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Energy Efficiency Guidelines for Vermont Wastewater Treatment Facility Upgrades[1]

Introduction

This guidance document has been developed to enhance the understanding and incorporation of operational efficiency, life cycle cost analysis, and best design practices during major facility upgrades and refurbishments of wastewater treatment facilities (WWTF). Significant energy efficiency opportunities exist in the wastewater treatment sector. Most Vermont municipalities will need to undergo major facility upgrades at their WWTFs to comply with new clean water standards – particularly around the Lake Champlain Phosphorus TMDL and the Long Island Sound Nitrogen TMDL. Choosing efficient designs will result in long-term impacts and significant energy savings. Energy, which can commonly represent between 60-80% of the operating costs for a wastewater treatment facility.

This guidance document outlines potential cost effective energy efficiency improvements that can be discussed between the client and engineer for new design projects and simple equipment replacement/refurbishing upgrades. Reviewing these concepts early in the design process can help achieve early buy in from facility staff and set the stage for additional efforts in partnership with Efficiency Vermont to educate and provide the tools needed to provide a clear path for wastewater facility staff to maintain system efficiency after the upgrade is complete. The document is intended to only be a guideline at this time.

Key feedback provided by the VT DEC during the review process included the following:

- For any project seeking funding through the Vermont Clean Water State Revolving Fund (CWSRF), the Preliminary Engineering Report (PER) must discuss and address energy and water efficiency.
- DEC considers energy process audits as eligible planning expenses under the CWSRF.
- For any project applying for a Step III Construction Loan through the CWSRF, WRRDA requires the municipality to submit a Fiscal Sustainability Plan that also includes a certification that efficiency measures have been adopted to the maximum extent possible.
- DEC is considering revised language for NPDES permits that would require energy efficiency to be addressed in 20-year evaluations.

[1] The guidance was prepared by Steve Bolles, Process Energy Services under contract with Efficiency Vermont.

Guideline Initial Scope

The original proposal outline for the draft guidance document included the following topics:

- Discussion of general instrumentation recommendations and SCADA data monitoring features, which encourages staff to monitor system energy use and gives them the data needed to recognize when a system is operating inefficiently.
- Equipment sizing and how this impacts long term energy use and demand costs. This will include reviewing the benefits of having VFDs and different capacity standby equipment.
- The benefits of minimizing square footage that needs to be ventilated and heated. Simple design changes that allow large maintenance areas to be unheated during the year.
- Heating and ventilation system controls that provide flexibility for operators to optimize system operation.
- Developing an energy balance to estimate energy costs for the proposed upgrade.
- Elements to include in a life cycle cost analysis and how process upgrades can impact operating costs for other facility systems.
- Framing of how the document would fit in with existing regulations and standards.

Examples of efficient and inefficient designs from recent energy evaluations would also be included when available (without facility reference).

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Attachment A: LCCA Examples

1. Background

The improvements discussed in this guideline include cost effective design approaches, specifically for Vermont wastewater facilities, based on reviewing over thirty facilities over the last three years. The recommendations have been selected based on long-term energy consumption savings (kWh, fossil fuel reduction) and energy demand (kW) savings. Although a simple payback approach is adequate to justify the majority of the proposed improvements included in this guide, a life cycle cost analysis approach is recommended when multiple improvement options are available or when comparing large-scale capital-intensive projects for complete process system upgrades (e.g., dewatering process, biological treatment process).

The guideline includes recommendations to monitor equipment operation to develop a more effective energy management program, however, it does not include the following initiatives that are not directly related to energy savings.

- Building materials that claim to be more sustainable.
- A focus on LEED program points (although we recognize that LEED can encourage good design practices)
- Projects that are focused more on reducing greenhouse gasses than reducing energy costs.

It also does not address other potential facility cost/resource savings such as city water use, chemical cost savings and sludge cost saving projects (however these costs are included in one of the Appendix LCCA examples).

We have included a discussion on renewable energy technologies, but with an emphasis on low cost design modifications that can make it more cost effective in the future to pursue a full investment in these technologies (with the expectation that incentives would be needed to justify these types of projects). Based on numerous sources, it is common knowledge within the energy field that "the greenest, most cost effective kWh is the one that is never used". Based on this, energy savings through system optimization is emphasized in this document.

This document is intended to supplement the following codes and standards applicable for municipal wastewater facilities. In the event of a conflict between this document and the listed standards, the standards shall take precedence.

- TR-16: Guide for the Design of Wastewater Treatment Works, 2011 Edition http://www.neiwpcc.org/tr16guides.asp
- Ten State Recommended Standards for Wastewater Facilities, 2004 Edition http://10statesstandards.com/wastewaterstandards.html
- Vermont Commercial Building Energy Standards, 2015 Edition http://publicservice.vermont.gov/energy_efficiency/cbes
- USDA Bulletin 1780-2 Preliminary Engineering Reports for the Water and Waste Disposal Program http://www.rd.usda.gov/files/UWP_Bulletin_1780-2.pdf
- National Fire Protection Association. *Fire Protection in Wastewater Treatment and Collection Facilities*, NFPA 820, 2016 Edition http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=820

This document does not cover client/engineer communication, pre-design meetings or milestone meetings. However, we hope this document will facilitate a discussion of energy related ideas and concepts as part of the design process. Early participation and buy in from the client (facility operator) is a critical part of the process.

One of the key recommendations included throughout this document is to install additional instrumentation, monitoring as part of SCADA systems, and standard operating procedures (SOPs) for facility staff to recognize when equipment is not optimized. To justify the cost for these improvements, a reasonable reality check would be to calculate the additional energy use for a 5% decrease in efficiency over a ten-year period (which the instrumentation, monitoring and SOPs would most likely identify) to see if justifies the extra expense. When the additional expense cannot be justified, low cost additions that can facilitate the use of portable equipment (such as pump suction/discharge pressure taps) can be pursued. A low cost approach to obtaining power values (kW) can be determined from data available on VFD interface screens.

2. Evaluating High Energy Use Projects

2.1 Fundamental Energy Saving Guidelines

There are two fundamental energy guidelines that that can be considered for new facility design/equipment upgrades;

- First invest in control systems and system components that are capable of adjusting the equipment capacity to consistently match process requirements.
- After optimizing the control systems, establish a new baseline of energy use with real measurements and evaluate the benefits of high efficiency equipment.

These simple guidelines apply to all types of process and building systems.

2.2 Energy Baseline & System Benchmarking

Before the benefits of energy saving improvements can be determined, an energy balance must be done to provide a baseline of system energy use at average flow conditions so that energy savings (or increase in energy use) can be calculated based on data that is relevant to real world conditions. Important considerations include the following:

- For all major equipment (5 hp and higher and operated more than 2000 hours/year), a kW field measurement can be taken at average operating conditions.
- 12 months of equipment run time data can be used to account for seasonal changes. If recorded equipment run time is not available, run time can be estimated based on operator input.
- 12 months of average facility process data and recent facility electric energy use from the utility bills is needed to benchmark the data and verify the energy balance.

For a full facility energy balance, equipment can be grouped together by process. A partial example of an energy balance performed by Process Energy Services is shown in Table 1. A motor load between 70% and 85% is typically used for low hp equipment, not requiring a direct kW measurement (under 5 hp). Since there was no recorded operating hours for some of the equipment (with the exception of the aeration blowers), annual run time was estimated based on discussions with plant staff.

Table 1: Facility Sample Energy Use Breakdown

Existing Equipment	Hp	Estimated Load	kW	Annual Estimated Hours	Existing kWh	Notes
Aeration System						
Anoxic Zone Mixer	5.0		2.3	8760	20.148	2.3 kW measured
Anoxic Zone Mixer	5.0		1.4	8760	12.264	1.4 kW measured
Aeration Mixer 1-1	15.0		2.2	8760	19.272	2.2 kW measured (low speed)
Aeration Mixer 2-1	15.0		2.2	8760	19.272	2.2 kW measured (low speed)
Aeration Blower #1	125.0		38.0	5184	196.992	38 kW measured at typical VFD
Aeration Blower #2	125.0		38.0	5256	199.728	Measurement from Blower #1
Aeration Blower #3	125.0		38.0	0	0	Estimated
			55.0		**467.676**	
Final Clarifiers/RAS						
Final Clarifier Drive	1.0	0.80	0.6	8760	5.228	kW based on estimated load
Final Clarifier Drive	1.0	0.80	0.6	8760	5.228	kW based on estimated load
RAS Pump #1	30.0		5.4	8760	47.304	kW for RAS Pump #3 used
RAS Pump #2	25.0		5.4	0	0	Spare
RAS Pump #3	30.0		5.4	8760	47.304	5.4 kW measured
Scum Pump	10.0	0.80	6.0	200	1.194	kW based on estimated load.
Blended Scum Pump	5.0	0.80	3.0	200	597	kW based on estimated load.
Blended Scum Pump	5.0	0.80	3.0	200	597	kW based on estimated load.
			14.0		**107.451**	

After completing the energy balance, a summary of annual energy use for each system was assembled as shown in Table 2. This was compared to the total energy use from 12 months of utility bills.

Table 2: Facility Sample Energy Use Summary

Plant System	Baseline Annual Use (kWh)	Percent of Total	Plant Process Parameter (Average annual flow)	Annual Benchmark Value
Prelim Treatment	126,113	6%	2.96 mgd	117 kWh/mg
Septage	143,911	7%	2.96 mgd	133 kWh/mg
Primary Treatment	22,764	1%	2.96 mgd	21 kWh/mg
Aeration System	467,676	23%	2.96 mgd	433 kWh/mg
Secondary	107,451	5%	2.96 mgd	99 kWh/mg
Sludge Process	162,679	8%	2.96 mgd	151 kWh/mg
Service Water	11,151	1%	2.96 mgd	10 kWh/mg
UV System/Post	416,124	20%	2.96 mgd	385 kWh/mg
Misc. Process Systems	8,057	0%	2.96 mgd	7 kWh/mg
Building Systems	577,665	28%	--	--
Annual Total	**2,043,591**	**100%**		**1892**
Annual Electric Bills	**2,122,800**	**--**		

The energy balance provides a reality check to be sure equipment hours and energy measurements make sense when compared to annual energy bills. The benchmark values could be improved with additional system-specific data (e.g., aeration dissolved oxygen levels/lbs of BOD, gallons of septage, gallons of sludge processed).

2.3 Energy Calculations

Energy saving calculations can be structured to first account for using simple, low cost technologies before establishing the existing system energy use that will be used to justify more costly system improvements. Examples of this include calculating the potential savings for only using DO controls before investing in new high efficiency blowers, savings for effluent source heat pumps before accounting for lower energy use with low temperature thermostats, and tighter ventilation controls.

There are times when grouping technologies are needed to fully realize savings, however it is recommended that this strategy is presented to decision-makers and regulators to understand the reasoning for the project approach instead of blending the savings to justify a more costly project (the LCCA approach is ideal for these types of projects).

Industry standard "rule of thumb" calculations for energy saving estimates are acceptable when more extensive calculations would not be practical (e.g., 2% savings per degree reduction for space heating savings instead of building modeling). However, engineers must be aware of simplified calculation limitations that could significantly overestimate energy savings (such as using the affinity laws to calculate VFD savings for a high static head pump system).

2.4 Performing a Life Cycle Cost Analysis

A life cycle cost analysis (LCCA) has been recommended for significant capital projects to determine the most cost effective long-term savings option. For lower cost projects (such as equipment upgrades), a LCCA analysis is also recommended when a simple payback comparison is not adequate to determine the best solution.

Most engineers take the initiative to perform a life cycle cost analysis (LCCA) when there is not a clear choice between competing technologies for large system upgrades. The analysis is typically done using spreadsheets with an investment discount rate, cost escalations for energy, maintenance, labor, and inflation. For lower cost projects (such as pump/blower equipment upgrades), a life cycle cost analysis is not typically done. *The Consortium for Energy Efficiency* summarized the benefits of a life cycle cost approach below.

CEE Energy Efficiency RFP Guidance for Energy Efficiency

This energy efficiency document, published by The Consortium for Energy Efficiency summarized the need for the LCC approach as follows: *Discussions with engineering firms and treatment facility operators revealed that the decision making process for plant upgrades and new construction focuses primarily on first costs and capital expenditures, rather than on operating expenses and life cycle cost. Capital cost evaluation alone fails to account for operation and maintenance costs, which typically exceed – sometimes many times over – the up-front cost of the equipment. Lifecycle cost analysis is a means of integrating operations and maintenance costs into the evaluation and planning of a facility upgrade or expansion project. Lifecycle cost simply means evaluating the cost of a piece of equipment over an expected lifetime for that product, including the energy and maintenance costs that it will incur over that time. When two or more products are compared, the basis for this comparison should be the full cost of each product over this lifecycle.*

Attachment A presents two life cycle cost examples. The first is a large dewatering project that compares three dewatering system options, and the second example is from *Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems* published by the Hydraulic Institute that looks at four options for improving a pump system. These examples outline the methodology of a life cycle cost analysis. The discount rate, inflation, maintenance, and energy escalations in both examples are higher than the USDA Bulletin 1780-2 *Preliminary Engineering Reports for the Water and Waste Disposal*

Program, which references Appendix C of OMB Circular A-94. The inflation and real discount values in the Bulletin are listed in Table 3. The USDA Bulletin also provides specific guidance on how the LCCA should be developed.

Table 3: 2016 Inflation and Real Discount Rate

Description	3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
Real Discount Rate	0.1%	0.4%	0.7%	0.9%	1.2%	1.4%
Maintenance Labor,	1.6%	1.8%	1.8%	1.9%	1.9%	2.0%

An important consideration of an LCC analysis is that the result is only as good as the project cost estimate and O&M data. If the O&M data is off by 20 to 30%, the analysis error over 10 or 20 years will magnify considerably.

For low cost, fast payback projects (under $20,000, payback less than 3 years) with limited improvement options and incomplete O&M data, a simple payback calculation is usually an adequate method to evaluate project cost effectiveness.

When an LCC Analysis is warranted, we recommend the following considerations for the energy cost components of the analysis:

- Include energy consumption and demand costs (if applicable) as part of the energy use/cost estimate. If a new building is required, heating costs can also be estimated for each option.
- The baseline energy use can be determined using actual kW measurements (for existing equipment) at average flows and process loads.

3. Wastewater Process Systems & Equipment with the Greatest Impact on Energy Use

As described in the CEE Energy Efficiency document, three systems typically account for the majority of wastewater facility energy use: pumping, aeration, and solids handling/odor control. These three systems combine to make up approximately 85% of energy use at a typical activated sludge wastewater facility. Control systems, energy submetering, and equipment monitoring can help facility staff monitor and optimize equipment operation to reduce energy costs. A review of common energy related improvements for these systems are provided below.

3.1 Pumping

Every wastewater plant should strive to achieve the following pump optimization strategies:

- All large pumps (20 hp and higher) operating at least 2000 hours have an average mechanical efficiency of 75% or higher, and all small pumps/solids pumps (less than 20 hp) have at least a 65% average mechanical efficiency.
- Pumps that are equipped with variable frequency drives can have the minimum and maximum VFD speed set to maintain the pump within 15% of the design point efficiency.
- Pump flow is matched to what the process requires through the use of controls and variable frequency drives. For example, if a dewatering system that requires plant water pressure of 80 psi is not on line, then a lower general use pressure of 40 psi can be maintained.
- Pump efficiency is monitored periodically and repairs are made to maintain high efficiency.

- Proper sized pumps used for current low flows with provisions to upgrade if flow increases.
- Use of premium efficiency motors when cost effective.

Selecting the right pump to handle maximum rated flows while handling lower typical flows efficiently is a challenge for design engineers. The standard approach of having two pumps available for peak flows and a third pump for back up is typical for most systems. The pumps usually have identical ratings and are rotated to insure all three pumps are maintained for service. Applying variable frequency drives for the pumps has been a common approach to adjust pump capacity to match lower flows. However, when a pump VFD speed is reduced with a high static head system, operating the pump at low flows can cause the pump to operate in a low efficiency region of the system curve. This is one of the most challenging aspects of sizing a pump equipped with a VFD for high flows while operating at a reasonable efficiency when flows are reduced.

NHDES Design Guidelines:

As part of the 2014 NHDES Engineering Design Standards (Env-WQ 700), the document requires consideration of the use of jockey pumps (small pumps) when appropriate for water and wastewater pump stations to pump low flows more efficiently. The document also recommends providing an analysis of existing baseline energy use and calculating the energy use after the proposed improvements at the full range of flow conditions and power monitoring instrumentation for large pumping systems.

To improve pump system efficiency, the following strategies can be investigated:

- Pumps are often selected based on a best efficiency point at the maximum operating flow and head. If the engineer can select a pump with a steeper head curve and a best efficiency point closer to the average flowrate, the pump will operate more hours in an efficient region of the curve. Although the pump may operate at a lower efficiency at full capacity, the minimal operating hours at that point will not impact annual energy use significantly and optimize long term pump system operation.
- Limit VFD operating ranges (by adjusting min/max VFD speed settings) to achieve a reasonable efficiency. Many pump systems with VFDs have been commissioned to operate continuously. However, at low flows, pump efficiency can drop below 30%. In most cases, there is no reason a VFD equipped pump can't be activated and deactivated just like a full speed pump to maintain a higher operating efficiency.
- For high static head systems, an alternative to using a VFD is to include an additional smaller pump (or two smaller pumps equivalent to a large pump) that would be more efficient at low flows. This solves the problem of operating a large pump inefficiently at low VFD speeds by having a new set of efficiency curves.

The example shown below illustrates that installing a smaller pump as a retrofit project, may not always be cost effective. However, it provides an overview of how to develop a flow profile to evaluate these types of projects. The economics would change if the pumps were at the end of their useful life or needed major repairs.

Investigating the Potential Energy Savings for Installing a Smaller Pump:

A raw sewage pump system at a New York Wastewater Treatment Plant consisted of three vertical angle non-clog centrifugal pumps. Each pump was equipped with 60 hp motors and VFDs. The majority of time, the flow to the plant was low enough so that one pump was adequate. If the flow exceeded the capacity of one pump, the control system would start an additional pump.

Based on the curve data, the pump system has been designed to meet a peak flow rate of 10 MGD (6944 gpm) with two pumps operated in parallel. With three pumps installed, this followed the standard design of having one pump as a spare. Based on maintaining this approach, the potential of installing a smaller, more efficient pump unit would most likely need to be added to the existing three-pump configuration. For this station, a spare bay was available to pursue this option.

Based on average flow data from 2011 and 2012 and diurnal 24-hour flow data from two weeks of flow charts, a flow interval profile was developed to summarize the annual hours at various flow rates.

Flow Interval	Average Flow in gpm	Annual Hours at Flow	kW Based on Flow Relationship	Annual Total Power (kWh)	Existing Pump Efficiency	Proposed New Pump Efficiency	New Power Use (kW)	Annual Total Power (kWh)
0.5 to1.0	521	0	15.5	0	--	--	--	0
1.0 to 1.5	868	0	17.2	0	--	--	--	0
1.5 to 2.0	1215	0	18.8	0	--	--	--	0
2.0 to 2.5	1563	882	20.5	18,060	51%	75%	13.6	12,014
2.5 to 3.0	1910	1429	22.2	31,652	59%	78%	16.3	23,251
3.0 to 3.25	2174	2280	27.0	61,560	56%	77%	19.1	43,458
3.25 to 3.75	2431	2432	24.7	59,955	69%	77%	21.6	52,644
3.75 to 4.0	2694	1155	25.9	29,942	--	--	--	29,942
4.0 to 4.5	2951	91	27.2	2,476	--	--	--	2,476
Above 4.5		456	29.7	13,522	--	--	--	13,522
	Total	**8725**		**217,167**				**177,307**

A previous report recommended installing a smaller non-clog sewage pump, equipped with a 40 hp motor pump rated to provide 2750 gpm @ 34'. The new pump efficiency was determined from the manufacturer's pump curve at each flow rate.

Improving the existing efficiency with a smaller pump operated 7023 hours/year (80% of the time) would provide the following annual savings:

Pump Energy Savings: (217,167 kWh – 177,307 kWh) = 39,860 kWh * $0.109/kWh = $4,345

With an estimated project cost of $150,000, the 30+ year simple payback was not cost effective.

Pump Efficiency Testing

For high-energy pump systems, baseline conditions for each pump can be initially provided as part of the commissioning process. Facility staff can readily perform periodic pump efficiency testing if flow, pressure and power (kW) instrumentation is included in new system upgrades. With flow meters fairly standard for major process systems, the addition of pressure and kW instruments would not increase project cost significantly. The essential data can be displayed on the SCADA system (or collected at each pump by facility staff) to perform the simple pump efficiency calculation shown below.

$$\text{Pump Efficiency} = \frac{\text{Flow (gpm)} * \text{Head (ft)} * .746}{3960 * E_m * E_{vfd} * \text{Power (kW)}}$$

Flow: Total flow in gallon per minute (gpm)
Head: Discharge pressure (psi) * 2.31 = head in feet - suction pressure (psi) or level in feet (additional considerations include velocity losses, suction piping losses and other unaccounted for component losses).
Conversion of brake horsepower to kW: 0.746
Centrifugal pump constant: 3960
E_m : Nameplate motor efficiency with adjustments based on age/number of rewinds
E_{vfd}: Variable frequency drive efficiency (97% typically used for new AC PWM drives)
Power: kW measured with a true RMS meter between the VFD and the power supply disconnect.

The above calculation could also be done automatically in the control system logic and displayed on the SCADA system operator interface screen.

Matching Pump Flow to Process Requirements

The simple strategy of matching pump flow to process requirements is often overlooked for many types of systems. A few examples for wastewater process systems are provided below.

- For plant water systems, flow may be circulated or sprayed into clarifiers when it’s not needed.
- Return activated sludge pumps with VFDs may be operating at higher speeds when lower flows would be adequate for certain conditions.
- For mixing applications, the original rated pump/mixer capacity can be reviewed to see if the equipment capacity could be reduced while still providing adequate mixing for the process.

The engineer can provide specific guidelines and energy saving calculations in the O&M manual for different operating conditions to help facility staff determine the energy saving benefit for operating facility pump systems at lower flow capacities.

3.2 Biological Process Systems

The biological process in a wastewater facility includes systems that use microorganisms to degrade organic contaminates from wastewater. Wastewater facilities in Vermont typically use the following types of biological process systems:

- Biofilm Systems: Rotating Biological Contactors (RBCs) & Trickling Filters
- Activated Sludge (with fine bubble diffusers)
- Oxidation Ditch (also called racetrack systems) with mechanical aerators
- Lagoons (diffusers/blowers or surface mechanical aerators/mixers)
- Sequencing Batch Reactors (SBRs) with blowers/mixers
- Membrane Bioreactor

These systems may also include nitrogen and phosphorous removal as part of the process. With the exception of RBCs that use low horsepower shaft drives, the high-energy use equipment for these systems include blowers, mixers and pumps.

For biological system upgrades, these energy efficient characteristics can be considered to optimize system design:

- Before the biological system is upgraded, it is beneficial to determine if cost effective primary treatment removal improvements can be made to reduce the process loads for the high-energy biological system.
- Advancements in dissolved oxygen instrumentation and ORP controls make automatic blower capacity/control valve adjustments a standard feature for all upgraded aeration systems. Controls/blower capacity can be specified to achieve an average dissolved oxygen level between 1.0 and 2.0 mg/l based on what is suitable for the process requirements.
- Anoxic/Anaerobic zone high efficiency mixers, timers and/or VFDs can be considered to provide operators the flexibility to adjust mixing as needed to optimize system energy use.
- SBR system manufacturers can be encouraged to incorporate energy efficient features that include floating mixer/motive pump VFDs, and controls to help optimize the process.
- It is recommended that the lead blower, diffuser system and tankage is sized to maintain the target dissolved oxygen level at least 90% of the time for the historical diurnal process flows and loads while maintaining adequate mixing.
- For aeration systems equipped with fine bubble diffusers, the system can be equipped with diffusers matched to existing flows to provide a reasonable diffuser density and include additional heads with blanks inserted for future peak loads. This will allow airflow to be reduced at low flows without compromising minimum diffuser airflow values.
- The O&M manual can include specific energy data to provide staff with an understanding of how equipment adjustments affect energy use.
- Airflow meters for each tank can provide staff with the ability to evaluate blower and diffuser performance.
- Selecting premium efficiency motors for all blower/mixer equipment (reference VT Commercial Building Energy Standards for specific motor efficiency requirements).

Energy related process system improvements are listed below.

Primary Treatment Optimization

From an energy perspective, the primary treatment process can be one of the most important systems in the plant. The higher the BOD removal efficiency of the primary clarifiers, the lower the energy needed for the high-energy biological process. In addition to reducing the organic process load, increasing the primary to secondary sludge ratio can improve digester performance and dewatering solids.

Short-circuiting or areas of turbulent flow can cause lower than normal removal rates. Peripheral and mid radius baffles (for round tanks), influent baffles, mid tank baffles, and end weirs (for rectangular tanks) have been used at many facilities. A wastewater facility in Massachusetts installed primary baffles in 2012 to improve BOD removals with the specific goal of reducing blower energy use in their aeration system.

Oversized Blowers

Installing oversized blowers have occurred at numerous wastewater facilities in New England. For some plants with older blowers, the projected growth that was expected when the plant was originally designed was never realized, and the operators did their best to operate the large units at a reduced capacity. However, recent equipment over-sizing has also occurred in many plants with new high efficiency blowers. Even with the 30 to 40% turndown available with these blowers, it has not been enough to match the blower output to maintain the target DO setpoint. Unfortunately if a high efficiency blower can't match process requirements, the improved efficiency provides minimal energy savings compared to a less efficient, smaller blower that can ramp down further to maintain the DO setpoint.

Consideration can also be given to installing multiple smaller blowers with an "adaptive" control system that looks at the air required for the process and determines the best combination of blowers at the optimum speed to provide it most efficiently.

NHDES Blower Design Requirements:

The NHDES requires that multiple blowers for diffused air systems be sized to meet current facility peak aeration demand, and that the blowers have enough turndown capability for low process loads. The blowers must also be designed to operate most efficiently at average organic loading conditions and they must not over-aerate or require blowing off excess air at initial year minimum flows. The blowers must also be designed to avoid over-aerating at current daily minimum flows.

The DES added the option for facilities to initially install adequate blower capacity to meet current aeration peak demands as long as the blower room is large enough to accommodate additional blowers when needed. If this option is chosen, the community also needs to demonstrate financial capacity to install the additional blower(s) when needed. Some design engineers may not be comfortable allowing the facilities to be constructed without aeration capacity for peak design loadings, but the NHDES took this initiative to provide communities with the option of selecting a more efficient facility matched to current process requirements instead of over sizing equipment for potential higher process flows and loads in the future.

DO Control Systems and Blower Airflow Instrumentation

Installing a dissolved oxygen control system with optical (no membrane) probes and blower air flow meters has become standard practice for most new aeration system designs. However, the proper placement of the instrumentation and built-in system flexibility is a critical part of the design process.

It is recommended that plants have suitable controls/blower capacity to be able to achieve an average dissolved oxygen level between 1.0 and 2.0 mg/l based on what is suitable for the process requirements. This includes having multiple probes/airflow meters for all tanks, having the ability to average probe readings or using one probe for adjusting blower capacity, including control valves to optimize air distribution for larger systems, and

Importance of Airflow Meters:

One Vermont wastewater facility used a side stream of air (with the ability to adjust flow with a manual valve) from an aeration blower system for an aerated grit channel. Even though the blower system had an airflow meter, the amount of air going through the side stream was not metered. Without this data, the potential of excess air being directed to the grit system could not be determined and blower system efficiency (compared to the process load it was treating) could not be calculated.

when control valves are used, including a "most open valve" control strategy to minimize system backpressure.

Excessive Mixing/Airflow

Advanced nutrient removal treatment systems and sequencing batch reactors (SBR) systems in Vermont use a combination of diffused aeration and pump/mechanical mixing for the process. Mixers and recirculation pumps for the anoxic/anaerobic zones (or cycles) are often oversized for an extra level of assurance to meet peak process conditions. Some of these systems at Vermont wastewater facilities are equipped with VFDs and timers to allow operators to adjust the equipment operation to match actual process requirements. Given the high operating hours for this equipment, adjusting equipment capacity to lower levels when possible is a key optimization strategy for these systems.

Pursuing High Efficiency Equipment

For projects that are being justified based on energy savings, it is more cost effective to pursue low cost control system improvements first before pursuing expensive high efficiency equipment. The additional incremental savings after control systems have been fully optimized may not support the expense of high efficiency equipment, but it is a more accurate way to evaluate the real cost effectiveness of the equipment.

3.3 Solids Handling/Odor Control

Various equipment technologies are available for the wastewater solids handling system. Most of the time the systems are used to reduce the volume of sludge disposed through land application, incineration, or other means. When a new system is considered, it is important that in addition to direct energy comparisons of the equipment, other costs such as trucking and disposal, chemical, odor control, and plant water system energy use is considered.

The amount of equipment and associated maintenance costs for solids handling systems vary considerably. Examples of a low energy and high-energy system are described below. These examples do not include other O&M costs such as sludge disposal, labor, trucking and polymer costs.

Example of a Low Energy/Low Capital Cost Sludge Thickening/Dewatering System:

A low energy/low capital cost solids handling system begins with gravity co-thickening primary and secondary sludge in the primary clarifiers (no separate thickening process) with the clarifiers also used for sludge storage. Sludge is pumped directly from the clarifiers through a belt filter press or rotary sludge press for dewatering, and the final sludge cake (~17% to 20% solids) is trucked off site. This system has no separate thickening process (RDT or GBT), no sludge storage blowers, and no digesters. A centrifuge could also be an alternative for this low cost system (the higher centrifuge energy use is offset by the lower plant water energy costs). The centrifuge option also requires a smaller building footprint and potentially a smaller odor control system. This low energy system may result in higher trucking costs due to the lower solids output that may occur when secondary sludge is not thickened.

Example of a High Energy/High Capital Cost Sludge Thickening/Dewatering System

A high-energy solids handling system typically has separate primary thickening (gravity thickener tanks) and secondary thickening (rotary drum or gravity belt thickener). After thickening, the sludge may be pumped to separate primary/secondary sludge holding tanks and mixed/aerated or pumped to anaerobic digesters before being dewatered (belt filter press/rotary sludge press/centrifuge). Final sludge cake (~18% to 25% solids) is trucked off site. A more extensive odor control system(s) may be required for the separate thickening process and sludge holding tanks.

The additional tanks, equipment, piping, and instrumentation would have a significantly higher capital cost than the example low cost system. This system would also have higher electric energy costs and possibly require supplemental fuel for the digestion process. The lifetime maintenance costs would also be higher for all the equipment and instrumentation needed.

Sludge Process Equipment Energy Saving Opportunities

Contrary to popular belief, high horsepower centrifuges may not use more energy (kWh) than low horsepower belt filter presses, rotary presses or screw presses, depending on hours of operation, motor loading and plant water energy use. An energy analysis based on projected motor loadings is a better approach than using equipment motor horsepower since motors may be under-loaded. With many of these systems operating less than 1000 hours year, a sludge holding tank mixer or blower may use far more energy (kWh) than the actual dewatering process.

Although minimizing the need for sludge holding tanks is the ideal approach to reduce system energy use, if tanks are needed, one of the best opportunities for energy savings is to include timer controls and VFDs for the sludge holding tank mixers/blowers. These simple low cost controls have been used at many Vermont wastewater facilities to minimize sludge storage energy usage.

Anaerobic Digesters

Compared to other states, Vermont has a significant number of municipal wastewater plants equipped with anaerobic digesters used to reduce the sludge volume, achieve a Class A sludge, destroy pathogens, and improve sludge dewaterability. The original design expectation is that these systems will generate enough digester gas to provide adequate fuel for the digester heating system to maintain the sludge at approximately 95° F (for a mesophilic process), and depending on the size and process load of the plant, they can provide the opportunity to use the excess digester gas for heating site buildings. There are several facilities in Vermont that have taken this a step further and installed combined heat and power (CHP) generators to use the digester gas to generate electric power.

Over the years, numerous articles and papers have suggested that anaerobic digesters with CHP are a worthwhile investment. On paper, opportunities to generate power and waste heat as part of the treatment process look like a great idea. Unfortunately these documents do not provide specific cost benefit data to go along with the recommendation. We have found that many facilities have invested millions of dollars into these systems only to realize that the high operating/maintenance costs and supplemental fuel costs do not justify the benefit. This occurs most often with small plants that do not have large enough process loads to support the process. Some of the details that need to be considered include:

- Digester gas can be burned in boilers with simple pretreatment equipment. However, before it can be used in a CHP system, the gas must be conditioned with a more extensive process. A CHP system is more complex and will have much higher O&M costs.
- After the gas has been used in a CHP system, approximately 50% of the energy content may be available for waste heat. Given that less digester gas is available for direct digester heating, it may be more difficult to maintain digester heating without using supplemental fuel.
- To make the CHP process viable, plants are encouraged to take in more fats, oils, and grease to help digester gas production. Unfortunately, this also increases maintenance for other process systems.

For facilities with existing anaerobic digesters that are struggling with high operating costs and inoperable instrumentation (observed at some plants), we recommend the following improvements:

- First make all repairs, optimization improvements, and instrumentation upgrades needed to minimize supplemental fuel. This includes investing in gas flow meters to be able to document how much gas is used for heating the digester and how much gas is flared. Improving digester insulation to reduce heat losses can also be considered. We reviewed several wastewater plants in Vermont (with average flows below 1 mgd) with supplemental fuel oil costs that exceeded $50,000 annually.
- Improve digester/process piping insulation.
- Evaluate the potential of using excess digester boiler capacity to provide space heating to other nearby site buildings using underground hot water distribution lines. These systems can also be equipped with BTU meters to track usage.
- Evaluate the gas production benefits of accepting FOG, and other high strength wastes versus the tradeoff of increased maintenance costs (hydraulic capacity must also be considered). Continue optimizing the use of digester gas for heating buildings during the winter months. Buildings that are heated with digester gas can include tight temperature/ventilation controls to minimize digester gas use (instead of considering it as “free” fuel).
- If surplus digester gas is still available after optimizing system operations and fully utilizing the additional capacity for space heating, then the potential savings for a combined heat & power (CHP) system can be evaluated.

Odor Control Systems

For Vermont facilities, carbon type systems are the most common odor control method used. These systems typically include a 10 to 20 hp blower that when operated continuously, can result in significant energy use. Some manufacturers have equipped their blower units with two-speed fans to provide a low speed energy saving option, but to provide additional flexibility and energy savings, several wastewater facilities in New England have taken this a step further and installed variable frequency drives.

Odor control systems are typically arranged to serve multiple areas. Some areas like sludge holding tanks require continuous airflow, but the volume can be adjusted seasonally when cold temperatures decrease biological activity. Dewatering and thickening rooms can also be adjusted to lower airflow rates when sludge is not being processed in these areas.

If odor control systems can include VFDs and a local interface panel or SCADA control capabilities, facility staff could vary system operation by adjusting the VFD speed at operator selected times (such as when the dewatering process is not operated) to optimize system operation.

3.4 Electrical Systems, Controls & Instrumentation

Energy Submeters

It is becoming more common to install energy submeters for multiple sub panels or high-energy systems with the intention of providing useful energy use data. Unfortunately the meters are typically not used by facility staff due to complicated menus and no guidance provided as part of the project commissioning to train facility staff and provide sample templates on how the data could provide useful trends that would help evaluate system efficiency.

For this improvement, we recommend the following:

- Install kWh/kW meters for each major process instead of for each MCC. For example, monitoring energy use specifically for the influent pump system will allow facility staff to evaluate energy use compared to total flow pumped. If energy use increases, it will help identify if pump efficiency has decreased, or if controls need to be adjusted to optimize pump/VFD operation. The key factor is to be able to assess system efficiency by benchmarking energy use with a process variable.
- Specify simple meters that provide instantaneous kW and cumulative kWh. Having the ability to activate and deactivate demand/energy use data collection for trending is also a useful feature.
- As part of the facility OM manual, include an example of how the energy use data can be recorded and used to evaluate system efficiency.

Power Factor Correction

In addition to reducing energy consumption and peak demand costs, a new or upgraded electrical system design provides the opportunity to improve the facility's power factor.

Power factor is defined as the ratio of real power to apparent power. In a purely resistive circuit, such as an incandescent light, the two are equal and power factor is unity or 1.0. In a circuit with inductive loads such as an AC induction motor, there is reactive energy present (kVAR) and apparent energy (kVA). As power factor decreases, the kVA value increases more than the real energy (kW). When the power factor is below a value specified on the utility rate schedule (usually 0.85), a penalty is added to the bill. For some Vermont wastewater facilities having poor power factor has resulted in thousands of dollars of fees added to the utility bill

> **Power Factor Correction Example:**
>
> A Vermont Wastewater Facility was charged $2,353 in 2013 for a low power factor of 0.87. To increase this up to 95% (a typical value to avoid penalties), the facility would need to install approximately 31 kVAR of capacitance. With annual energy cost savings of $2,300 and an estimated project cost of $4000, the project payback was less than 2 years.

Facilities that have poor power factor, can improve electrical system efficiency by adding capacitance to the electrical distribution system to increase kVAR, which brings the power factor closer to unity (1.0). This investment typically has a fast payback (2 to 3 years). New AC variable frequency drives can also provide the additional benefit of improving power factor enough to avoid utility penalties.

SCADA Control Systems

New control systems are a standard part of facility upgrades. A typical facility SCADA control system includes the following components:

- Field instrumentation to monitor key system operating parameters (flow, pressure, run time).

- A local control system that includes a programmable logic controller (PLC). These panels are often supplied by the vendor and may include an operator interface screen that displays system operation.
- A central SCADA/computer system that communicates with local PLCs or directly with individual electronic components (such as VFDs or electric submeters). The SCADA system typically includes visual representations of each process system with data displayed adjacent to the equipment graphics. Energy data collected directly from the utility meter is also a cost effective approach when SCADA is available.
- Some systems also include the ability to remotely control equipment with a laptop.

Tracking Run Time Manually:

Staff at one VT facility resorted to printing and filing screen shots on the first of each month to track monthly run time. This was useful to estimate equipment energy usage during a recent evaluation.

The majority of Vermont wastewater facilities are equipped with basic systems that are primarily used to display run time/flow/process data (visually on a system schematic screen). Additional screens summarize equipment run time and can provide graphs of the process data over a selected interval (day/week/month). Features that are typically not included but would help quantify system performance and potentially identify efficiency improvements include:

- The ability to display an average of the selected interval process data (some VT SCADA systems have this feature on the graphed data summary) – this provision can be configured to exclude inactive equipment operation data.

- Having a screen that displays equipment run time is a standard feature for most facilities. However, the run time display is typically a cumulative value from when the system was initially installed. We found that only a few systems in VT could provide run time for a specific time interval (such as monthly which is the most useful for monitoring equipment trends and identifying energy saving opportunities). Including an interval run time feature (such as a reset column next to a cumulative column) could be included as part of a SCADA system design at a minimal cost.

- Although it would be ideal to also monitor pump run time for collection system pump stations, the current practice of writing daily pump run time in operator logs is a standard practice for most facilities. Equipping a remote pump station with SCADA capabilities would not be cost effective for most small stations.

- For field instrumentation, collecting flow, pressure, and process data is extremely useful to evaluate equipment efficiency and optimize equipment operation. Examples of instrumentation for high energy systems include:

    1. High energy aeration/biological systems: Energy submeter, dissolved oxygen levels for each tank, and blower airflow rate (additional meters if air is shared with another process).

    2. Influent pump systems: Energy submeters, pressure transmitters and system flow meters provide the information needed to evaluate pump system efficiency. For VFD equipped pumps, the kW value displayed on the VFD can be used for instantaneous energy monitoring. When pressure gauges are not practical, simple taps/shut-off valves can be included for future portable instrumentation use.

Optimizing a Plant Water System with Additional Control Features:

One facility optimized their plant water system by maintaining design system pressures during the day and automatically reducing VFD speed and the pressure setpoint to a lower level at night to reduce system water losses and pump run time.

3. Plant water pump system: In addition to activating pumps, transmitting system pressure from a local PLC based pressure control system to a central SCADA system can provide additional control capability such as maintaining a higher system pressure only when certain systems are on-line (i.e., intermittent high pressure for dewatering spray water systems).

3.5 Ultraviolet & Chemical Disinfection

Vermont wastewater facilities use ultraviolet (UV) or chemical disinfection systems for final effluent disinfection. The most important energy related issue observed for UV systems is the need for controls to modulate system output based on dose pacing and the ability to vary the number of on-line banks based on flow. From an energy perspective, having suitable controls that could adjust UV system capacity to the process requirements is far more important than focusing on component efficiency.

Some of the challenges that were identified for UV systems included the following:

- Traditional UV systems were not matched well with SBR systems. The UV manufacturers recommended that the banks should not be cycled on and off when the SBR cycle discharged effluent periodically. This resulted in keeping at least one bank on line 100% of the time even though flow was only being discharged less than 50% of the time. With the higher slug flow rate that is unavoidable with SBR systems, it was also necessary to maintain a greater UV capacity for the higher flow rates.
- Several Vermont activated sludge plants had UV systems that were equipped with flow based controls that would take a bank off line, which provided good savings but needed additional control system modifications to fully optimize the system.
- Some plants decided to completely remove the UV systems installed due to high energy and maintenance costs and found that sodium hypochlorite chlorination and bisulfite dechlorination was a more cost effective disinfection method. The most efficient chemical disinfection systems are configured to provide adequate mixing without the use of flash mixers.

We recommend that design engineers hold UV manufacturers accountable to provide systems capable of matching UV capacity with varying effluent flow and a life cycle cost analysis that includes maintenance and back-up power supply costs when comparing equipment options.

4. Building Systems

Building systems include all non-process systems such as heating and ventilation equipment, air conditioning systems (HVAC), lighting and miscellaneous equipment. In some cases the building system energy use will be affected by process changes (such as a changing the airflow rate of a odor control system). As was discussed for the process systems, an electrical and heating fuel energy balance is the best way to establish the system baseline energy use.

4.1 Lighting

Lighting does not usually represent a significant portion of the energy use at a wastewater facility. However, most facilities take advantage of lighting efficiency audits when available to upgrade their lighting periodically. Design engineers should always make an effort to use the latest proven technologies and take an inventory of all lighting, wattage and hours during the design phase to provide a baseline of energy use and to qualify for Efficiency Vermont incentives. When feasible, solar tubes and skylights can also be considered to supplement lighting systems.

4.2 Heating Systems

Most facilities have multiple site buildings, which have independent heating systems. Ideally the buildings have separate meters (for natural gas systems), separate propane bills, or separately tracked fuel oil bills to accurately track energy usage for each building and raise energy use awareness.

For facility upgrades that include new process/maintenance buildings, some key areas that can be considered as part of heating system designs include:

- Some process systems may not need heated buildings.
- An oversized process area will require more airflow to meet code requirements and result in higher heat loss. Designing these areas with low ceilings and maintaining separation from other non-classified areas will reduce ventilation and heating costs.
- Maintenance buildings can be designed with separate heated/unheated bays to allow for cold storage. In heated bays, water piping can be heat traced and insulated to allow for low room temperatures.

For facilities with anaerobic digesters, the supplemental fuel used for the digestion process may get blended together with heating bills, which makes it even more challenging to determine the fuel use breakdown. Facility staff must also view digester gas as a fuel that is just as valuable as natural gas or fuel oil. Even though the heating value of digester gas is less, for every 500 cubic foot of digester gas that is not vented or flared, approximately 300 cu ft of natural gas or 2 gallons of fuel oil could be saved in supplemental fuel or for heating costs (if the digester boiler is also used for space heating).

Given that heating systems are a low priority for most facilities, the corrosive environment takes its toll on heating units, thermostats, and fan systems. This is an important area that needs to be addressed as part of all facility upgrade projects. We also recommend the following design considerations:

- Matching the heating system output with space heating needs is a key part of optimizing facility operation. This includes low temperature thermostats for process areas; temperature reset controllers that reduce boiler temperature setpoints based on outside temperature, and programmable setback thermostats for office/lab areas that can automatically be increased before staff arrives in the morning. Large facilities may benefit from a full energy management system; however, for the majority of facilities, the inability to make simple adjustments without programmer assistance is not ideal for system optimization by facility staff. For medium and small facilities, we recommend individual thermostat controls that can be adjusted by staff.
- Infrared heaters can be considered for large process areas to direct heat where it is needed, but inexpensive wall-mounted unit heaters are typically adequate to provide low temperatures (~50 degrees) that are suitable for process areas that are not typically occupied.
- High efficiency heating systems that include condensing boilers, heat recovery systems, solar walls and effluent source heat pumps are worthwhile, but tight temperature and ventilation controls are far more relevant for maintaining low energy costs.

When comparing various heating sources, the heating value and unit heater efficiency must also be considered. An example electric and propane heat comparison is shown below.

Electric Versus Propane Heating System Costs:

The total wattage of pump station electric heaters were determined to be 6 kW indicating the heaters were running over 3000 hours during the year (based on an estimate for station auxiliary energy use). To reduce electric heating energy costs, a propane unit heater was recommended. Savings calculations are shown below.

To estimate savings, a heating value of 3412 Btu/kWh for the existing electric heat was used, 91,333 Btu/gallon of propane, and $0.15/kWh.

Propane required: 61.42 MMBtu * 1,000,000 /91,333 Btu/gallon / ~85% unit efficiency = 790 gallons

Annual Propane Cost ($2.50/gal) - $1,975
Annual Electrical Usage: 18,000 kWh
Annual Electric Energy Cost: $2,700
Annual Savings Using Propane: $725
Preliminary Project Cost: $2,500
Simple Payback 3.4 years

If the pump station was insulated and temperature controls were used to maintain a low room temperature of ~50 degrees, the baseline electric unit heater usage would have been closer to 1500 hours annually and the simple payback of the project would increase to 6.8 years.

4.3 Building Ventilation

Wastewater facilities typically have multiple process buildings, a maintenance garage, and a primary control building that includes offices, a lab and potentially areas for process equipment.

New systems are designed based on NFPA 820 Standard, which provide required airflow rates (air changes/hour) for wastewater facility process areas and pump stations. Although NFPA 820 is used by engineers to determine ”safe” ventilation airflows for new designs, the code specifically indicates that it is intended for fire and explosion hazards and does not apply to toxicity and biological ventilation. However, without any other code available that specifically addresses wastewater plants, the NFPA 820 Standard has evolved into the wastewater industry standard to determine airflow rates for process areas.

For each process area, the air change rate (cubic feet /hour) depends on what electrical classification the equipment is rated for. To be on the safe side, most new designs maintain the following air changes:

- Areas that are routinely entered by staff with exposed wastewater are typically ventilated at 12-air changes/hour.
- Ventilation of adjoining areas that are partially below grade (equipment areas) have an airflow of 6 air changes per hour.

A key aspect to consider is that the electrical classification of a space can change depending on the air changes. The tradeoff between higher energy costs versus the increased equipment capital cost of a Class 1, Division 1 electrical classification can be evaluated. Energy recovery devices for spaces that are continuously ventilated can be used to reduce heating costs.

As expected, with these high airflow rates, maintaining reasonable temperatures in a process building during the winter months is a challenge. For spaces ventilated at these rates, building envelope improvements do not have much of an impact on reducing heating costs.

Facilities that were designed before NFPA 820 was adopted are grandfathered until they upgrade their ventilation systems. These facilities typically maintain minimal ventilation rates. Although some systems automatically activate supply and exhaust fans when a light switch is activated, many facilities have inoperable systems.

Ventilation System Examples:

WWTF #1: The ventilation system at one wastewater facility was equipped with an adjustable timer to activate the supply and exhaust system 10 minutes/hour by the staff to balance heating costs with adequate ventilation.

WWTF #2: A recently upgraded wastewater facility included sophisticated control systems and heat recovery heat exchangers. A heat recovery unit can be beneficial for continuous high flows since they recover up to 70% of the exhausted heat. Unfortunately, for this particular facility the numerous fans installed throughout the facility ended up accounting for 30% of total facility energy use and used more energy than it saved. Facility staff indicated that the system was too complex for them to adjust temperature settings without the help of the vendor.

WWTF #3: A New England facility took advantage of dual ventilation rates specified in the NFPA code (applicable to spaces in Table 9.1.1.4), which allows ventilation rates to be reduced by 50% when the outside temperature is below 50 degrees. This provision requires controls that automatically increase the airflow when the area is occupied or when a combustible gas alarm occurs.

When a design engineer is tasked with upgrading a ventilation system, some engineers have included controls to allow operators to adjust equipment capacity to maintain more reasonable airflow rates during the winter months.

To balance the full capacity airflow rates recommended by the NFPA codes with controls that provide some flexibility, we recommend including the following features in new designs:

- For large high airflow systems, we recommend dual ventilation rates, automatic controls, and VFD speeds that can be adjusted locally or by using the SCADA system.
- For small systems, including VFDs/timers is ideal to allow staff to make adjustments when needed.

For the additional cost of only adding timers or VFDs to a ventilation system, we would expect the cost to be minimal. Savings would be difficult to estimate since it would be dependent on the operator's adjustments.

5. Renewable Energy Considerations

Renewable energy is typically the first initiative pursued by municipal administrators to reduce facility energy use with solar photovoltaic (PV) panels being the top choice. Having a colorful photo of the new panels and a summary of the financial incentives obtained look great on the town's annual report. The 20+ year simple payback of PV panels can't compete with a typical 2 to 4 year payback of process improvements, but when all the work can be contracted to a solar installer and no input is needed from facility staff, state agencies, or wastewater engineers, this alternative is attractive to many municipalities.

Wind is also a popular option discussed by municipal officials (another technology external to the wastewater process), but even with an ideal location these systems are not cost effective without significant incentives and credits.

Hydro turbines can be a great opportunity for a municipal water system with high elevation reservoirs. The combination of constant flow and high pressure that would otherwise need to be reduced with pressure reducing valves is an ideal system for a small hydro turbine application. A wastewater facility may have good discharge flows, but with minimal head, it is difficult to justify a hydro turbine installation. There are only a few hydro turbine installations at New England Wastewater Facilities. The two-wastewater facilities that Process Energy Services encountered were both 25+ mgd plants in Massachusetts. The following is a simple preliminary calculation that can help facilities determine if a hydro turbine is worthwhile:

Power (kW) = Flow (gpm) * Head (ft) * 0.18 * 70% unit efficiency /1000

Based on facility site visits, we found that most Vermont Wastewater Facilities with anaerobic digesters were using the biogas to minimize supplemental fuel for digester heating and provide some supplemental space heating. However, some operators and engineers still do not see the value in optimizing the use of digester gas. One engineer did not feel it was cost effective to use a burner/boiler to utilize digester gas for space heating and instead recommended flaring the gas while the facility used $60,000 annually for fuel oil.

For renewables, we have limited our recommendations to low cost design adjustments that can be made as part of a facility upgrade to make future renewable energy projects more cost effective.

- Buildings orientated with sloped roof facing south for future solar panel mounting.
- Reviewing the potential of installing transpired solar collectors (solar walls) on the roof or south side of buildings. If solar transpired collectors are not pursued, arrange ducting for potential future installation.
- For facilities with anaerobic digesters, provide floor space and piping blind flanges adjacent to digester gas supply equipment rooms to accommodate future gas conditioning equipment and CHP system. Install underground piping when cost effective to distribute excess hot water from the digester boiler to other site buildings. Even if excess gas is not available at the time of the upgrade, if the facility BOD load increases, the future increase in gas will be fully utilized.
- Ducting/piping to accommodate future heat recovery systems.

6.0 Design Review, O&M and SOPs

6.1 Design Review Process

For major wastewater facility upgrades in Vermont, the design/construction process typically includes the following phases:

- Walk through by Engineer
- Engineering Service Agreement (ESA)
- Kick-off Meeting
- Preliminary Engineering Reports (30%, 60%, 90% and final)
- Design Plans/Specs (30%, 60%, 90% and final)
- Construction Management Services

- System Training after Construction
- Assembling the Operations & Maintenance Manual

In addition to these milestones, multiple progress meetings occur as part of each phase. The VT DEC is an integral part of the process and reviews all the Preliminary Engineering Reports, design plans, and specifications.

In January 2015, Efficiency Vermont (EVT) met with the VT DEC to determine how it could increase their participation in the design process to identify energy efficiency opportunities at an earlier stage in the process. For past projects, Efficiency Vermont had been invited to review the project at the 60% Preliminary Design Report stage. Based on discussions, it was agreed that it would be worthwhile to have EVT participate earlier in the process, with the initial walk through stage being the ideal time to offer efficiency recommendations, and the option of reviewing the additional phases of the Prelimininary Design Report and the 90% Design Plans/Specs.

Previous discussions have also suggested that it would be worthwhile to perform an energy evaluation at the beginning of the process to establish an energy use baseline and identify additional energy saving projects that could be included in the upgrade. Efficiency Vermont can be part of this discussion to determine if an evaluation would be worthwhile.

6.2 O&M Manual & Project Commissioning and SOPs

As the construction process nears completion, the engineer is often tasked with providing an O&M manual that typically includes a description of system operation, and equipment operational and maintenance manuals. Following this task, manufacturing representatives and the engineer commissions the project and provides equipment training for staff. This process could be improved to help facility staff understand the energy impact of the upgrade and optimize system operation after the project is completed. These additional tasks could include:

- Adjusting the content of the O&M manual to minimize lengthy narratives, and instead having the engineer include hands-on process optimization data collected during new equipment commissioning.
- Providing a baseline of energy use/costs (and other operating costs) and including an estimate of how the facility upgrade will impact these costs.
- Creating standard operating procedures (SOPs) based on what is learned during the equipment commissioning/start-up, process optimization efforts, and how system operation relates to energy and other O&M costs. This is a task that engineers would gladly perform for the municipality, but with limited budgets, it is usually not requested. However, even when SOPs are developed, they typically do not include details on system optimization or energy use estimates for various operating modes.
- When developing SOPs, very few facilities in New England include a section on Energy Management. An effective energy management program provides a systematic approach to reducing facility energy use and costs. A successful program will provide an ongoing effort to continually evaluate new projects, track savings and encourage efforts within the organization to improve efficiency.

Based on these important elements of energy efficiency, this guidance document strongly recommends including SOPs and an energy management plan as part of the O&M Manual.

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ATTACHMENT A

Dewatering System Life Cycle Cost Example

An example life cycle cost analysis is shown below for comparing three dewatering alternatives considered for a wastewater facility. The tables summarize the cost over a 10-year period for using belt filter presses, centrifuges, and rotary screw presses.

As part of the analysis, a general overview of each system is presented in Table A-1.

Table A-1: Performance, Health and Maintenance

Selection Criteria	Belt Filter Press	Centrifuge	Rotary Screw
Percent Discharge Solids	20	25	20
Solids Capture Efficiency	>98%	95%	90-95%
Operator Attention	High	Low	Low
Maintenance	Medium	High	Low
Reliability	High	High	High
Footprint (ft3) for each unit	407	43	228
Noise Potential	Low	Medium	Low
Odor Potential	High	Low	Low
Operator Exposure	High	Low	Low

Table A-2 shows preliminary equipment sizing and project costs for the dewatering alternatives based on a one-shift period (8-11 hr/day). Horsepower for the belt filter press alternative was increased to compensate for higher ventilation horsepower requirements compared to the other alternatives.

Table A-2: Preliminary Sizing and Cost

Selection Criteria	Belt Filter Press	Centrifuge	Rotary Screw
Manufacturer	xx	xx	xx
Model #	xx	xx	xx
Connected	35	100	7.5
Units	3	2	3
Equipment Cost	$398,500	$794,400	$503,580
Total Cost	$1,195,500	$1,588,800	$1,510,740

Table A-3 provides a cost summary of the capital cost and annual operation and maintenance costs for each dewatering alternative, based on single shift operation. This planning-level cost opinion does not include all elements such as feed sludge storage tanks, odor control systems, etc. Power costs were calculated using $0.20/kwh. Polymer costs were calculated using $2.25/lb polymer. Contract biosolids handling and disposal costs were based on the city’s existing contract at $44.69/wet ton.

Table A-3: Dewatering System Cost Summary (Single Shift Operation)

Selection Criteria	Belt Filter Press	Centrifuge	Rotary Screw Press
Total Installed Cost	$1,195,500	$1,588,800	$1,510,740
Polymer Mixers/Floc Tanks	$18,404	NA	$40,160
Polymer Mix Feed Units	$69,320	$46,380	$69,320
Feed Pump	$138,090	$92,060	$138,090
Cake Handling System	$228,200	$228,200	$228,200
Dewatering Building	$5,841,000	$1,026,000	$2,702,700
Engineering (15%)	$1,123,577	$447,216	$703,382
Total Capital Costs	**$8,614,000**	**$3,429,000**	**$5,393,000**
Annual Maintenance	$80,000	$80,000	$40,000
Annual Power Cost	$32,585	$62,067	$6,983
Annual Polymer Cost	$104,151	$312,453	$104,151
Biosolids Handling &	$1,013,648	$786,094	$982,618
Total Annual O&M Costs	**$1,230,000**	**$1,241,000**	**$1,134,000**

Table A-4 provides a cost opinion of the 10-year net present value of capital, operation and maintenance costs for the different dewatering alternatives. The ten (10) year present worth costs were calculated using a constant 2 percent inflation rate and 5 percent interest rate.

With this simplified format, it can be seen in Table A-3 that the assumption for having a much larger building for the belt filter press option has a significant impact on the initial capital costs.

Table A-4: 10-Year Life Cycle Cost Opinion

Selection Criteria	Belt Filter Press	Centrifuge	Rotary Screw Press
Maintenance	$684,469	$684,469	$342,235
Power Cost	$278,795	$531,039	$59,742
Polymer Cost	$891,102	$2,673,305	$891,102
Biosolids Handling &	$8,672,636	$6,725,718	$8,407,147
Total O&M Life Cycle Costs	**$10,527,000**	**$10,615,000**	**$9,700,000**
Total Capital Cost Estimate	$8,614,000	$3,429,000	$5,393,000
Total LCC Cost	**$19,141,000**	**$14,044,000**	**$15,093,000**

Although there are no additional details on how maintenance and energy costs were estimated for this example, it appears that maintenance cost values in Tables A-3 and A-4 are ballpark estimates, and the energy costs did not account for the lower kW typically found once the centrifuge is up to speed. It also looks like higher plant water system energy use is not considered for the belt filter press. However, both of these costs are insignificant when compared to the polymer use/cost estimates and the difference in percent solids/disposal costs, which have the greatest influence on the analysis.

Pump System Life Cycle Cost Example

This example is from *Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems* published by the Hydraulic Institute.

The pump system is for a paper mill piping system equipped with a control valve. The system is a single pump circuit that transports a process fluid from a storage tank to a pressurized tank. A heat exchanger heats the fluid, and a control valve regulates the rate of flow into the pressurized tank to 350 gpm. The plant engineer is experiencing problems with a control valve that fails as a result of erosion caused by cavitation. The valve fails every 10 to 12 months at a cost of $4,000 per repair. A change to the control valve is being considered to replace the existing valve with one that can resist cavitation.

Before changing out the control valve again, the project engineer wanted to look at other options and performed an LCC analysis for alternative solutions.

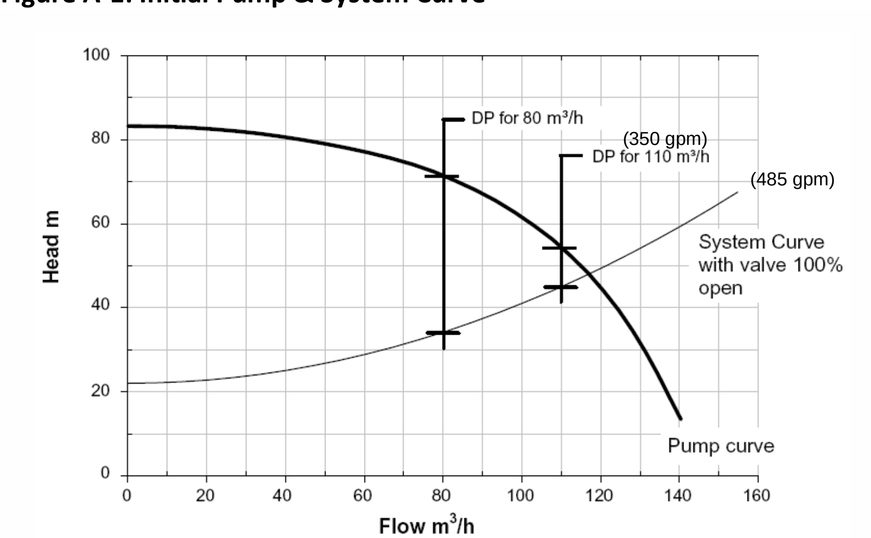
System Operation:

The first step was to determine how the system was currently operating and to determine why the control valve failed, then to see what could be done to correct the problem.

The control valve operated between 15 to 20 percent open with considerable cavitation noise from the valve. It appeared the valve was not sized properly for the application and after reviewing the original design calculations, it was discovered that the pump was sized for 485 gpm instead of the original design flow of 350 gpm, resulting in a larger pressure drop across the control valve than originally intended.

The pump operating points are shown on Figure A-1.

Figure A-1: Initial Pump & System Curve



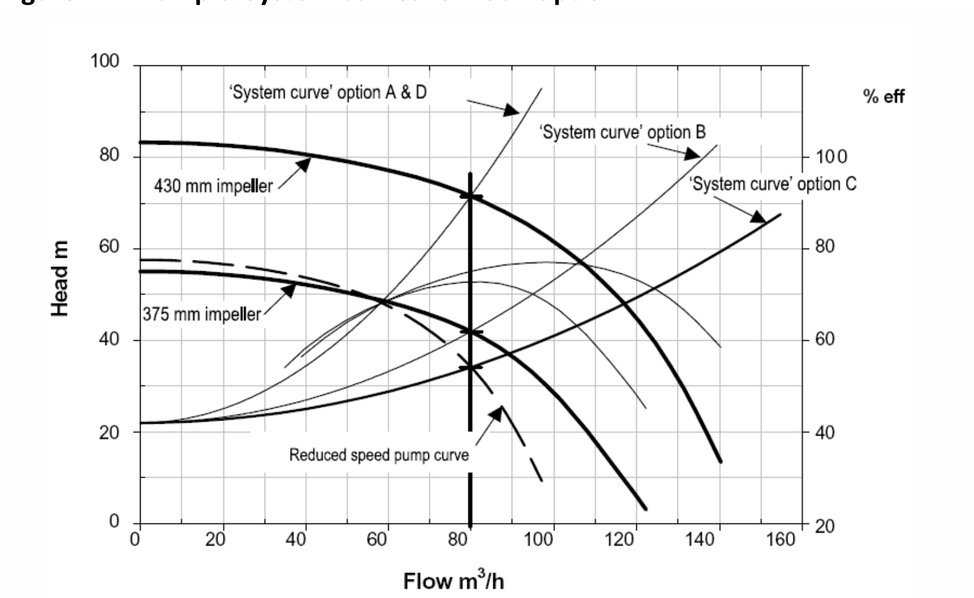
As a result of the large differential pressure at the operating rate of flow, and the fact that the valve was showing cavitation damage with regular intervals, it was determined that the control valve was not suitable for the process. The following four options were suggested:

- A new control valve could be installed to accommodate the high-pressure differential.
- The pump impeller could be trimmed so that the pump did not develop as much head, resulting in a lower pressure drop across the current valve.
- A variable frequency drive could be installed, and the flow control valve removed. The VFD would vary the pump speed and thus achieve the desired process flow.
- The system could be left as is, with a yearly repair of the flow control valve to be expected.

The cost of a new control valve that is properly sized would be $5,000 and the cost of modifying the pump performance by reducing the impeller diameter would be $2,250. The process operates at 350 gpm for 6,000 hours/year. The energy cost is $0.08 per kWh and the motor efficiency is 90 percent.

Pump and system curves for impeller trimming, variable speed operation, and different system curves are shown in Figure A-2.

Figure A-2: Pump & System Curves for Each Option



By trimming the impeller to 375 mm, the pump's total head would be reduced to 42 m (138 ft) at 80 m3/h (350 gpm). The drop in pressure would reduce the differential pressure across the control valve to less than 10 m (33 ft), to better match the valve's original design point. The resulting annual energy cost with the smaller impeller would be $6,720. This includes the machining cost as well as the cost to disassemble and reassemble the pump. A 40 hp VFD would cost approximately $20,000, and an additional $1,500 was estimated for the installation. It is estimated that the VFD would not need any repairs over the project's 8-year life. The option to leave the system unchanged would result in a yearly cost of $4,000 for repairs to the cavitating flow control valve.

A summary of the data for each option is shown in Table A-5.

Table A-5: 10-Year Life Cycle Cost Opinion

Parameter	Option A: Change Control Valve	Option B: Trim Impeller	Option C: VFD and Remove Control Valve	Option D: Repair Control Valve
Impeller Diameter	430 mm	375 mm	430 mm	430 mm
Pump Head	71.7 m (235	42.0 m (138	34.5 m (113 ft)	71.7 m (235
Pump Efficiency	75.1%	72.7%	77.0%	75.1%
Flow Rate	80 m3/h (350	80 m3/h	80 m3/h (350	80 m3/h (350
Power (kW)	23.1	14.0	11.6	23.1
Annual Energy Costs	$11,088	$6,720	$5,568	$11,088
Improvement Cost	$5,000	$2,250	$21,500	$4000

To evaluate the options using a life cycle cost approach, the following parameters were chosen:

- Unit energy cost: $0.08/kWh
- Annual hours of operation: 6000 hours
- Project has an 8 year remaining life
- The interest rate for new capital projects is 8%
- The annual inflation rate was estimated to be 4%

An existing pump maintenance allocation of $2,500 every two years was also included in the analysis. A summary of costs is shown in Table A-6.

Table A-6: Summary of Costs and LCC Value

Parameter	Option A: Change Control Valve	Option B: Trim Impeller	Option C: VFD and Remove Control Valve	Option D: Repair Control Valve
Initial Investment	$5,000	$2,250	$21,500	0
Average Power (kW)	23.1	14.0	11.6	23.1
Annual Energy Cost	$11,088	$6,720	$5,568	$11,088
Annual	$500	$500	$1000	$500
Pump Repair Every	$2,500	$2,500	$2,500	$2,500
Other Annual Costs	$0	$0	$0	$4,000
LCC Value	**$91,827**	**$59,481**	**$74,313**	**$113,930**

As shown above, trimming the impeller appears to be the most cost effective option for this pump system.