Early Adopters, Efficiency Experts, and a Market Breakthrough in the Wastewater Treatment Sector

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ABSTRACT

Facilities managers in charge of industrial processes are typically reluctant to adopt energy efficiency measures that affect their core processes—thus creating a stumbling block in an efficiency program's progress in achieving market transformation. The widespread adoption of any new energy efficiency technology in the industrial sector is hampered by perceived risk, high capital costs, and lack of familiarity with a new technology. End users commonly wait for someone else to serve as an early adopter, thus delaying indefinitely the potential benefits the technology could bring to the marketplace. Targeting those early adopters can make a substantial difference in efficiency program performance—and targeting the right end user as an early adopter can constitute a highly productive step toward market transformation.

A statewide energy efficiency utility identified such a barrier to participation for a new lagoon mixing technology in wastewater treatment systems, and targeted a progressive system operator willing to serve as an early adopter of that technology for the entire state's wastewater community. The efficiency utility served as a trusted energy advisor during project development, and sequentially overcame the operator's perceived risks by researching the mixing technology in the literature and by interviewing vendors, demonstrating effectiveness at a similar site, sharing the risk of implementation through a structured incentive package, and supporting the measurement and monitoring of the treatment process before and after implementation. This paper analyzes the progress to date on energy savings and demand reduction for the early adopter, and the extent to which the efficiency program has leveraged the initial success into statewide adoption of the technology.

Background

Wastewater treatment is a particularly entrenched market that is reluctant to adopt new energy efficient technology. Efficiency Vermont, a statewide energy efficiency utility, developed a holistic approach to transforming the wastewater treatment sector by identifying and promoting among facility managers a new technological approach to lagoon mixing. The new mixing technology complements aeration, the most energy-intensive process associated with lagoon-based wastewater treatment systems. The utility's engineering staff researched the performance of the technology to verify its operational and energy performance, located a candidate facility that could be approached for early adoption of the technology, and engaged the facility manager for the purpose of reducing barriers such as perceived risk and lack of capital. The goal was to develop a showcase installation to foster confidence and promote the marketwide adoption of the technology.

Efficiency Vermont began this targeted-implementation approach by sponsoring a "circuit rider" staff position similar to circuit riders used by U.S. Department of Agriculture Rural Development programs to provide technical support for rural municipal water and wastewater treatment plants. The circuit rider traveled around the state and paid visits to water and wastewater plants. He discussed energy efficiency best practices and innovations in technology, while promoting the positive benefits associated with adopting such practices and technology throughout the target market.

The circuit rider quickly identified market characteristics, such as the large percentage of lagoon treatment systems in the state, and market trends, such as the fact that the majority of energy in this type of plant was used for lagoon aeration and mixing. While researching energy-efficient methods of lagoon mixing, the circuit rider discovered an unexpected use of solar energy applied to mixing and aerating lagoon systems (EPA, 2005). This technology had not yet been adopted by any operators in Vermont, despite the presence of a very mature energy efficiency and renewable energy program. The technology offsets the energy associated with traditional aeration systems that employ either energy-intensive blowers or inefficient grid-powered mechanical aerators. Furthermore, the circuit rider located a published case study that outlined the effectiveness of solar mixing technology at several wastewater treatment facilities in New Hampshire. The study showed that the solar mixers performed very well from a process standpoint, and had a positive effect on reduced energy use at the plants. In fact, one plant reduced its overall energy consumption by 86% as a result of installing the solar mixing technology (Hudnell et al., 2011).

With relationships with the wastewater facilities managers already built, and now armed with compelling evidence of financial benefits of solar mixers, the circuit rider began to heavily promote the solar mixing technology to Vermont lagoon wastewater facilities. System operators, members of the engineering design community, town managers, and State environmental regulatory and funding agencies were all informed about the benefits of using solar mixers as an energy reduction measure in wastewater treatment. This widespread promotion activity met with unanimous skepticism regarding the technology. In fact, it became clear that the majority of the barriers to adoption stemmed from the fact that no one within the insular Vermont wastewater treatment community had embraced, or was willing to embrace, the solar mixing technology. Even the presence of valid and reliable data showing its effectiveness in New Hampshire was not enough to change the Vermont wastewater treatment community's minds.

So the circuit rider shifted strategies from widespread promotion to targeted promotion. This new strategy involved identifying a good "candidate" lagoon system—one with sound and progressive management and operations staff, adequate financial resources, and a real interest in exploring a new technology.

The circuit rider identified the wastewater treatment facility in Swanton, a village in the northwest corner of the state. Efficiency Vermont had worked with the Swanton staff on previous projects and had developed a relationship as a trusted energy advisor. The Village had strong, progressive leaders with sound management and technical backgrounds who possessed an excellent understanding of project economics. In addition, Village staff possessed a strong, can-do attitude that would prove to be instrumental to the success of the project. The circuit rider began a campaign to pitch the benefits of solar mixing technology to the Swanton Chief Plant Operator and the Village Manager. Initial conversations revealed a genuine interest in the operational and economic benefits of installing the mixers. Despite interest, the following barriers remained, echoing those expressed throughout the market:

- No local installations yet existed, so confidence in the technology was relatively low
- A large capital investment was required, carrying with it significant risk
- The State regulatory agency did not support the use of "unproven" mixing technology

Using some persistence and creativity, and because the players in Swanton sought to be innovators in their field, the circuit rider proceeded to address all of the barriers and to provide the Swanton staff with the knowledge and confidence needed to move forward.

The Early Adopter: Seeing Is Believing

As Efficiency Vermont engineering staff began gathering data to estimate the electrical savings, cost, return on investment, and potential incentive and financing packages, the circuit rider began to remove the other barriers that were preventing the project from moving forward.

It was clear that a good economic argument would not be enough to convince Swanton to make a large investment in efficient technology—which, in the Village's eyes, was unproven and might not work. Like every piece of infrastructure designed to protect public health, meeting regulatory standards on permitted effluents trumped energy conservation measures. If they could not be certain that solar mixers were an effective means of creating the aerobic conditions and mixing necessary to properly treat the waste and maintain environmental permit compliance, they would never move the project forward.

The circuit rider learned of a solar mixer installation in New Hampshire that presented a perfect profile for Swanton officials to gain confidence in the technology. One of the major doubts about the mixers concerned their ability to withstand freezing temperatures. The doubters had pictured the units' freezing in the winter ice, rendering them useless. The climate in New Hampshire is very similar to that of Swanton; and the experience of the New Hampshire units went back eight winters.

The Efficiency Vermont circuit rider organized a site visit for key decision makers from the Village of Swanton to the New Hampshire installation to get a peer-to-peer perspective on the operational effectiveness of the solar mixers. The visit, the positive testimonials from peers (not associated with sales of the technology), as well as the simple act of seeing the technology with their own eyes, resulted in a green light to begin discussions about regulatory acceptance, budgets, project economics, savings estimates, and incentive levels.

Even having seen a successful installation firsthand, Village management still was concerned about possible risks of the investment. Efficiency Vermont engineering staff provided Village management with a compelling outline of the project economics, including a generous incentive offer and reasonable estimated payback period. The management agreed that investing in the solar-powered mixers had an excellent return on investment, would significantly reduce a major component of the wastewater plant operating budget (electricity costs), and would position them to be leaders within the Vermont wastewater treatment community. However, they were still reluctant because of the very arduous and public nature of funding municipal projects through the bonding process. With a citizenry closely watching how tax and wastewater rate funds were being spent, any failure of the mixers would have disastrous results. It was deemed too risky for Swanton to go through the bonding process.

The Barriers: Creative Financing and a Catch-22

In response to this concern, engineering staff at Efficiency Vermont presented Village management with a creative and less risky funding option: municipal leasing. Municipal leasing would allow Swanton to borrow funds for the project without having to issue a bond. Efficiency Vermont provided a revised analysis of the project economics, using the municipal lease numbers. They also demonstrated a net positive cash flow in energy savings over lease payments, after application of the incentives. In addition, the municipal leasing option eliminated the risk of the Village's having to make payments if something should go wrong with the mixers.

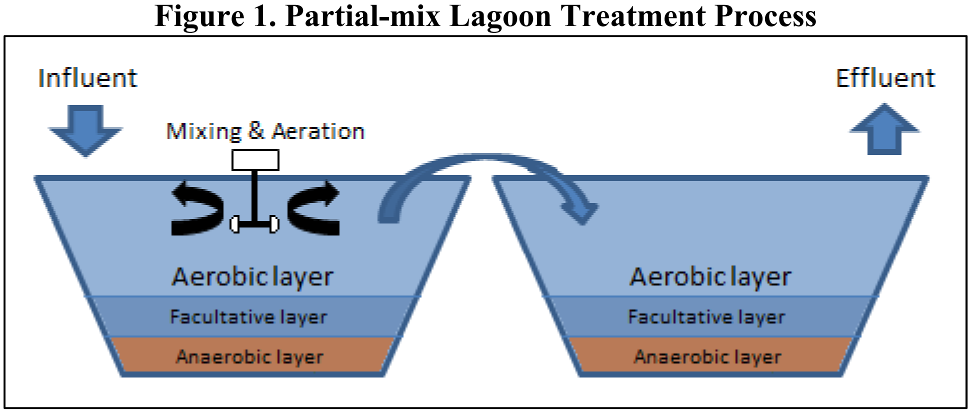
Under the lease agreement terms, the leasing company would own the equipment until the lease is paid off. If the units proved to be ineffective at properly treating the waste, Swanton would simply opt out of the lease, and allow the leasing company to take back the mixers.

Even after developing a confidence in the effectiveness of the mixing technology, and removing perceived risks through effective financing, the Village of Swanton was left with one remaining project barrier—namely, approval from State regulators. Municipal wastewater treatment systems must seek approval from relevant State or federal regulating agencies whenever they are proposing an upgrade or change in process equipment operations. The innovative nature of this project placed Swanton in the middle of a classic Catch-22. The regulators would not allow the use of solar-powered aerators, because it was not a proven technology in Vermont. That is, it did not meet "proven technology" criteria because it had not been installed anywhere in the state. Efficiency Vermont and the team in Swanton intended to prove the technology by installing the solar aerators in the Swanton lagoons. However, the regulators would not permit it because no one had ever done it before. This is where the can-do attitude of the Swanton staff became instrumental in seeing this innovative project to fruition and thus taking the first step toward transforming the wastewater treatment market. The chief operator of the Swanton wastewater plant came up with a brilliant solution. What if the old mechanical aerators remained in place, were turned off, and were available as backup, while the solar mixers were added to the lagoons? The regulators agreed to that plan, and the project came to fruition.

The System: A Partial-mix Lagoon Treatment Facility

The purpose of a municipal wastewater treatment system is to collect residential, commercial, and industrial wastewater, and to remove harmful contaminates or otherwise neutralize them. The treatment system applies mechanical, chemical, and biological processes to the wastewater to deliver outputs that can be safely returned to applicable, regulated environmental levels. There are many approaches to wastewater treatment. Figure 1 presents the steps in wastewater treatment with a partial-mix lagoon treatment process such as that at the Swanton Village Wastewater Treatment Facility.

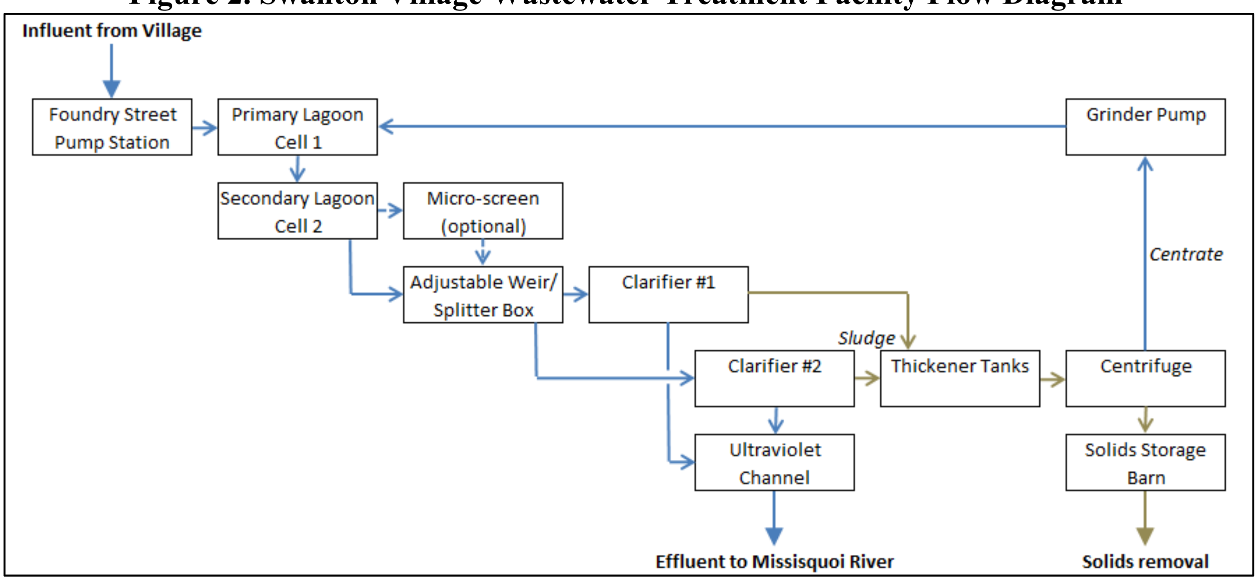
Figure 1. Partial-mix Lagoon Treatment Process



Source: Michael Socks

A pumping station brings raw wastewater, or *influent,* to the plant. Large pieces of debris that might interfere with the treatment process are screened out. The influent then enters the lagoon system and settleable solids drop to the bottom of the lagoon as the flow velocity decreases. Soluble and suspended organic solids provide food for the microorganisms in the lagoon, enabling bacterial growth and reproduction. Carbon dioxide and nutrients released by the bacteria are in turn consumed by algae. Bacteria and algae cells eventually die, sink to the bottom, and are themselves consumed. Once all biodegradable organic material has been consumed, the resulting inert non-degradable material settles on the bottom as sludge. The facility periodically monitors the depth of the sludge, which can accumulate at the bottom of the lagoon until it reduces the effective treatment capacity of the system. The facility can then remove the sludge from the lagoon by dredging, and move it off site. The biologically treated water exits the lagoon, and any remaining sludge solids are removed as the water passes through a clarifier. Water remaining in the sludge is removed by a thickener tank and centrifuge. The filtered water (*centrate*), removed by the centrifuge is returned to the primary lagoon for further treatment. The removed solids are temporarily stored and then trucked off site. Water that exits the clarifier is disinfected using high-intensity ultraviolet (UV) light. Ultraviolet light penetrates the cell walls of pathogenic microorganisms such as bacteria, viruses, and protozoa, destroying their ability to reproduce (EPA, 1999). The disinfection is achieved by directing the lagoon effluent through channels with banks of UV lamps. The disinfected effluent then exits the treatment system and enters the watershed at the neighboring Missisquoi River. Figure 2 is a flow diagram of the process in Swanton.

Figure 2. Swanton Village Wastewater Treatment Facility Flow Diagram



Source: Michael Socks

Critical parameters of the treatment process are:

- Influent flow: Raw wastewater entering the treatment process; measured in million gallons per day (MGD).
- Effluent flow: Treated water exiting the treatment process; measured in MGD.

- pH: Measure of the concentration of H+ ions in a solution. It ranges from 0 (strong acid) to 14 (strong alkaline). The treatment process is most effective at a pH near 7 (neutral).
- Biochemical oxygen demand (BOD5): A measure of the oxygen required by a population of microorganisms to aerobically break down a sample of organic material during a five-day test. This value is an indication of the organic loading of the wastewater. BOD is measured in milligrams of oxygen per liter (mg / L). Municipal influent has a typical value of 185 to 220 mg / L and the post-treatment effluent has a typical value less than 30 mg / L.
- Total suspended solids (TSS): A measure of the filterable solid material present in the wastewater flow.
- Fecal coliform count: The amount of the bacterium associated with the intestinal tract of humans. It serves as an indicator of the presence of waterborne pathogenic bacteria that cause typhoid, cholera, dysentery, and hepatitis. If coliform bacteria are absent, then related bacteria are also assumed to be absent.

The Process: Aeration and Mixing in the Treatment Process

Aerated lagoon systems require supplemental oxygen to support the digestion of organic material by microorganisms. This supplemental oxygen comes from mechanical aeration, and decreases the footprint of the lagoon relative to the treatment capacity of the plant. In this context, mechanical aeration might decrease the land area needed for wastewater processing—and thus reduce the capital cost required for the plant. Aerated lagoons, however, require significant energy input for the aeration equipment (EPA, 2002).

Both aerobic and anaerobic digestion of organic material occurs in partial-mix aerated lagoon systems. The upper layer has sufficient dissolved oxygen to support aerobic digestion of soluble organic solids and is termed the *aerobic layer*. The bottom of the lagoon lacks oxygen and therefore supports only anaerobic digestion of insoluble solids. An intermediate layer supports both types of digestion to some extent, and is called the *facultative zone*. The relative depth and thickness of these layers is a function of aeration and mixing through natural or mechanical means. Sufficient aeration dissolves atmospheric oxygen into the lagoon to drive the microbial digestion process. Sufficient mixing ensures the aerobic layer penetrates deep enough to break down all soluble organic materials introduced into the system and avoids excessive stratification. Because decomposition is performed by living organisms, the rate of decomposition within the lagoon is dependent on such factors as the level of organic loading, dissolved oxygen, water temperature, and availability of sunlight. In northern climates, seasonal changes in behavior, length of daylight, wind and wave action, and ice coverage introduce variables to the efficiency and effectiveness of the treatment process. As a result, operating practices such as the level of aeration might change seasonally.

Aeration systems commonly employ blowers supplying pressurized air to submerged bubblers at the bottom of the lagoon. They can also involve surface-mounted mechanical systems that use propellers or blades to agitate the surface. These methods increase contact at the air-water interface, and therefore increase the level of dissolved oxygen in the vicinity of the aerator.

The Technology: Swanton Wastewater Treatment Facility Aeration Upgrade

The Village of Swanton aerated partial-mix lagoon system covers approximately 30 acres. The lagoon is divided into two 15-acre kidney-shaped areas called Cell 1 (primary) and Cell 2 (secondary). Cell 2 is further divided into Cell 2A and Cell 2B by a curtain baffle that improves hydraulic flow and treatment characteristics. Each cell has a maximum depth of 5 feet. The total system capacity is approximately 19 million gallons and has an influent design capacity of 1.5 million gallons per day. The typical influent flow rate is 500,000 gallons per day. The typical organic loading, as measured by BOD, is estimated at 125 mg / L—a relatively low rate for a system of this size. The influent-to-effluent retention time is approximately 30 days. Figure 3 shows an aerial view of the Swanton lagoon system, indicating aeration and mixing equipment locations. Influent enters the lagoon at the southeast corner of Cell 1, where there is a concentration of aerators.

Figure 3. Swanton Wastewater Treatment Facility with Approximate Locations for Aeration and Mixing Equipment

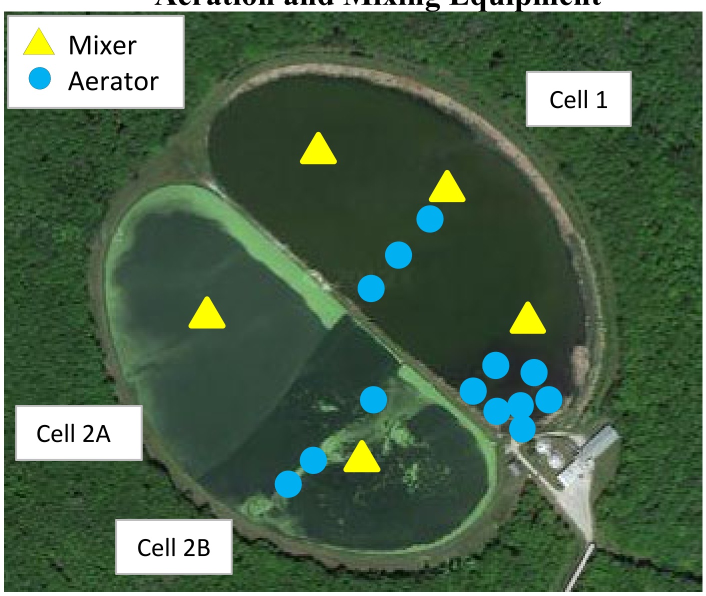


Photo Source: Google Earth; graphics: Michael Socks

Prior to the upgrade, sixteen 5-horsepower floating aerators dispersed throughout the lagoon cells were available for both mixing and aeration. A traditional aerator of the type used in Swanton is pictured in Figure 4. To achieve adequate mixing, the system used more mechanical aerators and ran them for a greater number of hours per aerator than was required just for aeration. Historically, almost all of the aerators—approximately fifteen—ran continuously during the summer (May through November) and eleven aerators ran continuously during the winter (December through April). Each aerator was spot-metered and found to require 3.0 kW on average. Total annual energy consumption for aeration was estimated at 350,000 kWh, accounting for approximately 67% of the total electricity consumed by the facility.

Swanton sought proposals for solar-powered mixers as an alternative to running the aerators. After reviewing several options, Swanton ordered five solar-powered, grid-tied mixers in August 2012. Each mixer contained a 50-watt motor that could run on approximately 25 watts of power, which would be provided by three 123-watt solar panels when adequate sunlight was available. When sunlight was not available, the mixers could run on grid power. The mixers were distributed evenly throughout the lagoon with three in Cell 1 and one each in cells 2A and 2B, as shown in Figure 3. A typical solar mixer is illustrated in Figure 5.

With the relatively low organic loads, an eventual power reduction of 70-90% is possible. However, given the timing of the vendor proposal and of the subsequent decision-making, the mixers were not installed until December 7, 2012. To ensure adequate performance in the event that a wintertime installation of the mixers might not enable the safe re-start of the aerators if they were frozen into the ice on the lagoon, engineers estimated a power reduction of 50%—a compromise both they and the system operators felt comfortable with. With the mixers installed on December 7, system monitoring indicated that after a one-month break-in period, seven of the fourteen operating mechanical aerators could be switched off. Power metering for two weeks spanning the period before and after the change indicated a reduction of 20.95 kW on the main facility motor control panel. These results were in line with the anticipated demand reduction for this phase.

Further reductions are anticipated for the summer of 2013 as organic loading increases and the layers within the lagoons respond to the additional mixing. The anticipated end state is five solar mixers and one aerator at the influent inlet, operating 24 / 7, year-round, in combination with three additional aerators running 8 hours per day in the summer and 24 hours per day in the winter. The annual electricity consumption under this scenario is 76,000 kWh, with annual energy savings of 274,000 kWh. This is a 78% reduction in energy required for lagoon aeration and a 52% reduction in the total annual consumption for the facility. At Swanton's blended cost of electricity of $0.0925 / kWh, this scenario results in a cost savings of $25,300 per year.

In addition to bringing energy savings, the mixers are expected to improve the amount and distribution of dissolved oxygen levels in the aerobic layer and to stabilize the facultative zone. This benefit will likely reduce the risk of seasonal inversions that might result in algae blooms or odor problems, and will likely improve anaerobic sludge digestion. Both the energy savings and the non-energy benefits of the upgrade will be closely monitored and recorded across the long term, to broaden the appeal of the technology.

Figure 4. A Typical Aerator in Swanton

Photo Source: Michael Socks

Figure 5. Swanton Solar Mixer

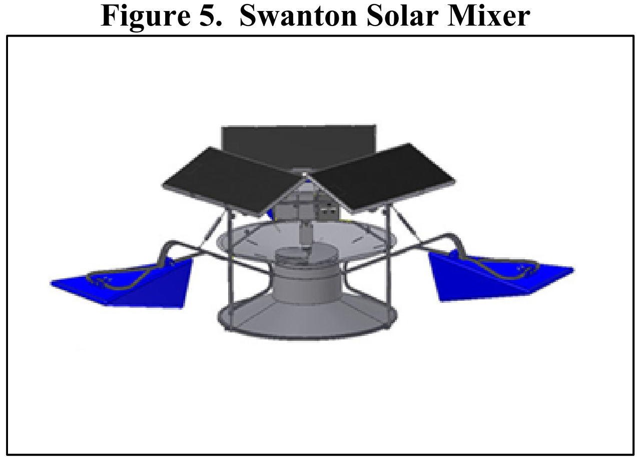


Image Source: Aeromix

The Payoff: Market Transformation?

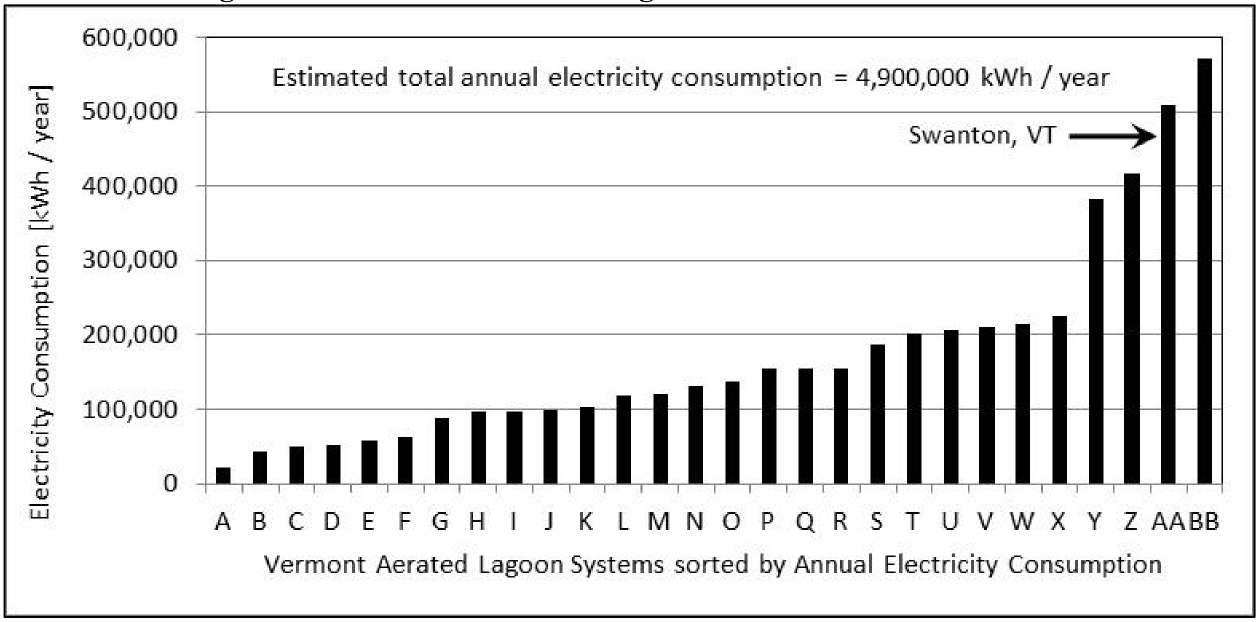
As new, innovative energy efficiency technology enters the industrial marketplace, operators are typically reluctant to adopt that technology. Despite the potential for short payback periods, operators tend to be cautious about possible risks, initial capital costs, and the validity of the purported benefits of a new technology. One highly effective strategy for gaining early adopters is for an efficiency utility to first vet the effectiveness of the technology, and then define the characteristics of an early adopter, targeting possible participants who meet those selection criteria. It is critical for the efficiency utility to have: (1) an existing relationship as a "trusted, independent energy advisor"; (2) a progressive staff who are competent not just in technical knowledge, but also in understanding customer finances; (3) sufficient availability of funds for such projects; and (4) a general willingness and patience to bring technology changes to the table for discussion. The Village of Swanton met the selection criteria for early adoption. As a result of the collaboration with the efficiency utility, they became the first plant in Vermont to invest in a highly efficient wastewater mixing technology.

The financing and installation phases of the Swanton project are now complete. With ongoing post-metering and monitoring of effluent quality, the word is beginning to spread among the close-knit wastewater community. Efficiency Vermont's next step is to leverage Swanton's actions into full-blown market adoption of similar technology. Marketing, training, and outreach efforts are in development to position the Village of Swanton as a shining example of a well-run, efficient facility. Once the critical data-gathering has concluded, and the confidence in the mixer performance is established, joint press releases from Efficiency Vermont and the Village of Swanton will highlight the benefits and resourceful nature of the partnership. Performance data for the solar mixers will be verified for both regulators and the design engineering community, as a testimonial to the effectiveness of the technology. In addition, open houses are planned this summer for operators of other lagoon systems to visit the Swanton plant and see the technology in action.

Vermont has 28 operating municipal lagoon systems with an approximate cumulative electrical consumption of 4,900,000 kWh / year. As with the Swanton lagoon system, the majority of the electricity consumed in these plants is used for aeration and mixing. The Swanton plant's energy reduction achievements will provide at least one point of comparison for other wastewater facilities statewide that are considering solar mixer installations. In Vermont alone, widespread market adoption of this efficient mixing technology, spurred by the successful and influential showcase installation in Swanton, has the potential to reduce market-wide electrical consumption by 2,500,000 kWh / year—essentially cutting in half the current consumption. Based on the 2011 average cost of industrial electricity purchases, $0.0994 / kWh as reported by the Vermont Public Service Department, this measure could save operators $248,500 per year.

Figure 6 presents the spectrum of all of Vermont's existing aerated lagoons, showing the potential for future energy savings if they were to switch to systems similar to Swanton's.

Figure 6. Vermont's Aerated Lagoon Wastewater Market Data



Source: Dmitri Hudak

Conclusion

Energy efficiency programs are well positioned to scope out and evaluate new technologies, and introduce the best of them to the marketplace. For technologies that have been commercialized, but have not yet been widely accepted within the program territory, promoting a pilot installation, with the cooperation of an early adopter, can be an effective first step in transforming the market. It is critical, however, to identify a progressively minded adopter that is trusted within the industry, has adequate financial and human resources to make it work, and is willing to serve as a leader for its peers. The energy efficiency program must provide adequate technical and financial assistance, be willing to collect data and objectively analyze them, and deliver information effectively to the industry.

The partnership between the Village of Swanton and Efficiency Vermont is one example of a successful early-adopter strategy. The solar mixing technology has achieved success even in its first months, and careful monitoring and data collection are expected to corroborate long-term effectiveness. Efficiency Vermont will publicize the success of this installation through technical roundtables, media coverage and marketing materials, and word-of-mouth when meeting with other operators. The statewide potential for energy savings from the technology is significant, and near-term strategies will focus on replicating this success with all of the aerated lagoon wastewater treatment system operators in Vermont.

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