A Systems Approach to Saving Energy in Water and Wastewater Facilities

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ABSTRACT

The municipal fresh water and wastewater treatment industry is estimated to consume 2 to 3 percent of the nation's total energy (approximately 75 billion kilowatt-hours annually). With increasing environmental regulations, tightening municipal budgets, rising electricity costs, and aging infrastructures, the burden of energy costs on municipal governments is growing.

The Northwest Energy Efficiency Alliance (Portland, OR) and BacGen Technologies partnered in a market transformation initiative to save energy in wastewater treatment plants. A systems approach to saving energy in municipal facilities was developed and demonstrated in small- and medium-sized communities. A fresh water and wastewater energy conservation program managed by the Bonneville Power Administration adopted this approach. The systems approach has many advantages compared with focusing on specific components (such as motors), including saving more energy. Structuring the services and the program with the facility operator in mind is critical.

Measured energy savings, dollar savings to the community, and many non-energy benefits are described.

Saving Energy in the Fresh Water and Wastewater Market

The municipal water and wastewater treatment industry is estimated to consume 2 to 3 percent of the nation's total energy, approximately 75 billion kilowatt-hours (Easton Consultants 1999). With increasing environmental regulations, tightening municipal budgets, rising electricity costs, and aging infrastructures, the burden of energy costs on municipal governments is growing. Relatively little energy conservation has been done in small- and medium-sized facilities. These facilities tend to serve rural communities and, therefore, do not have the municipal resources for sophisticated process engineering. While these facilities present a large opportunity for energy conservation, there are many barriers to servicing this market, including:

- Skeptical users (operators perceive a tradeoff between permit compliance and energy use)
- Extremely limited municipal budgets (with compliance considered the first priority and process improvements frequently deferred until absolutely imperative)
- Complex, dynamic systems and site-specific applications
- Cost inefficiencies of serving remote or unique customers

Wastewater

There are 997 municipal wastewater facilities in the Pacific Northwest (Quantum Consulting 2001) and 15,000 nationally. Of these, 20 large facilities consume about 40 percent of the total amount of energy. On average, energy comprises 7 percent of a wastewater utility's operating budget (Jacobs, Kerestes & Riddle 2003). Recently, several programs have begun to focus on motor usage by promoting high-efficiency and variable-speed-drive motors. Though this has been a positive trend, by focusing upon specific equipment, these energy efficiency efforts do not address the overall wastewater process itself. In large part, this is due to facility operators' paramount concern of maintaining compliance with the environmental requirements under which treatment plants are permitted and the substantial process complexity of these facilities. The fundamental (and rational) attitude of the operators is that no amount of cost savings is important enough to jeopardize the permit of a compliant facility.

Some large wastewater systems are operated relatively efficiently. However, there is little evidence of any energy conservation activity in facilities under 10 million gallons per day flow.

Fresh Water

There are 4,575 community water systems in the four Northwest states and 54,000 nationally (U.S. EPA 2002). Seven percent of these systems serve 81 percent of the people. On average, energy is 11 percent of a fresh water facility operating budget (Jacobs, Kerestes, & Riddle 2003). Similar to the wastewater sector, few energy conservation programs go beyond "stand-alone" components, such as pumps and motors. Again, there is little evidence of any energy conservation activity in small- or medium-sized facilities.

The Wastewater Market Transformation Partnership

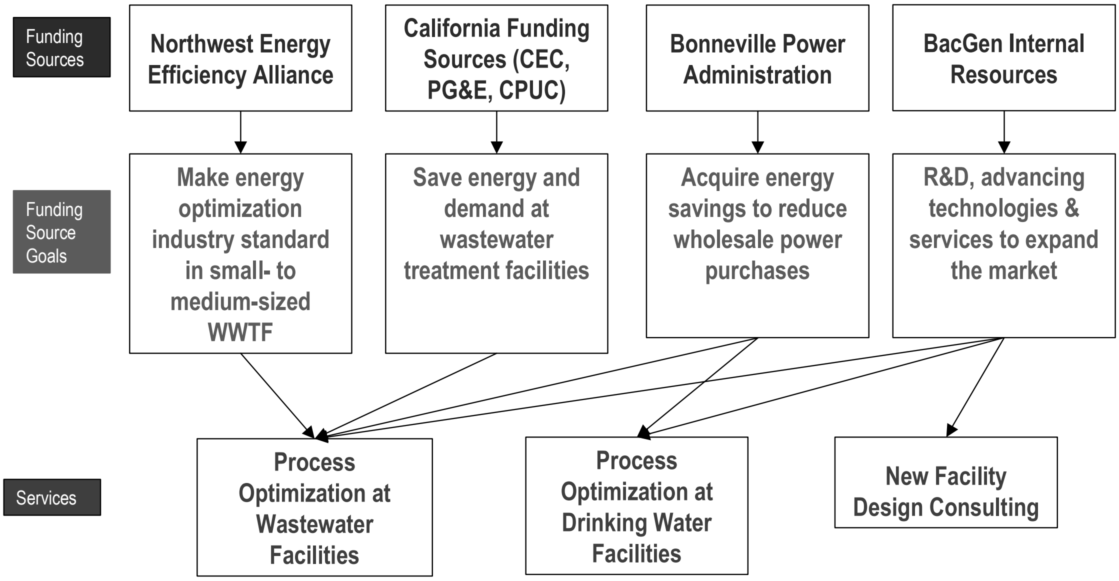
To transform the market for small and medium wastewater facilities, the Northwest Energy Efficiency Alliance (Alliance) began a project in 1999 with BacGen Technologies, Inc. (BacGen). BacGen was a start-up company operating out of Seattle Washington. Funding from the Alliance supported further development of the technical approach, field demonstrations in sites across the Northwest, and refinement of business and market strategies. BacGen first approached the Alliance with a proposal to "make micro-nutrient assisted facultative bio-digestion technology an industry standard in wastewater treatment lagoons." The proprietary technology of DNA targeting and optimized micro-nutrients increased the efficiency of bio-digestion by enhancing the microbiological community. By mid-2000, BacGen had utilized micro-nutrient additives at two demonstration sites. The projects were successful, both in terms of reducing energy usage and achieving permit compliance. However, the marketplace was skeptical over the efficacy of micronutrient utilization.

Concurrently, BacGen realized that, even without adding biological nutrients, the continuous and real-time monitoring of the wastewater treatment process provided information that could be used to optimize the aeration and pumping processes, allowing motor use to be substantially reduced while maintaining or improving effluent quality. The company, therefore, began focusing on the development and use of specialized instrumentation, data collection, and control systems. The instrumentation includes probes for Dissolved Oxygen, Suspended Solids, Oxidation Reduction Potential, pH, and temperature. Depending on the biological needs of the process as reported by the monitoring technologies, BacGen used process control technologies (e.g., SCADA logic) to optimize aeration delivery throughout diurnal and seasonal periods.

In 2001, the wastewater initiative was renewed with the new objective of making "energy optimization through process control strategies an industry standard in small- to medium-sized wastewater treatment facilities." The focus would be on facilities under 10 million gallons per day influent, a market that received almost no energy conservatin services. During this time, BacGen introduced optimization strategies at four more facilities directly funded by the Alliance.

Since 2001, BacGen's business has been greatly augmented by clients other than the Alliance: Bonneville Power Administration (Bonneville), and California state organizations and utilities (Pacific Gas & Electric, California Energy Commission, and the California Public Utilities Commission). These organizations have encouraged BacGen to expand beyond wastewater process optimization into fresh water optimization and design consulting for new and upgraded plants. The relationship between funding sources and BacGen's products and technologies is displayed in Figure 1.

Figure 1. Cooperating to Save Energy



Since 1998, BacGen has implemented optimization strategies at 39 wastewater treatment facilities and has contracts with Bonneville, the California Public Utilities Commission and several investor-owned utilities for approximately 136 more. For fresh water, BacGen has implemented five projects and is expecting to conduct 44 more under current contracts. BacGen is on the path to exceed the Alliance goals for number of participating wastewater facilities by 2005.

Key findings from Alliance/BacGen demonstration sites follow:

- ***Observed energy savings***. Five of six operators interviewed observed energy savings on their utility bills. On average, these facilities save approximately $16,000 each year due to optimization.
- ***Non-energy benefits***. While energy savings were important to operators, many felt that the other benefits of optimization strategies were equally important. These benefits are described later in this paper.

The Bonneville Water and Wastewater Program

Bonneville acquires electrical energy conservation primarily to avoid the purchase of power on the open market. Bonneville is a federal agency that transmits and sells wholesale power in the Pacific Northwest. The Water & Wastewater Program is part of Bonneville's Conservation Augmentation function. The program is limited to service areas of utilities whose electrical loads Bonneville must meet on a continuing ("load-following") basis. The program focuses on small- and medium-sized communities, a historically underserved (often rural) market. In 2001, Bonneville selected BacGen Technologies to provide its turnkey whole-system optimization services.

The Project Development Process

Over time, the following project development steps have been established:

1. Contact. The Contractor contacts, or is contacted by, the local municipality/facility owner. About 40 percent of the initial contacts are word-of-mouth referrals.
2. Assessment. The Contractor assesses the project (via a detailed screening interview and questionnaire) for its potential as a conservation project within the Program.
3. Pre-engineering. The Contractor visits the site to collect specific information necessary to prepare a technical and cost proposal for Bonneville and the facility owner/municipality.
4. The Contractor and Bonneville agree on a cost to be paid by Bonneville using pre-established pricing guidelines formulated on predicted energy savings.
5. The Contractor and the municipality agree on a cost-recovery service arrangement that will cover the remainder of the project's cost, typically 40 to 60 percent.
6. The Contractor installs the new equipment, trains operators, and arranges new operating protocols.
7. The energy savings are measured and verified according to a pre-determined procedure.
8. The Contractor continues to work with the site operators for the duration of the cost-recovery period, typically three to five years.

Bonneville's Water & Wastewater Program started with five pilot projects. Currently, 12 projects have been completed in five Pacific Northwest states. Over 40 additional projects are currently under varying levels of consideration for implementation under the Program, which is expected to continue through 2005.

Program Lessons Learned

The lessons learned from Bonneville's early Water & Wastewater Program experience include:

- **It takes time to get to yes**. Water and wastewater facility owners and operators are conservative. To feel comfortable with a project, operators need multiple meetings with the contractor and sterling references from other operators in the vicinity. City councils typically have two hearings relating to a project before making a decision. It is not unusual for a contractual commitment to take as long as six months.
- **Proximity matters**. Efficiencies have been achieved by clustering projects geographically. Once one community commits to a project, other communities in the area are likely to follow the lead. Travel costs associated with selling and implementing projects in the same vicinity are reduced. It is also highly efficient to arrange both water and wastewater conservation projects for a given community.
- **Develop a "pipeline" of projects**. The substantial time required to approve a project can be mitigated if multiple projects can be simultaneously guided along the path to approval and subsequent completion. This queuing of projects stabilizes the overall program.
- **The Program serves as a catalyst**. In four of 12 completed projects, the site operators implemented incremental efficiency steps recommended by the Contractor beyond the base design and funding. Additional measures included energy-efficient motor replacements, an ultraviolet treatment system, and a fine-bubble aeration system. These actions augmented overall energy savings and increased the leverage of program funding.

Measuring Energy Savings

Measurement and verification (M&V) of energy savings is complete for the first five projects in the Bonneville program (two fresh water and three wastewater). The total annual savings for those five projects was 2,391,000 kWh. This yields an annual savings of 478,000 kWh per plant. The range of savings varies widely depending on plant size and condition. Actual savings averaged 84 percent of predicted savings.

Determining the "actual" savings proved to be more difficult than expected. At the outset, M&V was thought to be a matter of comparing pre- and post-installation utility bills. The fact that metering was not dedicated to the affected equipment confounded this approach. Also, it was found that a facility's demand (in the case of freshwater) and loading (in the case of wastewater) vary considerably over time.

BacGen staff returned to several project sites and sub-metered the affected equipment for a sufficient time to capture typical post-project energy usage. Where necessary, facility operators brought the plant back to pre-project conditions to establish a baseline. Even so, some extrapolation was necessary to calculate annual savings.

One significant finding from this effort was that the equipment in operation is not necessarily the same size as shown on as-built drawings. This was a major reason why measured savings were less than predicted. (BPA considered 84 percent acceptable for the pilot projects.)

The Water and Wastewater Program now has a set of M&V principals. The principles include collection of detailed engineering data (especially to establish motor efficiencies) and pre-metering of the equipment operation (especially to establish load factors). A measure-specific methodology is also agreed upon for each site to establish how energy savings will be calculated. This may be further standardized in the long run. The US Department of Energy's *International Performance Measurement and Verification Protocol* (IPMVP) served as a reference in this process.

Case Study – Fresh Water Optimization

Cheney, Washington, is a college town with 9,000 local residents and a student population that doubles the town size when Eastern Washington University is in session. The water system is composed of six deep wells and four booster stations. The Bonnveille project addresses the operation of three wells. The project included facility modeling, three pump modifications, two replacement motors, two variable frequency drive installations, and modifying the existing SCADA system program for optimized operation strategies.

Project cost: about $70,000 (shared between Bonneville, the Alliance, and BacGen)
Verified savings: 304,000 kWh/yr
Project savings: 18 percent of the usage of the three targeted wells
Operational cost reduction: $7,448/yr at Cheney's $0.0245/kWh electricity rate (or $21,918/yr at the national average electricity rate of $0.0721/kWh (Energy Information Agency 2002))

Future plans include installation of new equipment on a fourth well, paid for by the community. BacGen will then reconfigure the operation strategy. An additional 22,000 kWh savings is anticipated for an approximate $10,000 additional cost.

Case Study – Wastewater Optimization

Bandon, Oregon, is a community on the Pacific Coast with 5,500 people living in the area. The wastewater treatment plant is an activated sludge facility. The plant has a design capacity of 1.5 million gallons per day with average daily influent flows between 500,000 and 900,000 gal/day. The optimization project included strategic placement of sensor units in the aeration and aerobic digester basins and dynamic modeling of the facility. This allows the existing SCADA system to be optimally programmed to control the blower motors and intake valve actuators. An upgrade of the UV disinfection system was also included in the project.

Project cost: about $83,000 (shared between Bonneville, the Alliance, and the City)
Verified savings: 294,000 kWh/yr
Project savings: 29 percent of the electrical usage of the facility
Operational cost reduction: $17,581/yr at Bandon's $0.0598/kWh electricity rate (or $21,197 at the national average electricity rate of $0.0721/kWh).

The motor savings were achieved by reducing a VFD blower from 80 percent to 20 percent speed averages; reducing a two-speed blower from high speed to low speed; and shutting off one 40 HP blower motor completely. The UV system upgrade saves 12,000 kWh/yr.

Bandon also plans to install a cover on one of the sludge drying basins to allow a reduced residency time. This will allow year-round sludge removal in a moist climate. Aeration energy use is expected to drop by an additional 190,000 kWh/yr at a cost of about $2,000. That's about a two to three month payback for the city. This discovered opportunity was recommended to the city as part of BacGen's ongoing consulting to the city.

The Systems Approach

Succinctly put, the approach to saving energy described in this paper is ***systems optimization***. It is applicable to fresh water treatment and distribution systems, as well as wastewater treatment facilities. The systems approach can be contrasted from "the component approach" by the inclusion of the dynamic interaction between all of the various system components when considering how to optimize a facility for the highest level of energy-efficient process possible. Typically, this involves process engineers benchmarking and modeling the system with dedicated software. Then, the various modes of operation can be studied and potential system modifications may be assessed to arrive at an optimal way of configuring and operating the system given real-world constraints. These constraints include the existing plant design, system performance requirements, and the cost-effectiveness of any physical and or process control modifications. In addition to mechanical, biological and electronic interventions, the systems approach also involves people and financing elements.

Illustrations of System Engineering

As an example, in a fresh water facility, there may be three wells providing the system's raw water (prior to treatment) supply. Component thinking would look for the oldest, least-efficient pump and motor combination and upgrade it with a new impeller and a more efficient motor. System thinking would ask how the combination of the three wells could deliver water most efficiently, could water be stored and pumped with lower fluid flow rates/lower friction loss, etc. The solution might include reducing the number of operating hours for the inefficient well and increasing pumping from more efficient wells. Then the question could be asked, how much can be saved by modifying or upgrading the equipment. Thus, more savings can be achieved at lower cost.

An aerated lagoon wastewater plant might be using several ponds for treatment. Component thinking would look at the blower motors and ask how they could be made more efficient. System thinking would model the flow of influent through the system and all of the associated biological processes. Modeling different treatment strategies might determine a way to decommission one of the ponds or substantially modify an aeration process using, as an example, low energy mixing instead. Process sensors can then be installed to determine, on a real-time basis, exactly when and for how long the blowers need to operate. This, again, results in more savings at lower cost.

The Operator as Part of the System

The operator is a critical part of any water or wastewater system. For larger facilities, this person may be a manager or lead shift operator. The operator determines if and when equipment gets turned on or off. The operator sees wasteful situations. The operator determines what repairs will be made. The operator gets blamed whenever a discharge permit violation occurs. The operator is often responsible for submitting and living with an operating budget. The operator is often guided by protocols established by a previous generation. The operator communicates regularly with a peer group of other operators. Yet, in small-and medium-sized facilities, the operator is typically poorly trained and likely does not have the process tools or depth of process understanding to determine how the facility is operating in real time.

With these circumstances, investing in the system operator becomes a point of leverage in the systems approach. Taking time to build rapport and mutual respect with the operator frequently opens the door to implementing a successful project. Learning what special concerns the operator faces (e.g., foaming, solids accumulations) suggests where system opportunities may lie.

Further, it has been noted that phasing in process protocol changes allows the operator to gain confidence and not be tempted to defeat an energy saving approach due to initial concerns about unfamiliar practices. Training the operator in energy efficiency measures will help him or her better meet professional requirements and see energy as a way to reduce operating costs. Overall, this individual advances their skills and, therein, their opportunity as an operator. Giving the operator access to real-time data allows him or her to clearly understand how and why to optimize their system by implementing simple process modifications as operating conditions change. Over time, the operator can find his or her own system efficiencies and gradually change old behavioral norms. This factor presents a significant potential transformation within the market segment.

These interactions with operators are already a key component of the efforts to save energy in water and wastewater facilities described in this paper.

Financing from a Systems Perspective

Financing a project involves yet another level of systems thinking. Municipalities typically do not have energy conservation measures as a budget priority. They also tend to have time-consuming decision-making processes when it comes to capital expenditures. These major barriers can defeat a program's effort to achieve the substantial savings objectives associated with implementing a large number of projects.

A solution to this conundrum is to finance a project in such a way that the city can fund the project within the facility's operating budget. Energy savings reduce operating costs. Project financing can, therefore, be crafted so that payments will be lower than energy cost savings. This avoids the city's approval process associated with capital expenditures. Establishing an acceptable payment period, in turn, helps determine the amount of funding needed from outside sources, such as a utility. This approach is used to craft project financing packages under Bonneville's Water & Wastewater program.

Services Provided Using the System Approach

The systems approach has significant implications for the breadth of services to be offered to fresh water and wastewater facilities. Measures such as efficient motors, variable speed drives, replaced pump impellers and fine-bubble aeration, while potentially important, may not be specifically mentioned. While these changes in system components often will be part of a project, they are not *the* product. They are the result of a total system optimization service. Table 1 describes the services that BacGen Technologies offers its clients.

Table 1. Freshwater and Wastewater Optimization Services

	Existing Fresh Water Facilities	Existing Wastewater Facilities	New & Refurbished Facilities
Optimize water distribution strategies	X		X
Automate pressure management	X		
Leak detection	X		
Real-time pipeline monitoring	X		X
Pump system modeling	X	X	X
Automate system monitoring and control	X	X	X
Metering and data collection	X	X	X
Improved aeration and mixing techniques		X	X
Operator training	X	X	X
Consulting to prime facility design contractor			X
Financing	X	X	X

Sustainability – Benefits to the Community and the Environment

Because BacGen has been focused on demonstrating and developing cost-effective technologies, the effect on community and environmental sustainability has not been fully quantified. Yet, we believe the BacGen project enables communities to make development choices with respect to the relationship between the economy, ecology, and equity.

Economy

The most easily quantified savings to the communities is in terms of reduced electricity operating costs. These benefits were quantified earlier in this report. Additional monetary savings can be achieved through peak shaving and peak shifting by establishing appropriate equipment control protocols.

Additional economic benefits from the facility optimization project include reductions in sludge removal, reduced polymer and chlorination use, and the possible deferral of capital construction costs. A significant portion of the dollars saved from energy and non-energy benefits can remain in the community as a direct cost benefit to ratepayers and other public purposes. Although there has been no documentation of application of the dollar savings to support other community needs, we expect that upcoming evaluation reports will address this issue.

Ecology

By reducing electricity usage, emissions due to power generation are avoided. To illustrate, if a facility saves 500,000 kWh/yr (the average of the first five BPA projects) it will reduce carbon dioxide emissions by 410 tons[1] (based on a national average of 1.64 pounds of carbon dioxide per kWh saved). That is equivalent to planting to 112 acres of trees or taking 82 cars off the road (ICF Consulting 1999).

Non-energy benefits associated with fresh water and wastewater project also have ecological ramifications. For example, by reducing sludge accumulation, some municipalities can avoid the emissions associated with trucking away the sludge as well as reduce the amount of solid waste that must be eliminated. In addition, when facilities are better operated, the need for chemical additives such as chlorine, polymers, and soda ash are mitigated. Improvements in water system efficiency can also lead to better management of our critical aquifer resources and water storage.

Equity

By optimizing their fresh water and wastewater facilities, communities can realize local gains and a sense of local control in the face of upwardly spiraling costs of energy, labor, hazardous waste disposal, and the liability associated with odors. Additional non-energy benefits include:

- **Increased staff capability**: Facility operating staff is educated regarding sophisticated optimization procedures.
- **Increased reliability and compliance**: System monitoring, leak detection, and repair are parts of predictive and preventative maintenance programs that increase system reliability. Leaks can allow contaminants to enter the pipeline, so compliance is potentially improved. Likewise, better control of the wastewater operation allows better compliance with discharge permits.
- **Decreased capital costs**: By reducing the amount of water the system uses, water utilities are able to defer capital expenses associated with increasing system capacity resulting from additional wells, dams and reservoirs, and pipelines. Optimized wastewater plant operation can result in an increase in capacity and deferral of new constructions.
- **Increased revenues (fresh water facilities)**: System monitoring, leak detection, and repair helps to identify other sources of unaccounted for water (UFW) such as unauthorized use and inaccurate meters. Addressing these sources of UFW helps to increase revenues.
- **Decreased variable costs (fresh water facilities)**: Energy and chemical costs are directly reduced by the amount of water no longer being used. In cases where the water utility must purchase water resources, the purchase costs are also avoided.
- **Safety**: Monitoring and control increases the safety of a system, allowing operators to rapidly shut down part, or all, of a system during an emergency. If and when

[1] This is based on a national average of 1.64 pounds of carbon dioxide per kWh saved. For Oregon, Washington, and Idaho CO_2 is reduced by 1.202 pounds/kWh.

infrastructure security becomes a priority these technologies may serve an additional and critical public safety need.

Changing the Market

There are tens of thousands of water and wastewater facilities across the country. The opportunities for efficiency improvements are far more than one company or even one program can handle. The Consortium for Energy Efficiency and the American Council for an Energy-Efficient Economy are both initiating processes to promote energy savings in fresh water and wastewater facilities. The market transformation concept developed in the Pacific Northwest is now mature enough to be emulated across the country by other organizations and companies. The following principles, which grew out of the experience in the Pacific Northwest, may be useful in establishing similar efforts.

- **Optimize the system**. The systems approach described in this paper has the potential to save far more energy than simply upgrading individual components. Rough estimates indicate that two to three times as much energy may be saved through such efforts.
- **Include the operator in the system**. Train the operator. Involve the operator in the installation and on-going process optimization of their system. Study and understand the operator's budget. When operators understand and practice system optimization, they will become leaders in transforming the market through personal pride and word of mouth.
- **Finance projects for positive cash flow**. Municipalities are generally not ready or willing to use capital project funds for efficiency tune-ups. Banks and other financing sources can provide the necessary resources.
- **Value the whole range of benefits**. Fresh water and wastewater facility optimization saves energy, reduces peak load, saves water resources, increases plant capacity, reduces emissions into the atmosphere, reduces the use of chemicals within facilities and reduces the cost of solids removal, etc. The more that energy and non-energy benefits can be valued as part of a given projects' financing, the more projects will be quantified as cost effective from each of the participants' points of view.

Systems optimization appears to be catching on in the market. One example of this is the CPUC wastewater treatment program conducted by Xenergy and Brown and Caldwell in the Pacific Gas & Electric and Southern California Edison territories. The program manual uses a systems optimization approach for larger facilities. This may have been catalyzed by BacGen wastewater projects in the PG&E service area. In the long run, project funding from large energy organizations may prove to be ephemeral. The market will be fully transformed when municipalities and industry, as a normal business practice, demand fresh water and wastewater facility system optimization and businesses are available to provide these services. The technology and the business expertise are available now.

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