



# Assessing Alternative Hydropower for Ann Arbor and Beyond

University of Michigan Dow Distinguished Award

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## I. Introduction

Municipalities require a substantial amount of energy to provide essential city services to its residents. More often than not, a city's water treatment services make up the vast majority of energy consumption among city departments. In the City of Ann Arbor, the water and wastewater treatment systems account for 54 percent of total electricity required by Ann Arbor municipal operations (Tripathi, 2007). High energy demand such as that required by water and wastewater treatment often comes with a large carbon footprint, as most regional energy grids still heavily rely on power produced from the burning of fossil fuels. Although the carbon intensity of most regional grids in the United States has decreased since the early 2000s, the average emissions intensity of electricity production in America is 439 grams of CO<sub>2</sub> per kWh (Schivley et al., 2018). The state of Michigan exceeds the national average, with an electricity production emissions intensity of 518 grams of CO<sub>2</sub> per kWh (Eia.gov, 2019).

As drinking water quality declines due to pollution, water treatment services will require increasingly expensive and energy-intensive technology to effectively treat water for human consumption. In Ann Arbor, new challenges including PFAS and 1, 4-dioxane pollutants require increased energy for treatment. At the same time, the global population is increasing, and in turn, the demand for drinking water will increase with it. As we await the energy sector's transition to a renewable energy future, energy efficiency technology can address the substantial costs and emissions of energy consumption associated with water treatment.

Enter micro-hydro turbine technology. Contrary to current hydropower technologies which operate on the 10-megawatt scale (i.e. dams), micro-hydro harnesses power ranging from 5 kilowatts to 100 kilowatts (Perez-Sanchez et al. 2017; Titus and Ayalur 2019). Untapped potential energy exists in the piping of water distribution systems. In areas where excess pressure exists, pressure reducing valves (PRVs) dissipate the excess potential energy into heat energy. The dissipated energy, however, can be harnessed with micro-hydro turbine equipment designed to convert flow into electrical energy.

We evaluated the implementation of micro-hydropower turbines from two manufacturers, Rentricity Inc. and SOAR Hydropower, at three distribution locations under municipal operation in Ann Arbor, Michigan. Of these locations, one demonstrated the optimal flow rate and duty cycles for maximum power output. Between Rentricity Inc. and SOAR hydropower turbines, SOAR hydropower produces the highest power output with a higher cost of installation.

Using billing information from each water distribution location, our team broke down monthly charges by dollars per kilowatt-hour over the course of one year (from January 2018 to January 2019). These charges include distribution rates set by one company, DTE, and transmission, market, and ancillary rates set by a second company, Constellation Energy. Our team multiplied these rates by the corresponding estimated hourly output of energy in kilowatts for each manufacturers' turbine technology. The product of these calculations gave an estimated annual savings at a minimum, average, and maximum expected output for each location. Using various economic forecasting, our team determined a financial and environmental benefit to the

implementation of micro-hydro. These estimates may vary depending on circumstances. This report details the significant criteria for municipalities to consider in adopting this technology and describes the best practices in the approach to evaluating micro-hydro in water treatment facilities.

### 1.1 Overview of existing hydropower systems

Hydropower is a popular form of renewable energy and exists all over the world, most commonly in the form of dams. Due to the world's increasing demand for energy, hydropower energy recovery technology is expanding to harness energy in existing water distribution systems, in addition to dam systems. Hydropower system sizes are dependent on the power output of the system and are categorized into large hydropower (>10 MW) and small hydropower (5 kW to 1 MW). Large hydropower refers to the installation of dams, such as the Hoover Dam, with a power capacity of 200 MW, and the Three Gorges Dam, with a maximum capacity of 20,000 MW. Small-hydro is further subdivided into mini-hydropower (100 kW to 1 MW), micro-hydropower (5 kW to 100 kW) and pico-hydropower (<5 kW) (Perez-Sanchez et al. 2017; Titus and Ayalur 2019).

Of these hydropower capacities, three types of hydropower plants exist. *Power plant in-flow/run-of-river systems* capture hydraulic head when flow exists, *power plants at the foot of a dam* are regulated by the upstream reservoir, and *power plants in water distribution networks* harness available excess pressure as energy (Perez-Sanchez et al. 2017). For the purpose of this study, we are focused on power plants in water distribution networks, which hereafter, will be referred to as in-line hydropower.

### 1.2 Types of in-line hydropower turbines

Many hydraulic energy recovery systems exist, but in-line hydropower falls under pressurized systems rather than open channel systems. Two categories of in-line turbines exist, traditional machines and adapted machines (see Figure 1). Two types of traditional machines exist, including ‘Reaction’ (Pelton, Turgo, and Crossflow turbines) and ‘Action’ (Francis, Kaplan, Deriaz and Bulb turbines).

Turbines are mechanisms that induce electromotive force (EMF) by converting fluid flow into electrical energy. Action, or impulse turbines, convert kinetic energy of the flow through curved blades that gain momentum and energy from the fluid striking the turbine blades and then reversing the

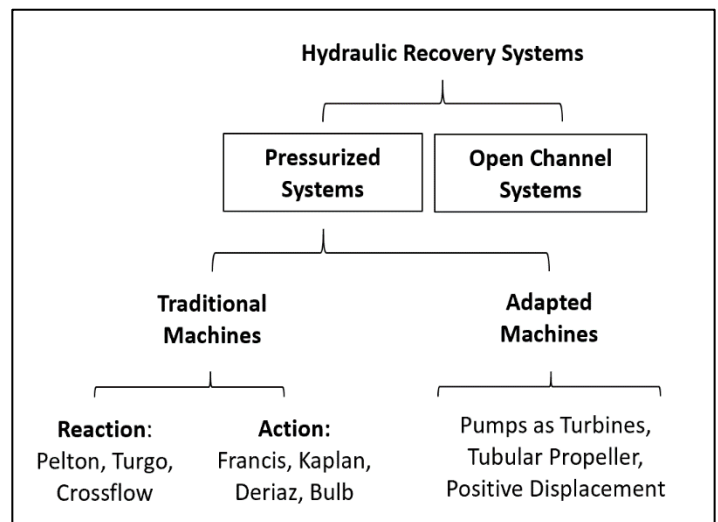


Figure 1. Hydraulic recovery systems adapted from Perez-Sanchez et al. (2017), with a focus on recovery systems for in-line hydropower.

velocity direction of the water flow. Alternatively, reaction turbines are submerged and driven by a change of fluid pressure when the water strikes the turbine. When a pressure drop occurs potential energy is converted into kinetic energy, the turbine begins to rotate, and EMF is generated. Adapted machines are unconventional turbines in which their original purpose was not as turbines, but as pumps. In terms of small hydropower, Pelton, Turgo and Francis Turbines are best for high elevation head (50 -400m) and low discharge (<10 m<sup>3</sup>/s). The cross-flow turbine is best for hydraulic head 1 – 50 m, and discharge < 20 m<sup>3</sup>/s and the Kaplan turbine is best for hydraulic head ranging between 2-10 m and discharge 1-100 m<sup>3</sup>/s.

The most common adapted machine is the Pump as Turbine (PAT) which are standard water pumps utilized as hydraulic energy recovery systems by reversing the flow direction across the pump, which rotates as a turbine (Novara et al. 2019). Other adapted machines include Tubular propellers and positive displacement machines. PATs, best for implementation in water distribution networks, include Multi-Stage Radial PAT, Radial PAT, Mixed Flow PAT, Double PAT and axial flow PAT (Perez-Sanchez et al. 2017). The maximum efficiency of the commercial pump is an appropriate estimation of the maximum efficiency of the pump when used as a turbine (Novara et al. 2019). PATs are used in flow range of 0.001-10 m<sup>3</sup>/s and can operate at an elevation head up to 1000 m (Perez-Sanchez et al. 2017). The maximum power of PATs are 250 kW, limiting the usage to small hydropower; furthermore PAT performance is most effective for power outputs less than 100 kW (i.e. micro hydropower) (Novara et al. 2019).

There are numerous benefits of PATs as opposed to traditional turbines. PATs are commonly manufactured and are standardized in industry, thereby reducing the purchase price and allowing for universal availability (Novara et al. 2019). Turbines are compact and have easy installation and reduced operation and maintenance costs (Novara et al. 2019).

Alternatively, PATs do not have flow regulation, and may not be efficient during low flow periods (Novara et al. 2019). Additionally, because in-line turbines are installed where PRVs exist, backpressure levels must be maintained through additional equipment (Novara et al. 2019). Complicated schemes to maintain back pressure can be avoided if PATs are installed in locations where backpressure flow is not required, thus reducing the cost of equipment and installation (Novara et al. 2019).

## **II. Feasibility Assessment**

### *2.1 Where to install in-line turbines*

The primary requirement for installing micro-hydropower is excess pressure head in the existing water distribution system. These areas are most likely accompanied by PRVs or fill valves. PRVs are used to dissipate pressure as heat for specific flow requirements or pressure operating conditions (Perez-Sanchez et al.). Fill valves operate by opening or closing the flow, but do not maintain a pressure.

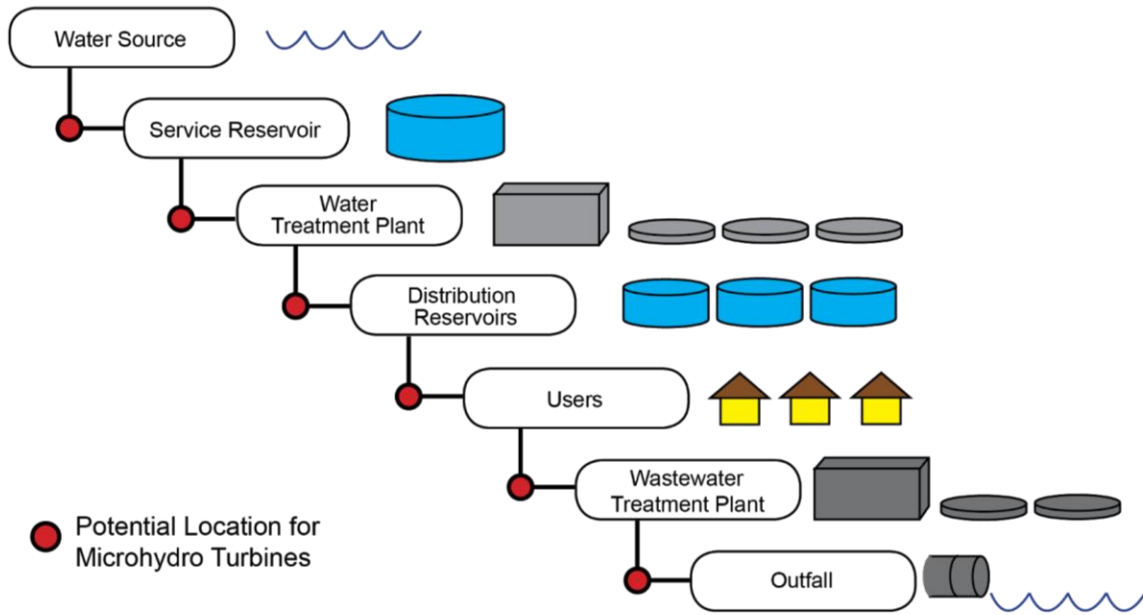


Figure 2. Potential locations for the application of micro hydropower turbines in a municipal water system. (Adopted from Loots et al., 2015)

The installation of micro-hydropower captures the energy typically lost to PRVs, reducing pressure while turning the resulting energy into electricity instead of heat. Excess pressure can be located anywhere throughout the system, providing multiple opportunities for energy recovery (Figure 2). In addition to flow and pressure, other factors must be considered when selecting a site for the installation of these turbines. Water quality can affect maintenance and upkeep of the equipment throughout its lifespan, therefore power generation from treated water can be preferable to wastewater or untreated water. The presence of existing infrastructure, particularly access to the power grid, is also an important factor that can determine the feasibility of a project and whether the energy captured can be sold back to the utility.

To site potential areas for micro hydropower, we looked at the current existing infrastructure components: elevated and ground storage tanks (ET and GST), water mains, pump stations, control valves, and master meters. The city of Ann Arbor distribution system is divided into five pressure districts. Within these 5 districts, there exists the main reservoir, three outlying reservoirs, three remote pump stations and two elevated tanks supply these districts. When comparing to Figure 2, Ann Arbor has PRVs located at the three pump stations (i.e. distribution reservoirs) and about 8-10 PRVs throughout the pipe distribution system (to users). The PRVs located in the distribution pipes are located underground and only accessible by manholes. Confined space is not ideal for installing in-line hydropower technology because it would increase the cost of installation. Furthermore, distribution flow rates and daily hours of flow at these locations are highly variable and flow data is not recorded. Therefore, we assess the feasibility of installing in-line hydropower at the three pump stations due to the large space to install equipment (located in pump houses accessible by door), recorded flow data and consistent flow rate.

## 2.2 Flow evaluation of pump station locations

Pump stations are the optimal location in Ann Arbor's water distribution system to install turbines primarily because these sites have more consistent flow (i.e. flow rate and daily hours of flow) when compared with flow in the pipe distribution system. We perform an expected power output of three pump stations to determine the payback period of installing in-line turbines. Power output is directly related to the flow rate and the duty cycles of flow. Thus, installing turbines will only be economically feasible if the power output allows for a payback period of 5-7 years. We acquired flow data for three pump stations, South Industrial, Liberty Pump and North Campus, during the 2018 year. At five-minute increments, the data included pressure on fill side (PSI), pressure on pumped side (PSI), storage tank levels (feet), fill rate (MGD), and distribution rate (MGD) (see figure 3).

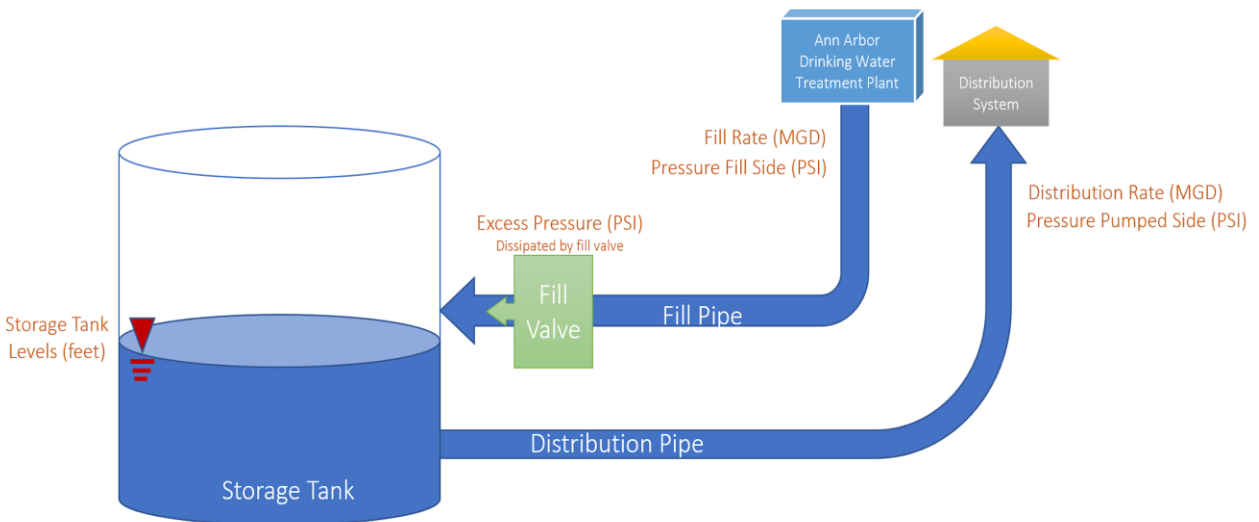


Figure 3. Sample pump station schematic. Daily averaged variables are listed in red.

We calculated the daily average hours of flow (i.e. duty cycles), daily averaged fill rate (MGD) and daily excess pressure (PSI) in the fill pipe. In Figure 4, we compared the daily duty cycles and the daily averaged fill rate of South Industrial, Liberty Pump and North campus.

The South Industrial pump station showed seasonal variations in its duty cycle. From June to October the duty cycle increases to a maximum duty cycle of 15 hours and approximately 5 hours from November to March (mean value of 7.22 hours). Liberty Pump and North Campus showed no seasonal variation in duty cycles, with a mean of approximately 9.45 hours and 10.48 hours, respectively. South Industrial has the greatest fill rate, with a mean value of 4.31 MGD  $\pm 0.418\sigma$ . Liberty Pump has the lowest mean fill rate of 3.13 MGD  $\pm 0.453\sigma$  and North Campus has a mean fill rate of 3.59 MGD  $\pm 0.472\sigma$ .

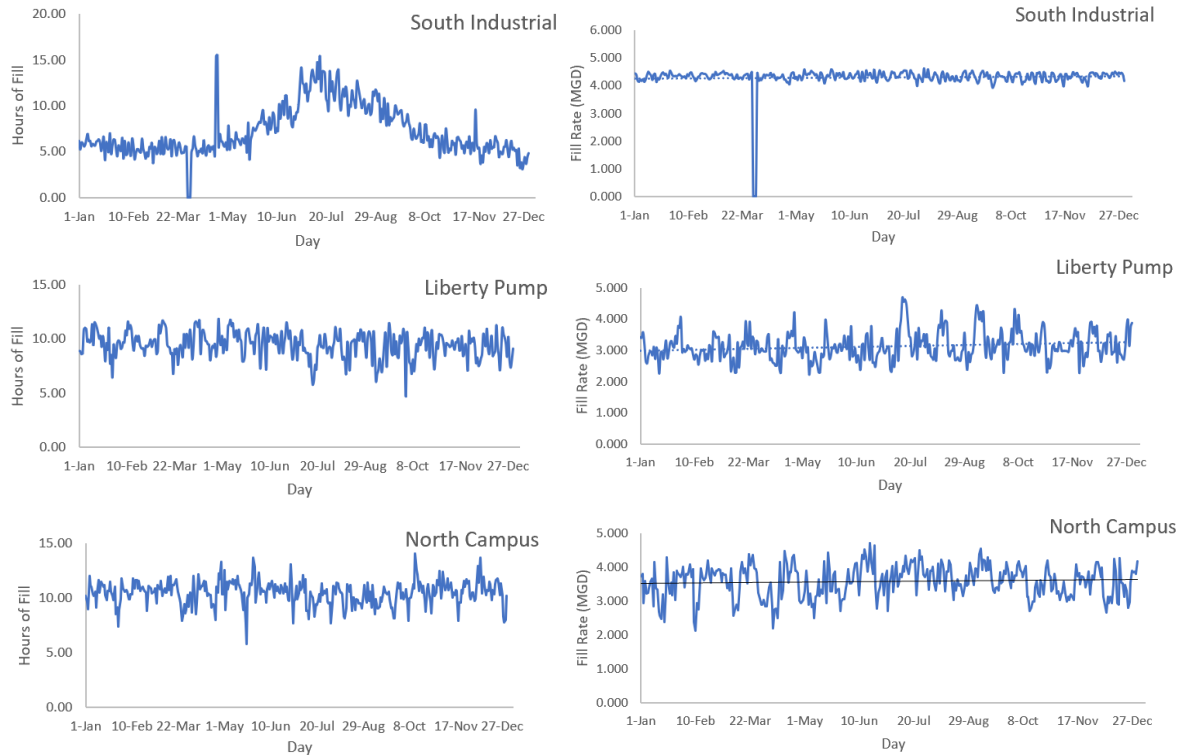


Figure 4. Assessment of duty cycles (left) and daily flow variability (right) of three pump stations.

### 2.3 Comparing power output of three potential micro-hydropower companies

Currently in the U.S. there are 3 companies implementing in-pipe micro-hydropower: SOAR hydropower, Rentricity Inc., and Lucid Energy. We assess the engineering feasibility of the three companies by comparing the expected power output of the three potential site locations based on the duty cycles and flow variability (see figure 4).

SOAR Hydropower manufactures custom, site specific turbines as part of their Inline Hydro Turbine Series (ILT-XX), available for pipes of size 4-24". The ILT series implements a combination Kaplan and Francis turbine design. The site-specificity of the turbines allows for maximum energy capture of flow. However, custom design leads to more expensive equipment than "off the shelf" turbine technology. SOAR hydropower provided a preliminary estimate for energy production and cost of installation for the three pump station locations. The SOAR representative estimated that North Campus can produce the highest expected power output of 73 kW with the highest energy production at 95,000 kw-hr/yr (Table 1). South industrial produced the next highest at 62 kW and 149,000 kW-hr/yr, while Liberty produced the lowest at 29 kW and 95,000 kW-hr/yr). Budgetary estimates include variable flow In-Line Turbine with adjustable wicket gates, vertical shaft generator, wicket gate actuator, drive couplings, fail-safe inlet valve, dismantling joint, control system and interconnection equipment for grid parallel operation.



Table 1. Energy and cost estimate provided by SOAR Hydropower (Mahone, 2019).

<b>Pump Station</b>	<b>Peak Expected Output</b>	<b>Energy Production (kw-hr / yr)</b>	<b>Cost to Install</b>	<b>SOAR Turbine</b>
South Industrial	62 kW	149,000	\$200,000-230,000	ILT12-45-9.0
Liberty	29 kW	95,000	\$190,000-220,000	ILT08-45-7.0
North Campus	73 kW	189,000	\$200,000-230,000	ILT12-45-9.0

Rentricity Inc. is a New York based company that implements their Flow-to-Wire™ system. Contrary to SOAR Hydropower, Rentricity turbines are Pumps as Turbines (see figure 1). These turbines are best for 20 kW to 350 kW range, with up to an 85% capacity factor, and SCADA system integration. Each Flow-to-Wire™ system includes a micro-turbine, turbine generator, control valve, and control cabinet (which can be used on site if connected to the grid for metered application). Cost to install includes turbine generator, control valve, control cabinet (electricity can be used on site or connected to grid for net metered application), engineering estimates, and ‘simple’ installation (whereby it is already installed in an existing vault and no excavation is necessary).

SOAR turbines utilize a standard pump technology and are not customizable compared to those of Rentricity Inc.. The standardized technology allows for more competitive equipment pricing but results in less energy capture of flow. Thus, the best location for PAT technology exists where there is consistency in flow rates and duty cycles. We see that the cost of installation for Liberty pump station is the least expensive at \$100,000 but also results in the least expected power output. South Industrial and North Campus have the same estimated cost of installation at \$150,000. Based on an 85% capacity factor of the Flow-to-Wire™ system, the Rentricity representative estimated that North Campus can produce the highest expected power output of 60 kW with the highest energy production of 200,000 kW-hr/yr (Table 2). South industrial produced the next highest at 58 kW and 175,000 kW-hr/yr, while Liberty produced the lowest at 32 kW and 100,000 kW-hr/yr).

Table 2. Energy and cost estimate provided by Rentricity Inc. (Zammataro, 2019).

<b>Pump Station</b>	<b>Peak Expected Output</b>	<b>Energy Production ( kW-hr/yr)</b>	<b>Cost to Install</b>	<b>Rentricity Turbines</b>
South Industrial	58 kW	175,000	\$150,000	Flow-to-Wire System™
Liberty	32 kW	100,000	\$100,000	Flow-to-Wire System™
North Campus	60 kW	200,000	\$150,000	Flow-to-Wire System™

LucidPipe™ Power System (LPS) is the largest micro-hydropower system of the three potential companies. The system requires a minimum pipe size and flow of 24” and 24 MGD, respectively. Two larger pipe size options exist, 42” (min. flow of 61 MGD), and 60” (min. flow of 128 MGD). The pipe systems, in order of increasing size, have a power capacity of 18 kW, 50 kW and 100 kW. We exclude an energy production analysis for Lucid Energy due to the system scale. The maximum flow of all the pump stations in Ann Arbor is 5 MGD. Thus, the Ann Arbor water distribution network operates on a scale too small to implement LPS technology.

Portland, Oregon is a model example of the city scale necessary to implement LPS technology. The water distribution network installed four 42” turbines in series, 42” creating a 200kW, upstream from a PRV. The system is estimated to generate 1,100 MWh of electricity a year (powering 150 house equivalent) (LucidEnergy, 2017).

Rentricity Inc. predicted higher energy production values for all three pump stations when compared to SOAR Hydropower. SOAR turbines are custom designed and theoretically should have higher energy production values due to the higher efficiency of the turbine type. Because each representative performed a limited analysis, the peak expected output is only a rough estimate. Thus, we recommend the AA DWTP hire representatives from both companies to perform a full site analysis to acquire a more accurate power analysis. However, for the purpose of this study, we will conduct the cost-benefit analysis with the numbers provided by the SOAR Hydropower and Rentricity Inc. representatives.

#### *2.4 Cost-benefit analysis and emission reduction effect of turbines*

To conduct the economic analysis, the team collected energy bills starting in January 2018 until December 2018. We used these documents to identify the average rate structures applied to energy use, and thereby determined potential cost savings associated with micro-hydro implementation. The pumping station energy bills also gave our team a sense of the variations in energy demand associated with seasonal changes throughout the year.

The team calculated the costs of installation and operation of the micro-hydro turbines and compared it to the estimated energy expenditure savings created from the generation of electricity and the sale of excess electricity to the City’s energy provider. The most current year-round billing rates for the city were considered to calculate the savings. The team applied a projection of DTE emission factors to estimate avoided emissions. We also used the social cost of carbon at a 3% discount rate to compute the avoided social cost of carbon resulted from generation of hydro-turbine power (EPA, 2019).

The team first calculated the expected annual energy production of each turbine in each distribution location by multiplying daily hours of turbine operation and expected output of the turbines in kilowatt-hours. The team then multiplied the energy outputs by monthly energy rates billed by DTE and Constellation Energy, which was collected over the course of January to December 2018, and computed the annual savings of energy expenses. The team then applied a 3.6% discount rate to calculate the present value of savings. The discount rate was determined by deducting inflation rate from the current market nominal rate. We also factored in fixed installation

and annual maintenance costs to compute the net present value of the turbine installation. The team consulted with representatives from SOAR and Rentricity Inc. for estimated maintenance activities and costs. We also found research that suggests the maintenance cost is approximately 3% of annual investment (IRENA, 2012). The team incorporated the findings and determined the maintenance cost by dividing installation cost over the 30-year lifetime multiplied by a 3% rate. We computed the present value of financial return by deducting the turbine costs from energy savings. We then determined the social benefits of emissions reductions and financial savings by subtracting the turbine costs from the total of energy savings and avoided social cost of carbon.

In general, we found a Rentricity Inc. turbine is more attractive than a SOAR turbine when considering financial return to energy generation compared to capital expenditures. The generation cost from SOAR turbine is 60% higher than the Rentricity Inc. turbine because of a higher installation cost. We found that the North campus location operating a Rentricity Inc. turbine is the most cost-effective scenario with an 8-year payback period, although this period could be decreased if Water Treatment Services were to acquire additional upfront funding in the form of grants or subsidies. Installing a Rentricity Inc. turbine will cover 37.2% of energy demand from the pump station, which is equivalent to saving \$341,971 from energy bill over the lifetime of the turbine (Table 3,4).

We can also reasonably expect GHG emissions will be reduced by 1,957 metric tons over the 30-year lifetime of the equipment. In terms of environmental benefit and emissions externalities, the installation of the Rentricity turbine in the North Campus pump station will avoid \$66,230 associated with the social cost of carbon to the global economy. Additionally, the City of Ann Arbor is considering an internal carbon fee on all city departments. By monetizing avoided emissions, the impact of the implementation of micro-hydro technology is much more evident. Water Treatment Services would stand to save much more financially when these costs are taken into account. Recent public discourse has promoted a carbon fee as a viable option for reducing carbon emissions and it is very likely that more governments, local and otherwise, will look to these policy options as a means for accomplishing climate goals. With this in mind, it would stand to serve most organizations to assess the costs associated with climate impacts when considering capital projects such as micro-hydro technology.

Table 3. Annual electricity consumption of pump stations

<b>Pump station location</b>	<b>Liberty</b>	<b>South Industrial</b>	<b>North Campus</b>
Electricity consumption (KWh/yr)	313,920	400,400	539,200

Table 4. Cost-benefit analysis of Rentricity Inc. turbine in three pump stations

<b>Pump Station</b>	<b>Liberty</b>	<b>South Industrial</b>	<b>North Campus</b>
Present value costs (\$)	106,307.58	156,307.13	156,307.13
Present value energy savings (\$)	161,577.71	227,661.96	341,971.53
Present value avoided social cost of carbon (\$)	31,818.63	49,083.00	66,230.94
Present value of financial return (\$)	55,270.58	71,354.83	185,664.4
Payback period (yr)	12	13	8
Present value of social benefits (\$)	87,089.20	120,437.82	251,895.34

As exhibited in Table 4, the implementation of a Rentricity turbine at the North Campus pumping station shows the most potential for cost savings and benefits. It is less financially beneficial to install turbines in the South Industrial and Liberty pump stations. The installation of turbines from both manufacturers have an estimated payback period greater than 8 years, which is higher than the expected payback period when considering a capital project (Table 4,5).

Table 5. Cost-benefit analysis SOAR turbine in three pump stations

<b>Pump Station</b>	<b>Liberty</b>	<b>South Industrial</b>	<b>North Campus</b>
Present value costs (\$)	208,723.57	218,905.21	218,905.21
Present value energy savings (\$)	166,930.42	225,790.45	305,901.68
Present value avoided social cost of carbon (\$)	31,316.12	51,317.11	62,302.59
Present value of financial return (\$)	(41,793.15)	6,885.25	86,996.47
Payback period (yr)	23	18	13
Present value of social benefits (\$)	(10,477.03)	58,256.36	149,299.06

However, if Water Treatment Services can acquire additional upfront funding to install Rentricity Inc. turbines in the two locations, the payback period could be shortened. In addition, if we consider avoided GHG emissions and the social cost of carbon, installing hydro-turbines is an additional cost-effective strategy to help the city achieve its carbon neutrality goal and reduce emissions externalities caused by a coal-intensive energy grid.

### **III. Enabling State and Federal Policies**

Federal and state governments have recognized in-line micro hydropower as a possible source of clean renewable energy. Since 2013, the Federal Energy Regulatory Commission has approved the applications of 115 in-conduit hydroelectric projects, split between municipal, agricultural, and industrial uses (FERC, 2019). Many government programs that incentivize renewable energy generation can be applied to micro-hydro turbine projects. In addition, multiple pieces of federal legislation have been passed in the past decade to ease the regulatory requirements for the installation of in-conduit turbines, greatly reducing the time needed for project review and inspection. California, Colorado, Massachusetts, and Oregon have all enacted programs specifically aimed to support the development of energy recovery hydropower within their state. The following policies form the basis of in-line micro hydropower adoption within the United States and provide resources for new projects.

#### *3.1 Hydropower Regulatory Efficiency Act of 2013*

Amending Part I of the Federal Power Act (FPA), the Hydropower Regulatory Efficiency Act of 2013 (HREA) created a category of hydroelectric facilities that did not require a Federal Energy Regulatory Commission (FERC) license or an exemption. The act allowed facilities to forgo the long FERC licensing process, instead only requiring a Notice of Intent (NOI) that could be completed in as little as 60 days. In order to qualify for the qualifying conduit NOI process under HREA, the facility must generate electric power on non-federally owned conduit not primarily used for electricity generation and the capacity must not exceed 5 MW (Johnson, 2018).

#### *3.2 America's Water Infrastructure Act of 2018*

The America's Water Infrastructure Act of 2018 (AWIA) is a comprehensive water resources bill that includes provisions specifically targeted to incentivize new hydropower development. The bill touches on various forms of hydropower, promoting investment in both new and existing facilities. As it relates to in-conduit hydropower, the AWIA increases the Hydropower Regulatory Efficiency Act's 5 MW size limitation for its Notice of Intent process, allowing projects up to 40 MW to forgo the licensing process. It also reduces the time for FERC to make a qualifying conduit determination decision from 60 to 30 days after an entity files a NOI to construct such a facility (White 2018).

#### *3.3 New 242 Program Federal Incentives*

The Energy Policy Act of 2005 authorized the creation of the "Section 242" program, which aimed to benefit both energy recovery hydropower and traditional hydropower technologies. It wasn't until 2014 that Congress provided appropriations for the Section 242 program for the first time. The program provides incentive payments on a per-kilowatt-hour-generated basis, with payment amounts depending upon overall program participation. Maximum

payments are capped at \$750,000 per year for a given project for up to 10 years, subject to availability through ongoing congressional appropriations (Johnson, 2018). Congress has appropriated funds every year since 2014, extending the program past its end date in 2015. In 2019, the program was appropriated \$6.6 million (Office of Energy Efficiency and Renewable Energy, 2019).

### *3.4 U.S. Department of Energy: Energy Efficiency and Conservation Block Grant Financing Program*

The U.S. Department of Energy's (DOE's) Energy Efficiency and Conservation Block Grant (EECBG) Program provides \$3.2 billion in block grants to Indian tribes, states, cities, and communities to develop and manage energy efficiency and conservation projects. The EECBG Program directly invest in energy efficiency and renewable energy technologies at local level that increase renewable energy capacity, technical knowledge, and deployment of energy efficiency in communities (DOE, 2019).

### *3.5 State Renewable Portfolio Standards (RPS)*

State Renewable Portfolio Standards are renewable energy requirements that state governments set for utility companies. Whether they apply to municipal-owned, cooperatives, or just investor-owned utility companies depends on the state. Typically, they call for a certain percent of energy generation from a provider to be from renewable sources. Today 29 states have adopted RPS's, of those 13 have requirements of 50% or greater (National Conference of State Legislators, 2019). Michigan has set a standard of 15% by 2021 and 25% by 2025 (Michigan Public Service Commission, 2019). Utilities that don't meet the state's standards are subject to financial penalties. Compliance with the RPS is demonstrated by renewable energy credits (RECs), which are equal to one MWh of clean energy produced for the grid. This creates a marketplace where renewable energy providers can sell excess credits as an additional revenue stream, thereby rewarding renewable energy generation. Credits can also be distributed for energy use reduction or energy production during peak-usage hours. Some credits can be transferred into the national or international marketplace where credits might have higher values depending on demand. Projects must be registered and approved by the state's appointed agency to receive RECs for their production (APX, 2019).

## IV. Case Studies and Best Practices

The following cases studies represent successful implementations of in-line micro hydropower turbines in municipal drinking water systems. Each case is unique, with external circumstances surrounding the projects that should be considered when evaluating a future project. These considerations are summarized in the best practices section.

### 4.1 Case Studies

#### Keene, New Hampshire

Configuration: Two different turbines installed in parallel with PRV

Generating Capacity: 54 kW

Estimated Energy Production: 180,000 kWh first year

Equipment Cost: \$156,000

Total Project Cost: \$588,000

The City of Keene, New Hampshire sought to develop an in-pipe hydro-system to recover clean energy while maintaining their standards for control of over-flow regimes and daily maintenance. In the system, water is gravity-fed from the Babbidge Reservoir through a 20-inch diameter conduit into the treatment facility. Inside the treatment facility, a PRV reduced the incoming water pressures before discharge into the treatment process. The City of Keene aimed to recover the energy released at the PRV valve located before the treatment plant's raw water storage tank (Rentricity, 2019). Utilizing contractors for the entirety of the work, the city installed two turbine generators that can operate either individually or in parallel, with Turbine Generator 1 generating 17-18 kW power and Turbine Generator 2 generating 36 – 38 kW power for a combined capacity of 50-55 kW (Zammataro, 2017). A surge release valve operates in accordance with local conditions to prevent overpressure or water hammer effects in the event of a rapid unplanned turbine shut down. In addition, the equipment was integrated into the City's existing SCADA (Supervisory Control and Data Acquisitions) system, which allows for remote control and monitoring of turbine operations and flow. Sorenson Systems was contracted for the controls and turbine procurement while Rentricity was chosen to handle systems engineering. The City of Keene earned an American Recovery and Reinvestment Act of 2009 (ARRA) grant of over \$287,000 as well as approximately \$10,000 annually from Renewable Energy Credits (RECs) from energy produced from the turbines (Allen, 2013).

#### Portland, Oregon: Vernon Station

Configuration: Turbine in parallel with an existing PRV

Generating Capacity: 25 kW

Estimated Energy Production: 205,900 kWh (175,000 kWh)

Equipment Cost: Approximately \$141,000 (48% of Total Project Cost minus \$120,000 for installation of 3-phase power)

Total Project Cost: \$543,000

The City of Portland Water Bureau (PWB) installed a 25 kW turbine within an existing municipal system vault, generating power using potable water at the location of an existing PRV in the city's water distribution system. Sited at the Vernon Water Tank, the turbine generated electricity from the pressure differential between the Mt. Tabor distribution zone and the local distribution system (Allen, 2013). PWB Maintenance & Construction crews were used for installation. The project had many unique aspects that the Water Bureau had to address while completing this project. Both the tank and vault are within a public park located in an urban residential neighborhood, with the vault built below ground. The PWC engaged with the local neighborhood organization to educate locals about the project and interruptions of the park's use. Oregon's water rights required a 6-month commenting period, for which the Bureau sent a letter to 30 agencies and held a public meeting on site. The vault required improvements to maintain working clearances for the electrical and safety codes. Improvements include improved access, lights, a ventilation fan, and intruder alarms. Approximately \$120,000 was spent to install 3-phase power onsite. The project received both state and federal funding including \$65,000 from the Energy Trust of Oregon, \$38,000 in Business Energy Tax Credits, and a \$65,000 grant from the American Recovery and Reinvestment Act of 2009. The total Cost to PWB after incentives was \$375,000 (Peters, 2013).

#### Basalt, Colorado

Configuration: Single turbine

Generation Capacity: 40 kW

Estimated Energy Production: 300,000 kWh (175,000 kWh with water rights restrictions)

Equipment Cost: \$207,000, including ancillary work

Total Project Cost: \$394,000

Basalt's pursuit of an inline hydro project was led by the Town's Green Team, a committee of residents and elected officials that advocate for waste reduction, improved energy efficiency, decreased greenhouse gas emissions, and overall sustainability within the town. The Town of Basalt enlisted the assistance of an outside consulting firm, Canyon Hydro, with experience in the design and development of similar projects, who provided the turbine, generator and controls for the project. The equipment was installed in a pipe connecting two springs- Basalt Springs and Luchsinger Springs- to the water treatment plant. A powerhouse was constructed to house the equipment, along with additional monitoring equipment to track operations. The Town has dealt with challenges related to water rights, which has limited the project's energy generation at 175,000 kWh compared to its full capacity of 300,000 kWh. The Colorado Energy Office supplied the project with \$119,000 in ARRA (federal stimulus) grant funds. The town partnered with Holy Cross Energy, who agreed to finance up to \$300,000 of the project, to be repaid through the electrical generation of the plant, estimated at 6,000,000 kWh. This agreement ultimately saved the town approximately \$60,000 in interest payments (assuming a 20-year loan at 2%) (The Colorado Energy Office, 2015).



## 4.2 Best Practices

There are over 51,000 municipal water systems within the United States, but the potential for implementation of inline micro-hydropower is not uniform across systems (Curtis, 2017). Feasibility is determined by both the physical characteristics of the water distribution system as well as the institutional infrastructure that permits and funds projects. While there is a large amount of variability among projects, the process for implementation is very similar, with common factors that can determine a project's success other than the flow and head running through the pipes.

The need to build additional infrastructure, such as utility hook ups and vaults, can dramatically increase the total cost of the project. The Portland Water Bureau spent approximately \$120,000, over a fifth of their total project cost, on installing 3 phase power to the site (White, 2013). Existing infrastructure can also bring additional value. Supervisory Control and Data Acquisitions (SCADA) systems can increase efficiency, allowing for optimal use throughout flow variations and reducing long-term maintenance costs. Turbines are typically installed parallel with existing PRV's to ensure continued usage in the event of a turbine malfunction. In addition, the ability to use the energy generated from the turbines on site for normal operations can be very attractive, depending on state metering legislation and the contracts between the municipality and the utility. Reducing overall energy use can result in larger returns if the rate given for returning energy to the grid is lower than the price to consume it.

All projects must be approved by the Federal Energy Regulatory Commission. Though the FERC process has drastically simplified since the early 2010's, going from a year long licensing procedure to a 30-day Notice of Intent, it still represents a bureaucratic hurdle that must be cleared before the project can start. The Colorado Energy Office offers streamlined permitting assistance services which has greatly helped municipalities implement micro-hydro in their water systems, especially before the Hydropower Regulatory Efficiency Act of 2013 (Curtis, 2017). Even without state support, municipalities can avoid unnecessary delays through proper due diligence.

Inline micro-hydro offers the ability to qualify for renewable energy credits. Though the value of these credits can vary depending on the market, registering the project for energy credits can bring in much needed revenue. In Keene, New Hampshire, applying for renewable energy credits brought in approximately \$10,000 a year, which during the projects 30-year lifespan could be more than \$300,000 (Zammataro, 2017).

Because inline turbines produce steady, predictable energy returns, project financing could be available through a Power Purchase Agreement. These agreements provide funding up front in exchange for the guarantee for power down the line. The rate that the buyer receives is typically lower, but the savings from avoiding loan interest and other financing charges can make the deal attractive to both parties. The renewable energy credits can also be used in a similar way, with the following years' credits guaranteed to the buyer. Utilities themselves can partner in the agreement, if they have a commitment for clean energy or are seeking RECs to meet portfolio standards. Rentricity offers various financing options, including taking full ownership of the equipment, which removes any risk from the municipality in exchange for all or most of the energy and tax credit revenues (Rentricity, 2019).

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