quantity of Digesters Needed	2		
Digester Volume	167,112	ft^3	
Digester Diameter	92	ft	
Digester Sidewater Depth	25.0	ft	
Food Waste Summary Table - 2045 Capacity and Loading Rates			
Digester Gas Needed After Planned Improvements	87,500	MMBTU/yr	
	277	SCFM of DG	
Quantity of Food Waste Needed	15.7	tons/day	
Digester Volume Needed	246,000	ft^3	
Volume to Existing Digesters	0	ft^3	
Volume to New Digesters	246,000	ft^3	
New Digester Size	1.25	MG	
Quantity of New Digesters Needed	2		
Digester Diameter	92	ft	
Digester Sidewater Depth	25.0	ft	
Energy for Heating Incoming Sludge			
Flow	37,650	gal/day	Based on total slurried food waste flow, assuming 10% TS
Digester Temperature	95	F	Assumed value
Inlet Sludge Temp, min	53	F	Assumed value
Inlet Sludge Temp, max	75	F	Assumed value
BTU Required to Heat Sludge, winter	549,061	BTU/hr	BTU/hr = GPM X (ΔT X 500)
BTU Required to Heat Sludge, summer	261,458	BTU/hr	BTU/hr = GPM X (ΔT X 500)
Digester Heat Losses			
Digester Cover Heat Transfer Coefficient	0.825	BTU/(ft^2*F*h)	
Ambient Temp, Min	20	F	Average daily low for December, January, February (https://www.weather.gov/mkx/monthly_climate_table)
Ambient Temp, Max	80	F	Average daily high for June, July, August (https://www.weather.gov/mkx/monthly_climate_table)
Digester Dome Height	25	ft	Assumed value
Digester Cover Dome Area	7,246	ft^2	
Digester Cover Heat Losses, Min	89,665	BTU/hr	
Digester Cover Heat Losses, Max	448,326	BTU/hr	
Digester Wall to Air Area	1,449	ft^2	Assumes 80% of digester is underground
Wall to Air Heat Transfer Coefficient	0.27	BTU/(ft^2*F*h)	Concrete wall / 1" air space / Brick
Digester Wall to Air Heat Losses, Min	5,869	BTU/hr	
Digester Wall to Air Heat Losses, Max	29,345	BTU/hr	
Cone Depth	10.0	ft	
Digester to Earth Area	12,636	ft^2	Assumes 80% of digester is underground
Earth Heat Transfer Coefficient	0.11	BTU/(ft^2*F*h)	Concrete floor exposed to earth
Digester to Earth Heat Losses, Min	20,850	BTU/hr	
Digester to Earth Heat Losses, Max	104,250	BTU/hr	
Total Heat Losses, winter	581,921	BTU/hr	
Total Heat Losses, summer	116,384	BTU/hr	
Total Heating Requirements			
Winter Conditions	1,712,903	BTU/hr	
Summer Conditions	494,226	BTU/hr	
Total	2,207,129	BTU/hr	
	19,334	MMBTU/yr	
HSW Energy Needed			
Total Flow Needed	**250**	**GPM**	System is comparable to EBMUD, which has 250 GPM flow rate. https://www.biocycle.net/green-energy-from-food-wastes-at-wastewater-treatment-plant/
Slurry Tank Mixers	3	Quantity	Assumed 3 mixers needed at 20 hp per mixer
	20	hp	
	60	Total hp	
Paddle Finisher (Brown 202)	3	Quantity	Capacity is 40-125 GPM. Quantity of 3 assumed for buffer. https://www.loebequipment.com/inventory/20-hp-ss-paddle-type-brown-mdl-202-pulper-finisher-paddle-type-w-2-blades-electrica/
	20	hp	
	60	Total hp	
Grinder (10K Open Channel Muffin Monster)	1	Quantity	Used for flow rate up to 550 GPM. https://www.jwce.com/products/10k-in-line-muffin-monster/
	5	hp	
	5	Total hp	
Peristaltic Pump (Bredel 2100)	1	Quantity	Provides flow rates up to 475 GPM. https://www.wmfts.com/en-us/bredel/hose-pumps/bredel-hose-pumps-65-2100/
	27	hp	
	27	Total hp	
Total Equipment Energy Needed	152	Total hP	
	114	Total kW Needed	
	389,000	BTU/hr Needed	
	3,500	MMBTU/yr	
Total Heating Energy Needed	20,000	MMBTU/yr	
Building Energy Needed	1,500	MMBTU/yr	Assuming a 40,000 SF building
Total HSW Energy Needed	**25,000**	**MMBTU/yr**	

ALTERNATIVE 3			
FOOD WASTE - Existing Conditions with Planned Improvements			
Parameter	**Quantity**	**Units**	**Notes and References**

User Inputs in BLUE

Constants			
Design VSLR	0.12	lbd/ft^3	BAFP Pg. 70
Minimum SRT	15	days	BAFP Pg. 70
Slurried Food Waste Characteristics	10%	%TS	Typical of Slurried Food Waste (GPSD January 2016)
	0.94	VS/TS	Typical of Slurried Food Waste (GPSD January 2016)
Expected VSR	85%	%	Typical of Food Waste (GPSD January 2016)
Specific Biogas Production Rate	16	ft^3/lb VSR	

Digester Gas Parameters			
Digester Gas Needed After Planned Improvements	19,600	MMBTU/yr	
	19,595	dTh/yr	
	19,596,000	CF/yr	
	37	SCFM	100% Methane
	62	SCFM of DG	Assumes digester gas has 60% methane

Biogas Production Potential			
Biogas Production Needed	90,000	SCFD	
Volatiles Destroyed	5,700	lb/day	
VS Loading Needed	6,800	lb/day	
	3.4	tons/day	
TS Loading Needed	7,300	lb/day	
	3.7	tons/day	
Additional Biosolids for Disposal	1,600	lb/day	

Digester Size (VS Loading Design Basis)			
Digester Volume Needed (Design)	57,000	ft^3	Volume needed based solely on design VSLR
	427,000	gal	

Digester Size (SRT Design Basis)			
Digester Hydraulic Capacity	8,753	gpd	
Digester Volume Needed (SRT Basis)	17,553	ft^3	Volume needed based on solids retention time
	131,295	gal	

Digester Volume			
Digester Volume Needed	**57,000**	**ft^3**	The greater of the two calculated digester volumes is used
	427,000	**gal**	

Existing Digester Volume			
Existing Digester Volume	2,045,455	ft^3	
Existing Design VS Loading Capacity	245,455	lbd VS/day	Only mesophilic digester space was considered due to unknowns surrounding food waste in thermophilic digesters
Current Sludge Feed	157,114	lbd VS/day	
Remaining VS Loading	88,341	lbd VS/day	
Remaining Available Volume	736,172	ft^3	
% of Remaining Volume Available for Food Waste	20%	%	
Digester Volume Available for Food Waste	147,234	ft^3	
Remaining Digester Volume Needed for Food Waste	0	ft^3	
Desired Buffer	20,000	ft^3	
Remaining Digester Volume Needed	0	ft^3	

New Digester Volume			
Digester Volume Needed	N/A	ft^3	
	N/A	gal	
	N/A	MG	
Desired Digester Size	N/A	MG	
Quantity of Digesters Needed	N/A		
Digester Volume	N/A	ft^3	
Digester Diameter	N/A	ft	
Digester Sidewater Depth	N/A	ft	

Food Waste Summary Table - Current Flow and Loadings (with Primary Clarifier Improvements)			
Digester Gas Needed After Planned Improvements	19,600	MMBTU/yr	
	62	SCFM of DG	
Quantity of Food Waste Needed	3.7	tons/day	
Digester Volume Needed	57,000	ft^3	
Volume to Existing Digesters	57,000	ft^3	
Volume to New Digesters	0	ft^3	
New Digester Size	N/A	MG	
Quantity of New Digesters Needed	N/A		
Digester Diameter	N/A	ft	
Digester Sidewater Depth	N/A	ft	

HSW Energy Needed			
Total Flow Needed	**250**	**GPM**	System is comparable to EBMUD, which has 250 GPM flow rate. https://www.biocycle.net/green-energy-from-food-wastes-at-wastewater-treatment-plant/
Slurry Tank Mixers	3	Quantity	Assumed 3 mixers needed at 20 hp per mixer
	20	hp	
	60	Total hp	
Paddle Finisher (Brown 202)	3	Quantity	Capacity is 40-125 GPM. Quantity of 3 assumed for buffer. https://www.loebequipment.com/inventory/20-hp-ss-paddle-type-brown-mdl-202-pulper-finisher-paddle-type-w-2-blades-
	20	hp	
	60	Total hp	
Grinder (10K Open Channel Muffin Monster)	1	Quantity	Used for flow rate up to 550 GPM. https://www.jwce.com/products/10k-in-line-muffin-monster/
	5	hp	
	5	Total hp	
Peristaltic Pump (Bredel 2100)	1	Quantity	Provides flow rates up to 475 GPM. https://www.wmfts.com/en-us/bredel/hose-pumps/bredel-hose-pumps-65-2100/
	27	hp	
	27	Total hp	
Total Equipment Energy Needed	152	Total hP	
	114	Total kW Needed	
	389,000	BTU/hr Needed	
	3,500	MMBTU/yr	
Building Energy Needed	1,500	MMBTU/yr	Assuming a 40,000 SF building
Total HSW Energy Needed	**5,000**	**MMBTU/yr**	

ALTERNATIVE 3			
FOOD WASTE - Existing Conditions with Primary Clarifier Improvements and Digester Improvements			
Parameter	Quantity	Units	Notes and References

User Inputs in BLUE

Constants			
Design VSLR (Mesophilic)	0.12	lbd/ft^3	BAFP Pg. 70
Design VSLR (Acid-Phase)	2.4	lbd/ft^3	BAFP Pg. 70
Minimum SRT	15	days	BAFP Pg. 70
Slurried Food Waste Characteristics	10%	%TS	Typical of Slurried Food Waste (GPSD January 2016)
	0.94	VS/TS	Typical of Slurried Food Waste (GPSD January 2016)
Expected VSR	85%	%	Typical of Food Waste (GPSD January 2016)
Specific Biogas Production Rate	16	ft^3/lb VSR	

Digester Gas Parameters			
Digester Gas Needed After Planned Improvements	19,600	MMBTU/yr	
	19,595	dTh/yr	
	19,596,000	CF/yr	
	37	SCFM	100% Methane
	62	SCFM of DG	Assumes digester gas has 60% methane

Biogas Production Potential			
Biogas Production Needed	90,000	SCFD	
Volatiles Destroyed	5,700	lb/day	
VS Loading Needed	6,800	lb/day	
	3.4	tons/day	
TS Loading Needed	7,300	lb/day	
	3.7	tons/day	
Additional Biosolids for Disposal	1,600	lb/day	

Digester Size (Design Basis)			
Digester Volume Needed (Design)	57,000	ft^3	Volume needed based solely on design VSLR
	427,000	gal	

Digester Size (SRT Basis)			
Digester Hydraulic Capacity	8,753	gpd	
Digester Volume Needed (SRT Basis)	17,553	ft^3	Volume needed based on solids retention time
	131,295	gal	

Digester Volume			
Digester Volume Needed	**57,000**	**ft^3**	The greater of the two calculated digester volumes is used
	427,000	**gal**	

Existing Digester Volume			
Existing Mesophilic Digester Volume	1,791,444	ft^3	
Existing Mesophilic Design VS Loading Capacity	214,973	lbd VS/day	Only mesophilic digester space was considered due to unknowns
Current Sludge Feed	157,041	lbd VS/day	surrounding food waste in thermophilic digesters
Remaining VS Loading	57,932	lbd VS/day	
Remaining Available Volume	482,765	ft^3	
% of Remaining Volume Available for Food Waste	20%	%	
Digester Volume Available for Food Waste	96,553	ft^3	
Remaining Digester Volume Needed for Food Waste	0	ft^3	
Desired Buffer	20,000	ft^3	
Remaining Digester Volume Needed	0	ft^3	

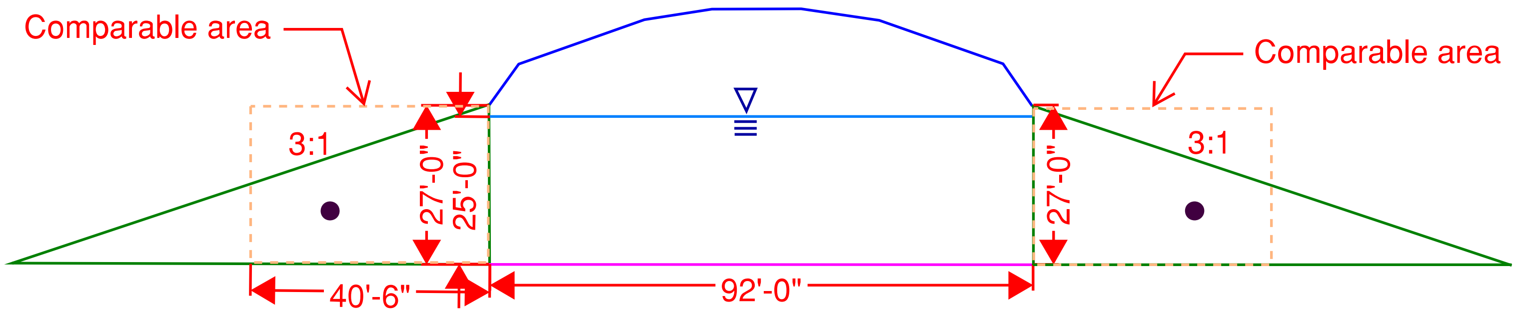
New Digester Volume			
Digester Volume Needed	N/A	ft^3	
	N/A	gal	
	N/A	MG	
Desired Digester Size	**N/A**	MG	
Quantity of Digesters Needed	N/A		
Digester Volume	N/A	ft^3	
Digester Diameter	N/A	ft	
Digester Sidewater Depth	**N/A**	ft	

Food Waste Summary Table - 2045 Capacity with Current Loading Rates		
Digester Gas Needed After Planned Improvements	19,600	MMBTU/yr
	62	SCFM of DG
Quantity of Food Waste Needed	3.7	tons/day
Digester Volume Needed	57,000	ft^3
Volume to Existing Digesters	57,000	ft^3
Volume to New Digesters	0	ft^3
New Digester Size	N/A	MG
Quantity of New Digesters Needed	N/A	
Digester Diameter	N/A	ft
Digester Sidewater Depth	N/A	ft

HSW Energy Needed			
Total Flow Needed	**250**	**GPM**	System is comparable to EBMUD, which has 250 GPM flow rate. https://www.biocycle.net/green-energy-from-food-wastes-at-wastewater-treatment-plant/
Slurry Tank Mixers	3	Quantity	Assumed 3 mixers needed at 20 hp per mixer
	20	hp	
	60	Total hp	
Paddle Finisher (Brown 202)	3	Quantity	Capacity is 40-125 GPM. Quantity of 3 assumed for buffer.
	20	hp	https://www.loebequipment.com/inventory/20-hp-ss-paddle-
	60	Total hp	type-brown-mdl-202-pulper-finisher-paddle-type-w-2-blades-
Grinder (10K Open Channel Muffin Monster)	1	Quantity	Used for flow rate up to 550 GPM.
	5	hp	https://www.jwce.com/products/10k-in-line-muffin-monster/
	5	Total hp	
Peristaltic Pump (Bredel 2100)	1	Quantity	Provides flow rates up to 475 GPM.
	27	hp	https://www.wmfts.com/en-us/bredel/hose-pumps/bredel-hose-
	27	Total hp	pumps-65-2100/
Total Equipment Energy Needed	152	Total hP	
	114	Total kW Needed	
	389,000	BTU/hr Needed	
	3,500	MMBTU/yr	
Building Energy Needed	1,500	MMBTU/yr	Assuming a 40,000 SF building
Total HSW Energy Needed	**5,000**	**MMBTU/yr**	

ALTERNATIVE 3			
FOOD WASTE - 2045 Flow Conditions with Digester Improvements			
Parameter	**Quantity**	**Units**	**Notes and References**
User Inputs in BLUE			
Constants			
Design VSLR (Mesophilic)	0.12	lbd/ft^3	BAFP Pg. 70
Design VSLR (Acid-Phase)	2.4	lbd/ft^3	BAFP Pg. 70
Minimum SRT	15	days	BAFP Pg. 70
Slurried Food Waste Characteristics	10%	%TS	Typical of Slurried Food Waste (GPSD January 2016)
	0.94	VS/TS	Typical of Slurried Food Waste (GPSD January 2016)
Expected VSR	85%	%	Typical of Food Waste (GPSD January 2016)
Specific Biogas Production Rate	16	ft^3/lb VSR	
Digester Gas Parameters			
Digester Gas Needed After Planned Improvements	19,600	MMBTU/yr	
	19,595	dTh/yr	
	19,596,000	CF/yr	
	37	SCFM	100% Methane
	62	SCFM of DG	Assumes digester gas has 60% methane
Biogas Production Potential			
Biogas Production Needed	90,000	SCFD	
Volatiles Destroyed	5,700	lb/day	
VS Loading Needed	6,800	lb/day	
	3.4	tons/day	
TS Loading Needed	7,300	lb/day	
	3.7	tons/day	
Additional Biosolids for Disposal	1,600	lb/day	
Digester Size (Design Basis)			
Digester Volume Needed (Design)	57,000	ft^3	Volume needed based solely on design VSLR
	427,000	gal	
Digester Size (SRT Basis)			
Digester Hydraulic Capacity	8,753	gpd	
Digester Volume Needed (SRT Basis)	17,553	ft^3	Volume needed based on solids retention time
	131,295	gal	
Digester Volume			
Digester Volume Needed	**57,000**	**ft^3**	The greater of the two calculated digester volumes is used
	427,000	**gal**	
Existing Digester Volume			
Existing Mesophilic Digester Volume	1,791,444	ft^3	
Existing Mesophilic Design VS Loading Capacity	214,973	lbd VS/day	Only mesophilic digester space was considered due to unknowns surrounding food waste in thermophilic digesters
Current Sludge Feed	287,854	lbd VS/day	
Remaining VS Loading	0	lbd VS/day	
Remaining Available Volume	0	ft^3	
% of Remaining Volume Available for Food Waste	20%	%	
Digester Volume Available for Food Waste	0	ft^3	
Remaining Digester Volume Needed for Food Waste	57,000	ft^3	
Desired Buffer	20,000	ft^3	
Remaining Digester Volume Needed	80,000	ft^3	
New Digester Volume			
Digester Volume Needed	80,000	ft^3	
	598,400	gal	
	0.60	MG	
Desired Digester Size	0.50	MG	
Quantity of Digesters Needed	2		
Digester Volume	66,845	ft^3	
Digester Diameter	58	ft	
Digester Sidewater Depth	25.0	ft	
Food Waste Summary Table - 2045 Capacity and Loading Rates			
Digester Gas Needed After Planned Improvements	19,600	MMBTU/yr	
	62	SCFM of DG	
Quantity of Food Waste Needed	7,300	lb/day	
Digester Volume Needed	57,000	ft^3	
Volume to Existing Digesters	0	ft^3	
Volume to New Digesters	57,000	ft^3	
New Digester Size	0.50	MG	
Quantity of New Digesters Needed	2		
Digester Diameter	58	ft	
Digester Sidewater Depth	25.0	ft	
Energy for Heating Incoming Sludge			
Flow	8,753	gal/day	Based on total slurried food waste flow, assuming 10% TS
Digester Temperature	95	F	Assumed value
Inlet Sludge Temp, min	53	F	Assumed value
Inlet Sludge Temp, max	75	F	Assumed value
BTU Required to Heat Sludge, winter	127,648	BTU/hr	BTU/hr = GPM X (ΔT X 500)
BTU Required to Heat Sludge, summer	60,785	BTU/hr	BTU/hr = GPM X (ΔT X 500)
Digester Heat Losses			
Digester Cover Heat Transfer Coefficient	0.825	BTU/(ft^2*F*h)	
Ambient Temp, Min	20	F	Average daily low for December, January, February (https://www.weather.gov/mkx/monthly_climate_table)
Ambient Temp, Max	80	F	Average daily high for June, July, August (https://www.weather.gov/mkx/monthly_climate_table)
Digester Dome Height	25	ft	Assumed value
Digester Cover Dome Area	4,583	ft^2	
Digester Cover Heat Losses, Min	56,709	BTU/hr	
Digester Cover Heat Losses, Max	283,547	BTU/hr	
Digester Wall to Air Area	917	ft^2	Assumes 80% of digester is underground
Wall to Air Heat Transfer Coefficient	0.27	BTU/(ft^2*F*h)	Concrete wall / 1" air space / Brick
Digester Wall to Air Heat Losses, Min	3,712	BTU/hr	
Digester Wall to Air Heat Losses, Max	18,559	BTU/hr	
Cone Depth	10.0	ft	
Digester to Earth Area	6,493	ft^2	Assumes 80% of digester is underground
Earth Heat Transfer Coefficient	0.11	BTU/(ft^2*F*h)	Concrete floor exposed to earth
Digester to Earth Heat Losses, Min	10,713	BTU/hr	
Digester to Earth Heat Losses, Max	53,564	BTU/hr	
Total Heat Losses, winter	355,670	BTU/hr	
Total Heat Losses, summer	71,134	BTU/hr	
Total Heating Requirements			
Winter Conditions	838,987	BTU/hr	
Summer Conditions	203,053	BTU/hr	
Total	1,042,040	BTU/hr	
	9,128	MMBTU/yr	
HSW Energy Needed			
Total Flow Needed	**250**	**GPM**	System is comparable to EBMUD, which has 250 GPM flow rate. https://www.biocycle.net/green-energy-from-food-wastes-at-wastewater-treatment-plant/
Slurry Tank Mixers	3	Quantity	Assumed 3 mixers needed at 20 hp per mixer
	20	hp	
	60	Total hp	
Paddle Finisher (Brown 202)	3	Quantity	Capacity is 40-125 GPM. Quantity of 3 assumed for buffer. https://www.loebequipment.com/inventory/20-hp-ss-paddle-type-brown-mdl-202-pulper-finisher-paddle-type-w-2-blades-
	20	hp	
	60	Total hp	
Grinder (10K Open Channel Muffin Monster)	1	Quantity	Used for flow rate up to 550 GPM. https://www.jwce.com/products/10k-in-line-muffin-monster/
	5	hp	
	5	Total hp	
Peristaltic Pump (Bredel 2100)	1	Quantity	Provides flow rates up to 475 GPM. https://www.wmfts.com/en-us/bredel/hose-pumps/bredel-hose-pumps-65-2100/
	27	hp	
	27	Total hp	
Total Equipment Energy Needed	152	Total hP	
	114	Total kW Needed	
	389,000	BTU/hr Needed	
	3,500	MMBTU/yr	
Total Heating Energy Needed	10,000	MMBTU/yr	
Building Energy Needed	1,500	MMBTU/yr	Assuming a 40,000 SF building
Total HSW Energy Needed	**15,000**	**MMBTU/yr**	

Digester Costs - Alternative 1



1. Concrete Estimate
- Assume 2.5' thick base
- Assume 1.5' walls
- Assume $1,200 / CY (for reinforced concrete)
- Assume $1,000,000 per digester for piles

2. Civil Site Work
- Calculate earth insulation quantity in CY
- Excavation = this quantity x 2 @ $60 per CY
- Backfill = this quantity x 1.5 @ $30 per CY

3. Digester Equipment (cover, mixing, heating, pumps, piping, valves, etc.)
-$3m per digester

4. Electrical @ sum of 1-3 at 30%, I&C at 10%

1. Concrete Estimate
- Base: 92' diameter x 2.5' thickness = 17,000 ft^3
- Walls: 27' height x 92' diameter - 27' height x (92' - 1.5') diameter = 6,000 ft^3
- Piles: $1,000,000 per digester
- Total = 17,000 + 6,000 = 23,000 ft^3 = 860 CY
- Cost = $1,200 x 860 CY + $1,000,000 = $2,032,000 per digester

2. Civil Site Work
- Earth Insulation Comparable Area: (1/2) * 81' x 27' (Triangle) = 40.5' x 27' (Rectangle)
- Earth Insulation Quantity Parameters:
    - Overall Diameter: 92' + 40.5' + 40.5' = 173'
    - Digester Diameter: 92'
    - Height: 27'
- Earth Insulation Quantity: 27' height x 173' diameter - 27' height x 92' diameter = 637,000 - 181,000 = 456,000 ft^3 = 17,000 CY
- Excavation = 17,000 x 2 x $60 = $2,040,000
- Backfill = 17,000 x 1.5 x $30 = $765,000
- Total = $2,805,000 per digester

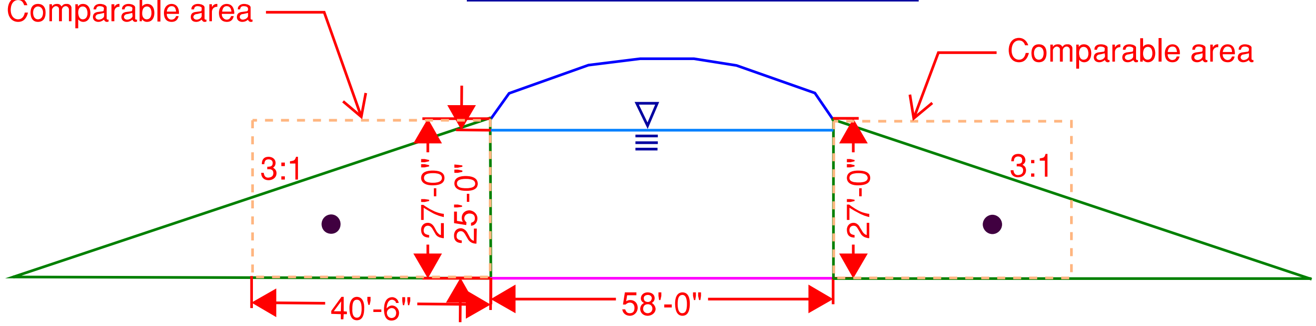
3. Digester Equipment: $3,000,000 per digester

4. Electrical: ($2,032,000 + $2,805,000 + $3,000,000) * 0.3 = $2,352,000
I&C: ($2,032,000 + $2,805,000 + $3,000,000) * 0.1 = $784,000

Total per digester = $2,032,000 + $2,805,000 + $3,000,000 + $2,352,000 + $784,000 = $10,973,000

2 digesters needed, so total cost = **$21,946,000**

Digester Costs - Alternative 3



1. Concrete Estimate
- Assume 2.5' thick base
- Assume 1.5' walls
- Assume $1,200 / CY (for reinforced concrete)
- Assume $1,000,000 per digester for piles

2. Civil Site Work
- Calculate earth insulation quantity in CY
- Excavation = this quantity x 2 @ $60 per CY
- Backfill = this quantity x 1.5 @ $30 per CY

3. Digester Equipment (cover, mixing, heating, pumps, piping, valves, etc.)
- $3m per digester

4. Electrical @ sum of 1-3 at 30%, I&C at 10%

1. Concrete Estimate
- Base: 58' diameter x 2.5' thickness = 7,000 ft^3
- Walls: 27' height x 58' diameter - 27' height x (58' - 1.5') diameter = 4,000 ft^3
- Total = 7,000 + 4,000 = 11,000 ft^3 = 410 CY
- Cost = $1,200 x 410 CY + $1,000,000 = $1,492,000 per digester

2. Civil Site Work
- Earth Insulation Comparable Area: (1/2) * 81' x 27' (Triangle) = 40.5' x 27' (Rectangle)
- Earth Insulation Quantity Parameters:
    - Overall Diameter: 58' + 40.5' + 40.5' = 139'
    - Digester Diameter: 58'
    - Height: 27'
- Earth Insulation Quantity: 27' height x 139' diameter - 27' height x 58' diameter = 410,000 - 73,000 = 337,000 ft^3 = 13,000 CY
- Excavation = 13,000 x 2 x $60 = $1,560,000
- Backfill = 13,000 x 1.5 x $30 = $585,000
- Total = $2,145,000

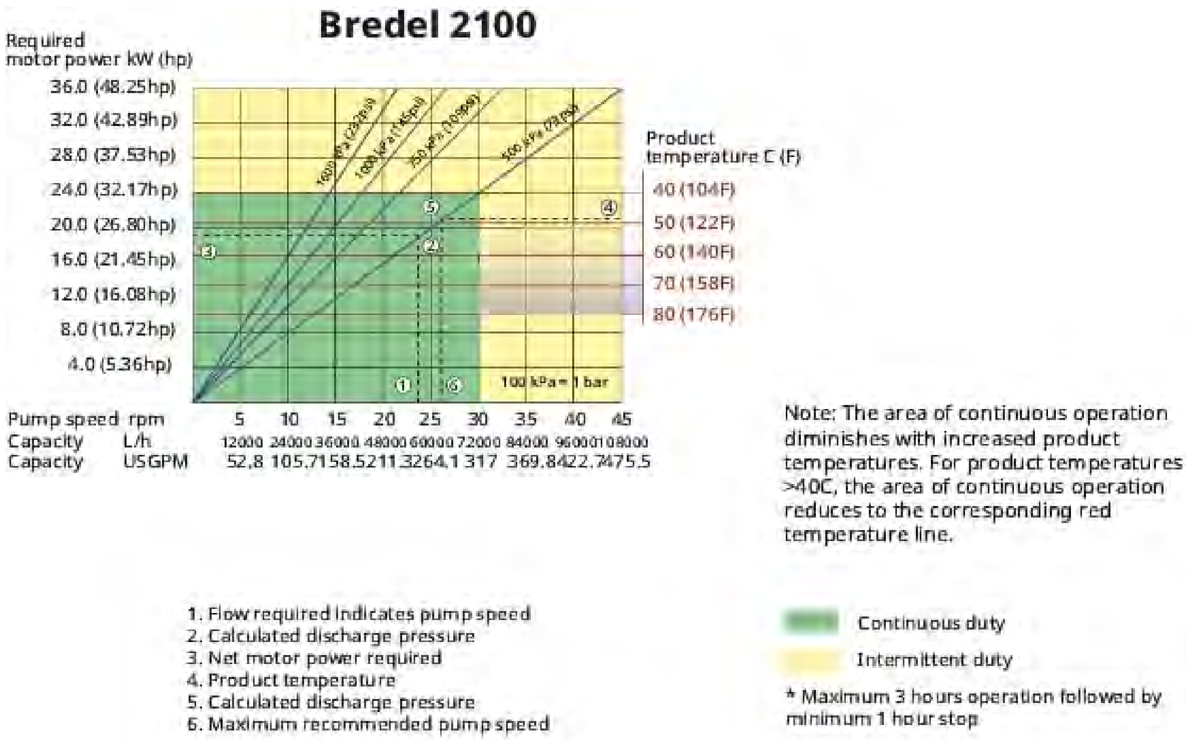
3. Digester Equipment: $3,000,000 per digester

4. Electrical: ($1,492,000 + $2,145,000 + $3,000,000) * 0.3 = $1,992,000
I&C: ($1,492,000 + $2,145,000 + $3,000,000) * 0.1 = $664,000

Total per digester = $1,492,000 + $2,145,000 + $3,000,000 + $1,992,000 + $664,000 = $9,293,000

2 digesters needed, so total cost = **$18,586,000**

Possible Pump Curve



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