Energy Matters: MWRA Perspective

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Abstract

Providing water and wastewater services to 61 cities and towns results in a significant physical footprint with pipelines, pump stations, treatment plants, and buildings for maintenance and administration. Urban water and wastewater transportation and treatment is an energy intensive enterprise, and environmental and public health improvements often require new processes or facilities that consume more energy, but the Massachusetts Water Resources Authority (MWRA) has developed a robust energy management program over the past 20 years to ensure that it is serving its ratepayers and protecting the environment by reducing its purchased energy consumption and carbon footprint.
MWRA energy management projects generally fall into the following categories:

- Energy Consumption Reduction: Energy efficiency projects, water and wastewater process optimization
- Renewable Energy Use: Solar photovoltaics, hydropower turbines, wind turbines, digester gas combustion
- Electrification: Transportation fleet electrification, facility electrification
- Alternative Market Participation: Demand flattening with battery storage, load shedding, renewable energy certificate purchases.

Energy management activities have contributed to a reduction in the MWRA's energy use, expenses and carbon footprint using a range of renewable energy technologies well as efficiency and electrification improvements. This has included the implementation of a policy of including energy efficiency and renewable energy analyses in all facility rehabilitation projects. In addition, projects such as a large, combined heat and power (CHP) replacement at the Deer Island Wastewater Treatment Plant (Deer Island) will further increase the share of energy derived from renewable sources and reduce the plant's dependence on the power grid

Keywords: Renewable energy, Energy management, Combined heat and power, Energy efficiency, Water utility, Wastewater Utility

1. Introduction

For much of its existence, the Massachusetts Water Resources Authority (MWRA) has worked to wisely manage both its energy consumption and where its energy comes from. In recent years, the threats from climate change have become clearer and clearer with the primary driver being the global need for energy. This has added a sense of urgency for MWRA to optimize its energy management program to ensure that both the ratepayers and the environment are served by mitigating purchased electricity costs and reducing greenhouse gas emissions. Where energy comes from and how it is used matters even more now than it has in the past.

This article provides an overview of energy matters at the MWRA. Energy management projects at the MWRA generally fall into the following categories:

- Energy consumption reduction
- Use of renewable energy

- Electrification

The following sections will cover each of these areas individually and discuss the policy of including an energy analysis into all facility rehabilitation projects. It also includes a project currently in the early design phase to replace the existing combined heat and power facility at the Deer Island Treatment Plant.

2. Energy Consumption Reduction

The best way to reduce the environmental and economic impact of energy consumption is to simply consume less of it. As an energy intensive enterprise this is a challenge for the MWRA, but not an insurmountable one.

2.1 Energy Consumption

The total electricity consumption of the MWRA during fiscal year 2021 was approximately 151 gigawatt hours (GWh). The total monthly electricity consumption is shown in Figure 1. (Renewable production is also shown on the bar graph.) Additionally, MWRA used about 1.2 million gallons of fuel oil and 569,000 therms of natural gas in FY21.

Although MWRA owns and operates approximately 50 facilities, one stands out as the primary energy consumer. Deer Island is the regional wastewater treatment plant for 2.3 million people in 43 communities in the metropolitan Boston area with a peak treatment flow capacity of over one billion gallons per day and an average of 345 mgd. In order to treat this volume of wastewater properly, Deer Island consumed a total of 102 GWh of electricity in FY2021. This is about 68% of the electricity consumption of the entire Authority. Deer Island's diesel fuel usage in FY21 was 686,429 gallons or about 58% of the total diesel fuel usage across the MWRA.

For comparison, the average home in New England uses approximately 8,200 kilowatt hours (kWh) of electricity per year, so MWRA's electricity usage is equal to the electricity use of about 18,000 homes.

2.2 Successful Energy Reduction Projects

With over 60 energy audits completed covering MWRA's medium to large facilities, implementation of audit recommendations and other optimization efforts have resulted in an estimated savings of $2 million annually.

To accomplish this, MWRA has worked closely with its electric utilities, signing its first memorandum of understanding (MOU) with Eversource in 2014 with a target of reducing electrical demand by 15% over three years, or approximately 18 GWh. The MOU provided the utility with a partner that is committed to energy use reduction and in turn, MWRA received slightly higher incentives amounts for all kWh reductions as well as specialized technical assistance on complicated projects. MWRA exceeded this target and subsequently signed another MOU with Eversource and National Grid. From 2008 to 2022, MWRA has received over $5 million in incentive payments from the utilities for completion of over 100 separate energy efficiency projects.

Examples of successful process modification efforts implemented to reduce energy consumption include:

- Improvements to the oxygen system at Deer Island, which included the addition of variable frequency drives (VFDs), instrumentation improvements and turning off unneeded equipment, saving 10 GWh per year.

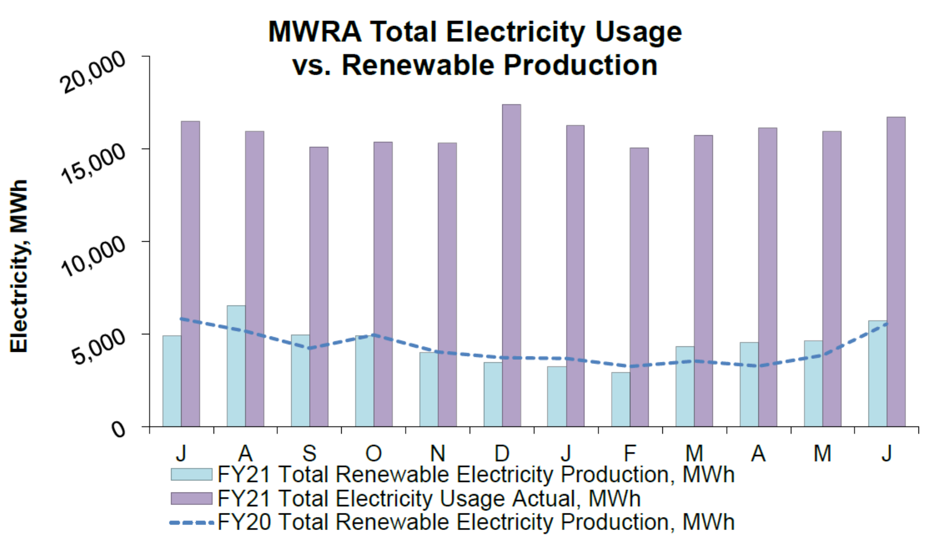


Figure 1. MWRA total monthly electricity consumption for Fiscal Year 2021 (MWRA 2022).

- Adjustment of the pumping shaft wet well level upward at Deer Island, which required the pumps to operate less frequently, saving 4.5 GWh per year.
- Installation of VFDs on a variety of motors for speed modulation to match demand.
- Turning off an unneeded soda ash mixing operation at the Carroll Water Treatment Plant, saving 1.8 GWh per year.

More traditional energy saving measures have also been implemented. For example:

- Replacement of exterior metal halide lights with LED fixtures at a Deer Island administration building reduced fixture energy use by 60%.
- Multi-phase lighting improvements were made across multiple facilities to upgrade to LEDs.
- Installation of an energy management system in an administration building reduced natural gas consumption by 33% in winter.
- Reduction of ventilation rates at a headworks when space is unoccupied reduced fuel usage by 43,000 gallons per year and electricity usage by 66 MWh per year.
- Installation of pump station pipe insulation eliminated dehumidification and reduced maintenance costs from condensation, saving approximately 118 megawatt hours (MWh) per year.

MWRA has implemented several energy consumption reduction projects, and upon reviewing their absolute magnitude of energy savings, it becomes evident that process improvements yield substantially greater energy reductions compared to HVAC modifications. The data indicates that the changes made in the operational processes have a more substantial impact on reducing overall energy consumption than the alterations in HVAC systems. This observation underscores the significance of focusing on process enhancements as an effective strategy for achieving significant energy efficiency gains within MWRA's operations..

3. Renewable Energy Generation

When energy must be consumed, the source of that energy is important to consider. MWRA has long been committed to using renewable energy.

3.1 Total Renewable Electricity Production

Over the years, MWRA has built up a significant portfolio of renewable energy installations. Figure 2 shows the total amount of electricity generated by renewable energy assets as a percentage of the total electricity consumed by the MWRA for FY2021.

The total renewable electricity generated by the MWRA 54,040 MWh, or approximately 28% of the total electricity consumed in FY2021.

An interesting aspect of the renewable electricity generation is that a significant percentage of it is not used on the site where it is generated, but exported to the grid. The exception to this is Deer Island where all the renewable energy is used onsite.

3.2 Wind Turbines

Due to the high population density surrounding many of the MWRA facilities there are limited opportunities for large wind turbine generator installations. There are, however, two installation locations: one 1.5 MW turbine at a wastewater pump station in Charlestown and two 600 kW turbines located at Deer Island. Figure 3 shows the turbines installed at Deer Island.

3.3 Solar Photovoltaics

As a low maintenance energy source, solar photovoltaics are an excellent renewable energy technology. MWRA has two primary installation locations: A ground mounted 496 kW system at the Carroll Water Treatment Plant and four arrays that total 736 kW installed at Deer Island. This includes the 234 kW ground mount system shown in Figure 3. MWRA also has a combined ground/roof mounted system totaling 76 kW at a new backup water pumping station near the Carroll Water Treatment Plant. This facility is also heated by a geothermal heat pump.

Additional sites are currently in the planning stage, including some using parking canopy solar as well as over underground water storage locations.

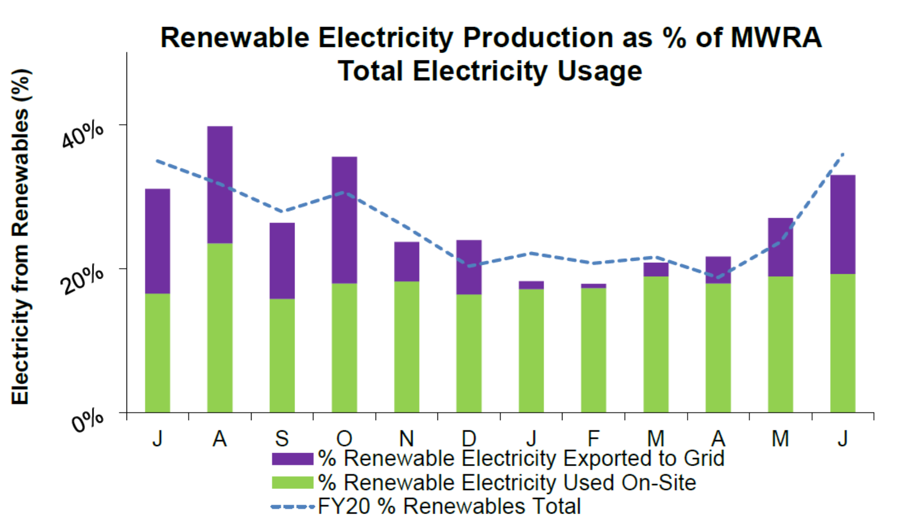


Figure 2. MWRA total monthly renewable electricity production (MWRA 2022).

3.4 Hydro Turbines

As a water utility, there are opportunities for hydro turbine installations that are not inserted into a river flow. In water systems there is often extra water pressure when a reservoir is at a higher elevation than the users of that water. This extra pressure can be used to generate electricity.

The MWRA has four installations in the drinking water system:

- One 3.5 MW hydro turbine at the Oakdale Transfer Station where drinking water is transferred between reservoirs.
- Two 1.7 MW hydro turbines at the Cosgrove Aqueduct where the water from the reservoir drops into the aqueduct.
- One 200 kW in-pipe hydro turbine at Loring Road Covered Storage Facility.
- One 60 kW in-pipe hydro turbine at the William A. Brutsch Water Treatment Facility.

In addition, there are two 1.1 MW hydro turbines at Deer Island, which capture the energy from the treated wastewater as it drops into the outfall at the end of the treatment process.

3.5. Digester Gas

Deer Island's iconic digester "eggs" produce digester gas, rich in methane, through the anaerobic digestion of the solids extracted from wastewater. Figure 4 shows some of the digesters at Deer Island visible from Boston Harbor and planes landing at Logan Airport.

Mimicking the stomach's natural digestion process, microorganisms naturally present in the sludge work to break sludge and scum down into methane gas, carbon dioxide, solid organic byproducts and water. Digestion significantly reduces sludge quantity. The byproduct of the digestion process is 65 percent methane gas, which is captured and piped to boilers that generate enough heat to warm the buildings on the site as well as for the heat-dependent treatment processes.

Deer Island generates an average of 278 GWh per year of digester gas. MWRA also operates a much smaller MWRA wastewater treatment plant in Clinton which generates a much smaller amount of digester gas estimated at 1.5 GWh per year. At the Clinton plant, the digester gas is burned in a boiler to provide heat for the digesters and to heat one of the buildings.

At Deer Island. digester gas is used for heating as well as generating electricity. This is discussed in more detail below.

Figure 3. Wind turbine generators and ground mounted photovoltaic array installed at Deer Island (MWRA 2023).

Figure 4. Two of the twelve digesters at Deer Island (MWRA 2023).

4. Deer Island Combined Heat and Power

As the primary consumer of energy for the MWRA, Deer Island is also one of its primary sources of energy through the generation of digester gas. How this digester gas can be most effectively used is the subject of a current design effort.

4.1 Current Deer Island Use of Digester Gas

The digester gas at Deer Island is currently converted into both heat and electricity using a combined heat and power (CHP) system. A traditional electrical generation system would waste the significant amount of thermal energy generated by burning the source fuel, and a traditional thermal system would generate heat efficiently, but wouldn't generate any electricity.

At Deer Island, the digester gas is to a certain extent a waste product and has to be disposed of shortly after it is generated. As a result, it is a time sensitive fuel source. For much of the year this fuel source's energy content exceeds the thermal energy needs of Deer Island. To make the most of it, it makes sense to generate electricity from it as well as meeting the plant's thermal demand.

Figure 5 shows a high-level schematic of the existing CHP at Deer Island. Digester gas is the primary fuel with some supplementary fuel oil consumption. These are both burned in a boiler that produces high pressure steam. This steam drives two steam turbine generators that generate electricity. The steam exhaust from the steam turbines is then used to meet the thermal demand of the treatment plant.

This system has worked effectively since the construction of Deer Island, meeting the thermal demand at Deer Island as well as being one of the largest sources of renewable electricity in all of the MWRA.

4.2 Proposed CHP at Deer Island

As this facility ages, MWRA has begun the process of replacing it by determining if the onsite energy resources can be used more effectively. A high-level schematic of the proposed design is shown in Figure 6.

In this proposal, digester gas would remain the primary fuel with a reduced amount of supplementary fuel oil. Some of the digester gas and all the fuel would be burned in an array of three boilers. Unlike the existing system, this is a hydronic boiler that generates hot water instead of high pressure steam. A hot water boiler has a few advantages over steam as it is generally more

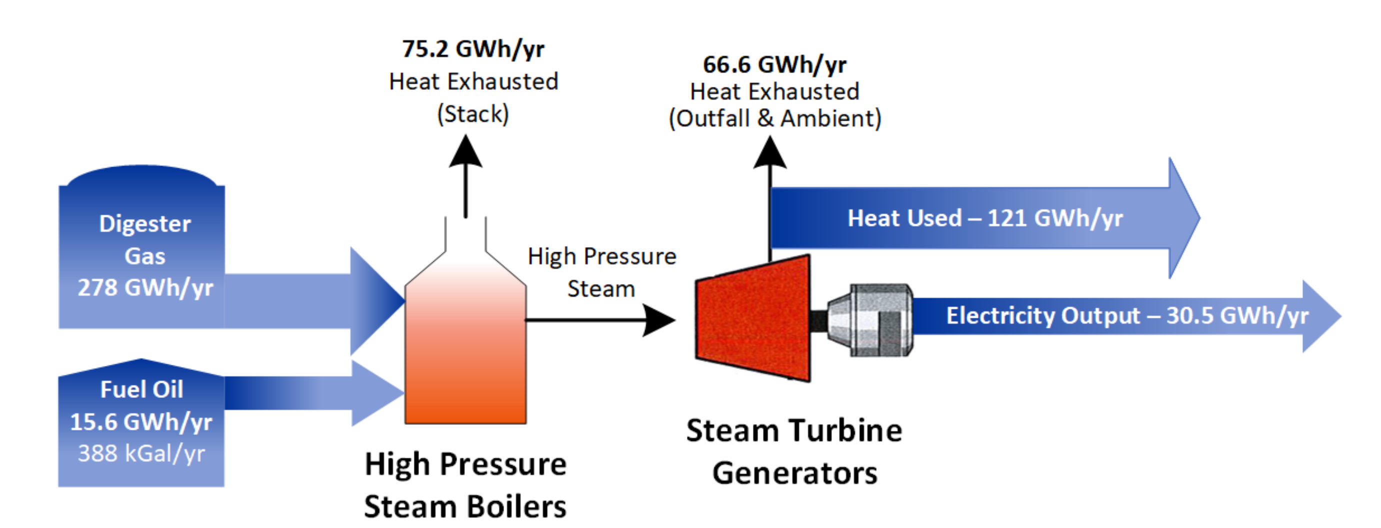
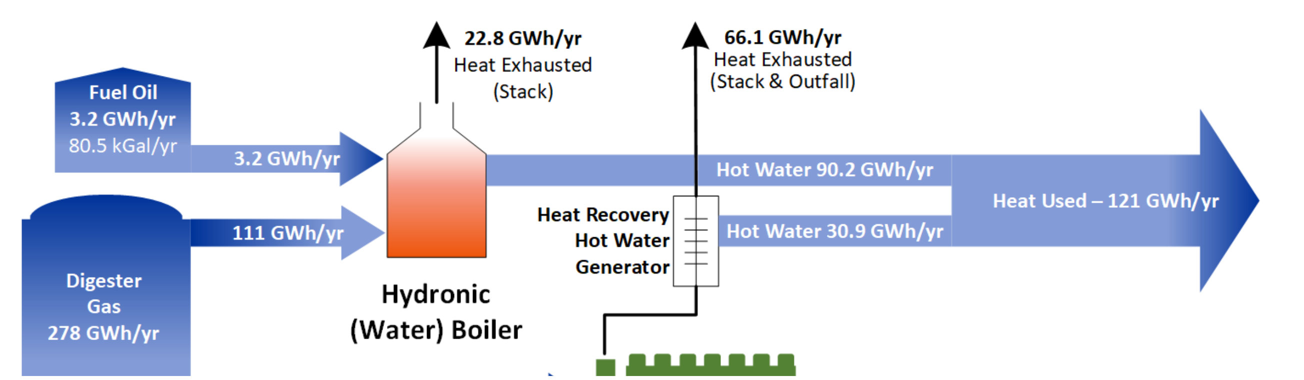


Figure 5. High level schematic of the existing CHP at Deer Island.



efficient, simpler and eliminates the hazards of high-pressure steam. This hydronic boiler would meet about two thirds of the thermal demand of the plant.

The remaining digester gas would be consumed in the CHP engine generators. The current design consists of an array of spark ignited reciprocating engines that are connected to electricity generators. This array is expected to consist of five units with a total electrical output rating of 15 to 17.5 MW. Some of the heat exhausted by these engines would also be captured and used to meet the remaining third of the Deer Island thermal demand.

The performance of this system has been predicted through simulations, one of which was created in Wolfram's Mathematica computational software using hundreds of calculations. Because Deer Island has extensive data collection of various parameters, this simulation was able to use actual resource and demands data from Deer Island in the calculations and pulled in 2.8 million data points. The performance of the new equipment was modelled, and the simulation predicted how it is expected to operate over multiple years when run with the Deer Island data. From this simulation the proposed CHP is expected to generate 69.3 GWh/yr of electricity which is about 2.3 times the electricity generated by the current system.

Table 1 lists three key parameters that are expected to increase with the installation of the new CHP. Currently, the CHP generates 21% of the total electricity consumed at Deer Island. The new CHP is predicted to increase this to 48%. Similarly, the overall yearly average CHP efficiency is expected to increase from 52% to 68%.

Table 1. Expected Increases from New CHP

	Existing CHP	Proposed CHP
Percent electricity from CHP	21%	48%
CHP Efficiency	52%	68%
Percent energy from onsite sources	~60%	~75%

As discussions of net zero energy have become more mainstream, the percentage of energy from onsite sources has become a more important metric. For an energy intensive enterprise like wastewater treatment, approximately 60% of total energy (both thermal and electrical) is generated from onsite sources, which is quite good. It would be very exciting to be able to increase this to approximately three quarters of the total energy consumption coming from onsite sources with the new CHP.

The new CHP is also predicted to have some metrics that will decrease as shown in Table 2. Fuel oil consumption is expected to decrease significantly − by about 300,000 gallons per year. From both the fuel oil consumption reduction as well the reduction of utility electricity consumption, greenhouse gas emissions are expected to decrease by 16,800 metric tons per year. This is the equivalent of about 42 million passenger car miles being driven. (Note, these calculations do not include data from renewable energy certificates and sales.)

Table 2. Expected Decreases from New CHP

	Reductions for new CHP
Fuel Oil Usage	300 kGal/yr
Greenhouse Gas Emissions	16,800 Metric Tons
Construction and 25-year Operating Cost	$43.1M Net Present Value

From a financial perspective, when analyzing the new CHP in comparison to the existing CHP over a 25-year evaluation period, it is projected to result in a significant cost advantage. The anticipated net present value of the new CHP is approximately $43.1 million lower than that of the existing CHP. This evaluation takes into consideration various factors, including the design and construction cost (estimated at $82 million) and the operational expenses of the new CHP. Additionally, it factors in the operating cost and replacement-in-kind cost of the existing CHP at the end of its useful life. The net present value method is utilized to account for the time value of money, facilitating a fair comparison of monetary values over time.

Considering the compelling advantages outlined in Table 1 and Table 2, proceeding with this project appears to be a sensible decision. A preliminary analysis conducted by both a consultant and in-house staff has been completed, and the MWRA (Massachusetts Water Resources Authority) is presently in the process of developing a detailed design contract.

4.3 Where the Energy Comes From

So, how it is possible for this new system to extract more useful energy from less total available energy? It's because the new CHP will convert fuel to electricity more efficiently than the existing system and the thermal demand varies over the course of a year.

In the existing CHP, fuel is converted to steam which then drives steam turbines to generate electricity. This has a fuel to electricity efficiency of about 10% and operates like that year round.

For the proposed CHP, however, when thermal demand is low (in the summer), the digester gas not used by the boiler would be sent to the reciprocating engines. These will convert the digester gas to electricity with an efficiency of around 40%. As a result, significantly more useful energy is extracted from the onsite digester gas resource during those months.

This is shown graphically in Figure 7. The horizontal axis shows months of the year while the vertical axis is the total energy for that month. The top data points in blue represent the total energy that is available or consumed by the existing CHP. The bottom orange data points are the useful energy generated by the existing CHP. The difference between these two curves is the amount of energy that is not used. During the summer months, this difference grows indicating an increase in energy being exhausted.

Similarly for the new CHP, the top green line represents the total energy available while the red data is the energy expected to be generated by the new CHP. As you can see, particularly in the summer months, the new CHP is expected to be able to extract more useful energy than the existing system.

The difference between the orange line for the existing CHP and the red line for the new CHP represents the additional energy that is expected to be extracted from the new system.

5. Electrification

Historically, using electricity for heating did not make a lot of sense from an overall use of source fuel standpoint. This is due to the amount of fuel energy exhausted as heat when generating electricity from fossil fuels. But with the advancement of heat pump technology and the growing percentage of renewable electricity on the grid, electrification appears to be an important step in the long-term lowering of greenhouse gas emissions. As a result, MWRA has begun a program of electrification.

MWRA has a fleet of approximately 400 vehicles ranging from SUVs to light- and medium-duty pickup trucks to large, specialized vehicles such as dump trucks, vactor trucks and backhoes. MWRA began purchasing hybrid SUVs and sedans at least ten years ago and has recently accelerated its purchase of all electric SUVs, buying approximately 5 or 6 per year with the goal of replacing all the SUVs with electric vehicles (EVs) as they age out. Additionally, with the production of electric light-duty pickup trucks beginning in 2023, MWRA will target the replacement of the existing 97 light duty pickup trucks beginning in 2023/2024.

In order to ensure adequate charging for the new EVs and to support electric vehicle purchases among staff for personal vehicles, MWRA is installing banks of primarily Level II smart charging stations along with a few DC Fast chargers at facilities where most of the fleet vehicles are garaged and staff are headquartered. MWRA is taking advantage of utility and state grant programs to help pay for the new electric vehicle charging stations beginning with thirty new ports for charging electric vehicles at its main administration building in 2023.

MWRA is also looking to reduce its dependence on fuel oil for heating its water and wastewater facilities by studying the feasibility of replacing fuel oil heat with either air source or water source heat pumps. MWRA recently completed audits in conjunction with the Industrial Assessment Center at the University of Massachusetts Amherst that looked at the feasibility of using heat pumps to heat two of its medium size pump stations. The audit showed that it would be possible to heat these facilities primarily using heat pumps. As a result of this the MWRA is moving forward with a design for using heat pumps at these

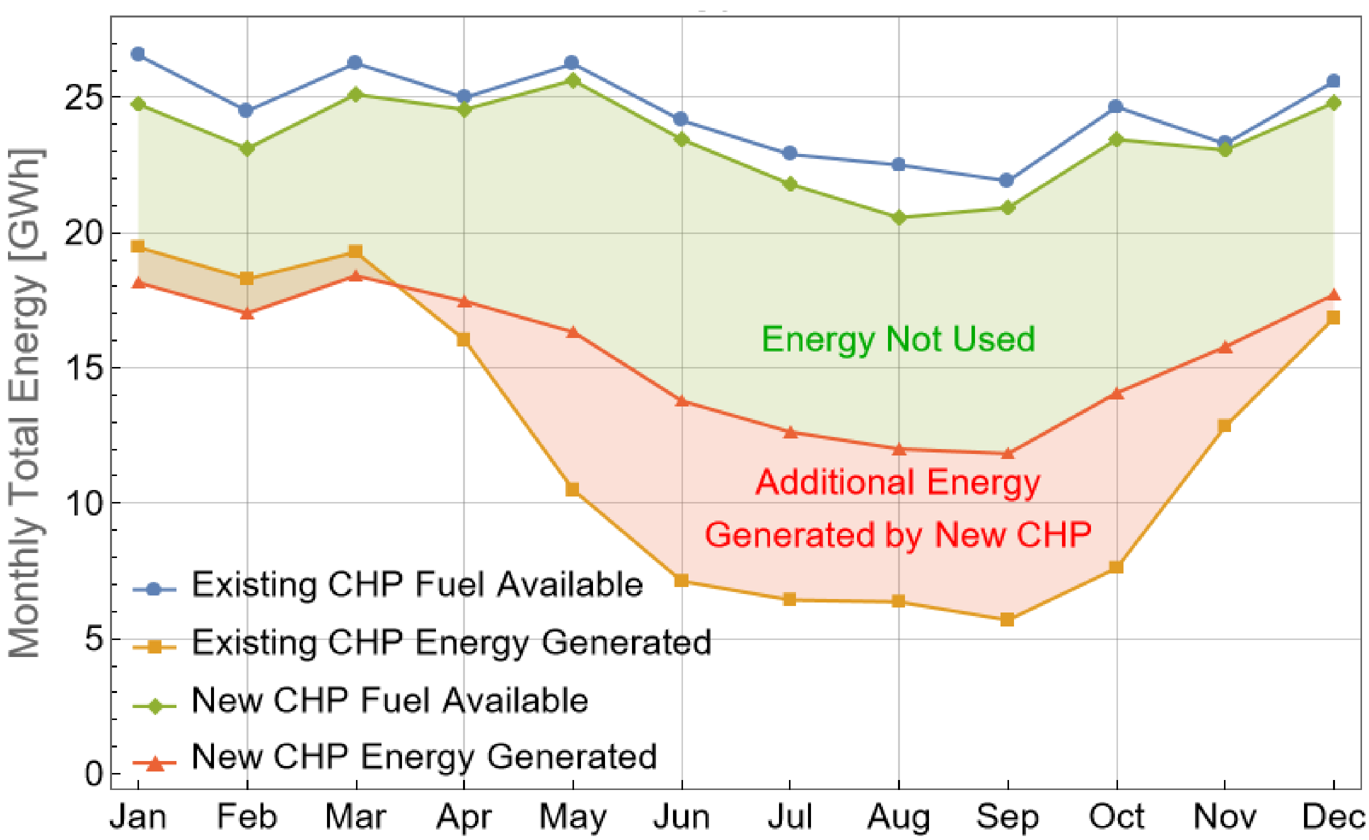


Figure 7. Total monthly energy available and used for the existing and new CHPs.

facilities as a pilot project that can potentially be rolled out to other facilities in the future.

6. Facility Rehabilitation Energy Analysis

MWRA has incorporated the goal of reducing its greenhouse gas emissions and energy costs into all of its planning processes, including its Five-Year Business Plan, master plans and monthly metric reports to management.

As it is easiest and most cost-effective to include energy improvements in significant rehabilitation projects or new construction, the MWRA explicitly includes energy efficiency and renewable energy considerations in its design process.

Engineering staff use previously completed energy audits to identify potential energy saving measures to be included in the design documents at the beginning of a rehabilitation project. MWRA's energy SOPs require an Energy Design Journal (EDJ) be included in the bid for rehabilitation or new construction of facilities. The inclusion of an EDJ, to be completed by the design consultant, ensures that all potential energy savings and reductions are considered in the early stages of the project. It requires that the design consultant look at current energy usage before rehabilitation, and expected future energy use based on the recommended energy efficiency measures so that MWRA staff can make the best decisions to ensure the rehabilitated facility will be as energy efficient as technically and financially feasible.

7. Conclusion

Creating a portfolio of energy practices and sources to meet the challenges of the future is a process the MWRA is actively engaged in. From renewable technologies that have operated for decades, to new installations currently in design, determining how it is possible to maximize the use of renewable energies is continuously investigated. Discovering ways of reducing energy consumption, sometimes with an increase in the service provided - such as additional odor control - is an active area of exploration. MWRA plans to continue maximizing energy value for its ratepayers as well as reducing the climate impacts of its operations.

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