Focused Optimization Efforts at two Wastewater Plants Leads to Meaningful Reductions in Energy Consumption

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ABSTRACT

Integration of energy management goals into the operational priorities at two Michigan membrane bioreactors resulted in a series of small projects and process changes that substantially reduced energy consumption at those two facilities. This paper describes the specific measures taken as well as the management approach that lead to them. Reductions achieved exceeded 30 percent at the Traverse City Regional Wastewater Treatment Plant and 40 percent at the Grand Traverse County Septage Treatment Facility.

INTRODUCTION

CH2M HILL operates and maintains the Traverse City Regional Wastewater Treatment Plant (regional plant) and the Grand Traverse County Septage Treatment Facility (septage facility). A project completed in 2004 converted the regional plant to a membrane bioreactor (MBR). At 8.5 mgd monthly average design flow, it was one of the world's largest MBRs at the time. The septage facility was constructed new to treat up to 90,000 gpd of trucked-in waste from household septic tanks and sewage holding tanks. This small plant was also built as a membrane bioreactor and became operational in 2006. For both plants, when run "right out of the package" so to speak, energy consumption, as the largest non-labor cost of operation, cried out for optimization. While cost management was a significant driver, global motivations played a role as well: We sought to reduce our operations' carbon footprints and energy resource consumption. By making it an operational objective as important as any other, staff conceived of and executed a series of equipment modifications, programming changes and changes in operational practices to produce a multi-year downward trend in electrical and natural gas consumption, which were instrumental in lowering overall operational costs at both facilities over a five-year period. Some of the specific steps taken, as well as the management approach leading to them, would be applicable at many treatment facilities.

ENERGY-SAVING MEASURES

The following are several of the specific measures we took to reduce energy consumption:

Scour Air

Scour aeration is one of the largest expenditures of energy at the regional plant. Our first attempts to manage it involved manipulating the flow thresholds at which membrane trains came into and out of production. Running more water through fewer trains meant fewer scour air blowers running at a time. We used this approach with some success until a better option became available for reducing scour air energy. At the regional plant, the change that resulted in the single largest reduction in energy use was modification of the membrane scour air program. Even while the Traverse City Regional Treatment Plant MBR was under design and construction, the membrane manufacturer, Zenon Environmental (now General Electric) was working on its next generation of membrane cassette (the 500d) and a scour aeration scheme that would use less energy. A year after start-up of the MBR at the regional plant, we engaged Zenon to provide programming that would adapt that scour aeration scheme to our 500c plant. The new programming reduces scour air blower run-time by an amount that approaches 50 percent. As installed, each membrane train was aerated for 10 seconds and went unaerated for the next 10 seconds. This program became know as 10/10 aeration. The new option, 10/30 aeration, provides 10 seconds of scour air to a train then 30 seconds without, thus requiring potentially half as many scour air blowers for a given number of running trains (Figure 1). Conditions at the surface of the membranes, specifically the rates of increase of cake resistance in each permeation cycle, are electronically monitored and trigger reversion back to the more intense scour aeration when necessary (Figure 2).

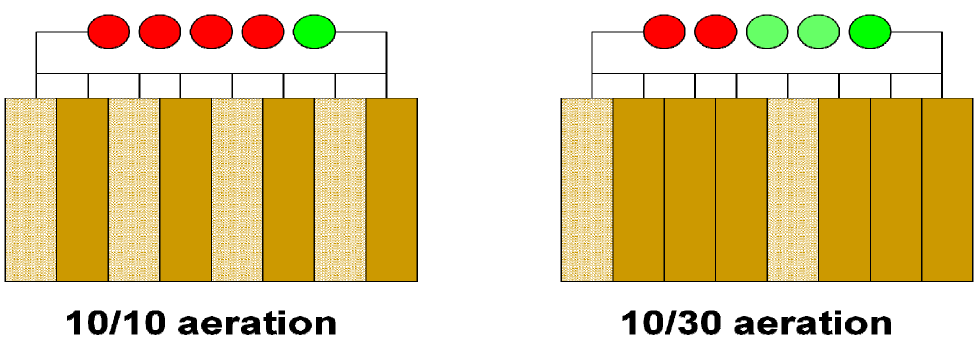


Figure 1 *At the regional plant, one blower must run for each train while it is aerated. Under 10/10 aeration, that calls for four blowers when all eight trains are in use. Under 10/30 aeration only two blowers are needed. In practice, while in 10/30 aeration mode, any number of trains called upon to run in excess of four will require two blowers, four or less will operate with one blower.*

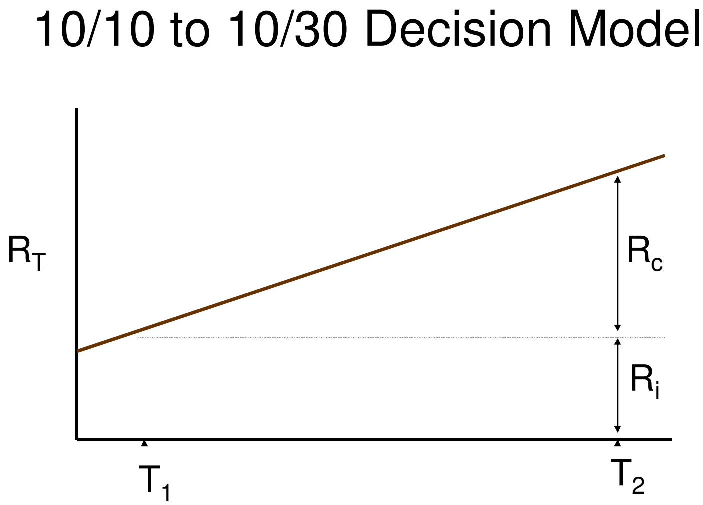


Figure 2 *Ri represents the initial resistance to permeation at the beginning of the 12-minute permeation cycle. One can regard it as the resistance inherent in the membrane itself. Rc represents the resistance to permeation attributable to an accumulation of MLSS on the membrane surface or "cake" over the course of a permeation cycle. If the rate of change of Rc exceeds a programmed threshold, the programming reverts back to 10/10 aeration to scour away that accumulated "cake."*

Process Aeration Optimization
The process aeration blowers (centrifugal) are separate from the membrane scour air blower system (rotary lobe). There are four process air blowers ranging from 200 to 400 horsepower. Their intakes and discharges both have valves regulated by programming that uses measured D.O. concentration to control D.O. to set points. Under different air requirements, different combinations of blowers are optimum. A simple but significant improvement was our addition of timers to turn off a blower at the (unstaffed) time overnight when a second blower becomes unnecessary to maintain the D.O. set point. The D.O. control system throttles the intakes to control total air delivered (and energy used) and throttles discharge valves to balance air between the two parallel basins. We must empirically establish the best fixed air balance on each basin using manual valves on individual air drops.

Also important for optimization of this process (as in any similarly configured activated sludge plant) are: Maintaining calibrated D.O. meters and tuned control loops; maintaining denitrification in the anoxic zones, optimization of the primary clarification upstream of it, and maintaining clean aeration diffusers. At the Traverse City Regional Plant, all continuously aerated portions of the bioreactors are equipped with stone diffusers (Sanitare). We have the capability to clean diffusers in place with gaseous hydrogen chloride but we prefer not to as this is a dangerous gas to handle. We hypothesize that we transfer oxygen efficiently through longer intervals between cleanings because of the presence of hydrogen sulfide in our supply air, which forms sulfuric acid at the diffusers and helps keep them clean. The preliminary and primary processes at the plant are covered for odor control; foul air is collected from the headspace above them and conveyed to the bioreactor process air intakes. When we purge condensation from the air diffuser headers it is plainly acidic. We dewater aeration basins and physically clean the diffusers at two-year intervals. We use a pressure washer and then apply liquid hydrochloric acid.

RAS Pumping

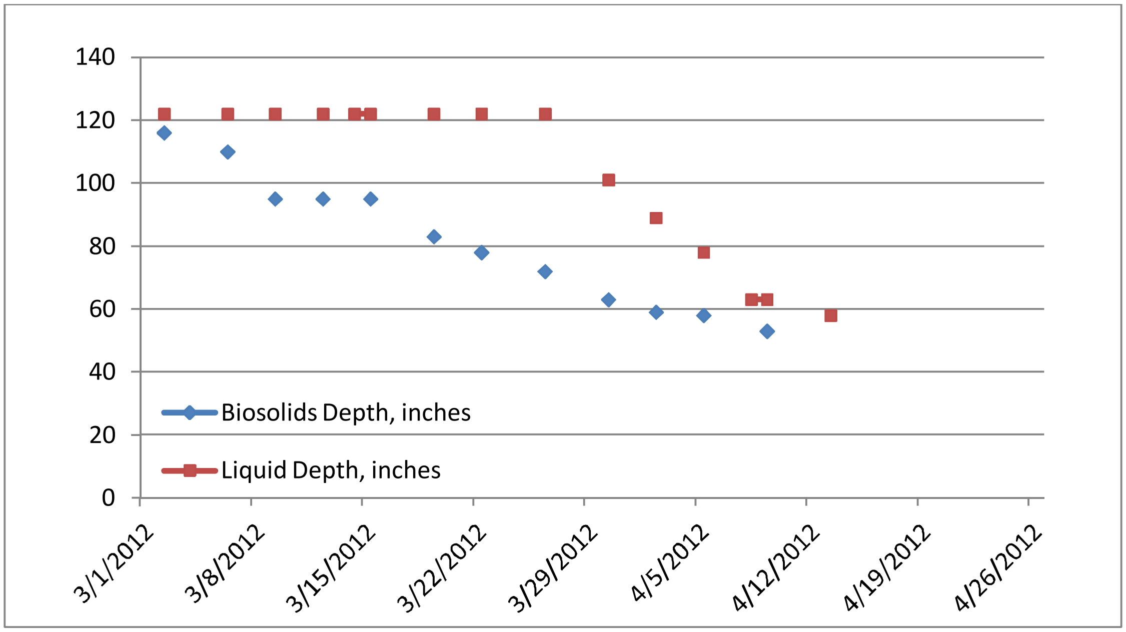
Reduction in RAS pumping energy requires optimization of RAS rate against the effects of increasing MLSS concentrations at the membranes. We reduced RAS pumping energy first by use of timers to turn a second pump on and off to match the diurnal change in the RAS rate requirement. We subsequently achieved further improvement in RAS rate control capability with the installation of RAS pump VFD control (utilizing a government incentive).

Vacuum system

Each of the regional plant MBR's eight trains has vacuum applied to an air separator just upstream of each permeate pump. The designers envisioned these air separators to be necessary to remove entrained or dissolved air coming out of the permeate after its withdrawal from the mixed liquor through the membranes. The vacuum system consisted of three vacuum pumps, two of which ran continuously by design with the third a redundant unit. We experimented with running individual trains while isolated from the vacuum system and learned that very little air or gas actually came out of solution under normal running conditions and that continuously running vacuum pumps may not necessary. We performed vacuum decay tests on the system, which revealed that some of the original valves were not vacuum duty equipment. After replacing them, the system became tight enough that under normal circumstances, vacuum could be maintained at the air separators with only brief and occasional runs of a single vacuum pump. Maintenance staff converted from the original constant-run system to a demand system that can run zero, one, two or three units as required. The system now only calls upon a single vacuum pump to run so infrequently that it totals only a few minutes per day. The change from two continuous to nearly zero running units reduced power consumption but more significantly, it reduced the maintenance requirement on this vacuum system, which had become extreme.

Biosolids Concentration

In the usual sequence of processes at the regional plant, after anaerobic digestion, sludges are concentrated in a rotary drum (or sieve drum) concentrator prior to storage pending application to area farm fields as class B biosolids. There are windows in the year when operations staff can use the empty storage tanks after biosolids hauling events as settling vessels to concentrate a portion of the biosolids by gravity as an alternative to running sludge concentrators with the associated electrical and chemical consumption. There is no permanent equipment to withdraw decant; we harvest supernatant liquid with hoses and small portable pumps. We have generated data on settling rates and terminal biosolids volume to establish when during the year there will be time for sufficient concentration by gravity to generate a payback. When using the technique, the cost of biosolids hauling and application, and those of concentration (power and polymer), must be optimized against each other.



Graph 1 *The terminal concentration of settled biosolids is not as high as that of concentrated biosolids. The cost of hauling slightly more volume must be balanced against the savings in power and polymer realized by not concentrating the initial volume of digested sludge using the sieve drum concentrator.*

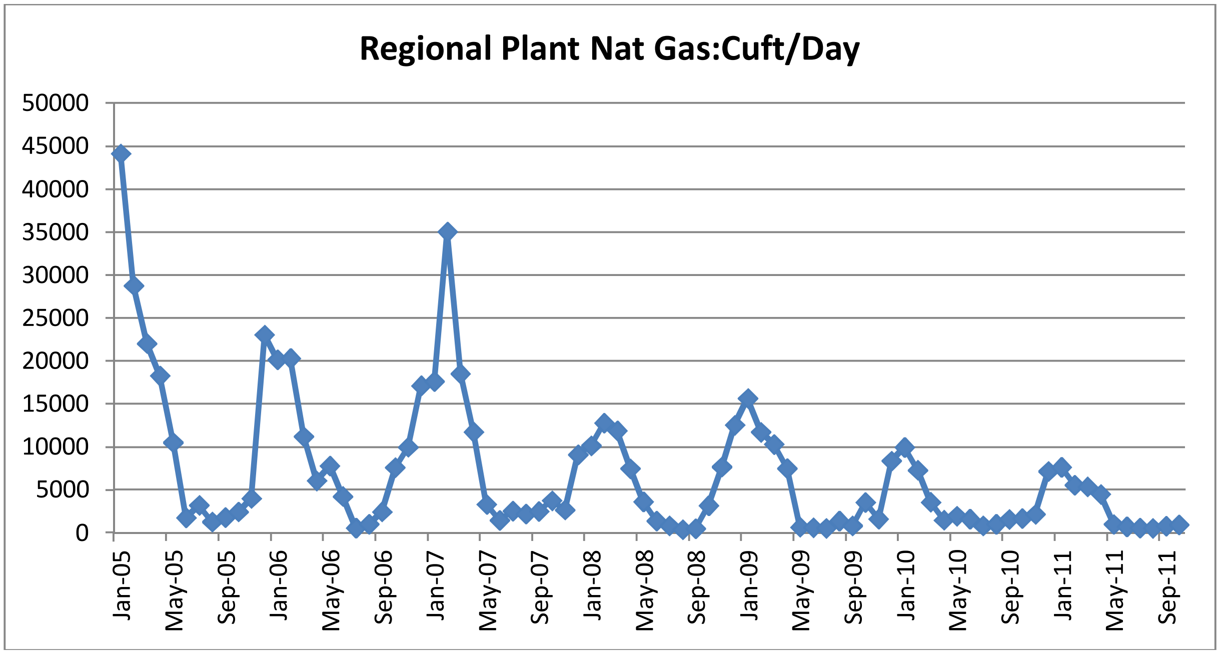
Regional Plant Natural Gas
Staff reduced natural gas consumption (Graph 2) by reducing plant heat demand and by increasing the utilization of anaerobic digester gas. In one process building we ceased heating with natural gas entirely as all liquid-containing pipes and process equipment are below grade. By closing and insulating the stair penetration, the space stays reliably above freezing without applying heat. We shut off heat to areas with no process requirement for it such as membrane building stairwells. We reduced process building temperature set points and examined air exchange rates to lower them where possible while respecting the designed air exchange rate necessary for health and safety. We applied additional insulation (2-inch foam board) to part of the outside of an anaerobic digester.

To improve use of gas from anaerobic digesters and thus minimize natural gas burned, we experimented with pressure regulator settings and floating digester cover operating levels. The optimization here pits gas storage capacity against the potential for the digesters to spill foam. The higher the pressure allowed in the digester gas system, the higher the floating cover rises and the more gas can be stored for use in the boiler. However, higher pressure regulator settings also mean greater displacement of sludge and foam out from under the cover. And, it can raise the shoulder of the floating cover above the concrete rim of the vessel (forcing any displaced foam out of the vessel rather than allowing it to spread inward onto the top of the cover). A higher liquid level maximizes the useful vertical travel (by preventing the cover from resting on its corbels before stored gas is used down to the low pressure threshold), but also increased the potential for foam-over.

We adjust digester feed and mixing cycles to reduce the frequency of gas pressure drops that cause dual-fuel boilers to toggle to natural gas. We time the feeding and mixing of the digesters each day, so that the resulting bump in gas production filled in the time of day when we would otherwise experience a dip in pressure. With haphazard timing, within any day, we might flair off gas while generating it faster than we can use it, yet burn natural gas when digester gas pressure was inadequate to fire the boilers.

Staff identified and replaced gas control valves that were prone to failure caused by the moist and corrosive nature of digester gas. Such valves resulted in frequent, unnecessary switchovers of the dual-fuel boilers from digester to natural gas.

We reconfigured the main digester gas header that conveys digester gas to the dual-fuel boilers to improve the effectiveness of water traps. Previously we had experienced frequent "trip-outs" of the boiler, caused by water while burning digester gas. Each trip-out obligated the system to convert to burning natural gas for 30 minutes before trying digester gas again. Without effective water removal, significant time could be spent burning natural gas even while adequate digester gas was available.



Graph 2 *Reductions in natural gas use result from reducing overall gas consumption and maximizing utilization of digester gas.*

Other Improvements
Other improvements at the regional plant involved installing timers on mixing equipment to supply only the needed amount of mixing energy and at off-peak times or times that best enhance utilization of digester gas. Mixing energy is perhaps the easiest to waste since there is often no tangible indicator when homogeneity is achieved.

We also replaced inefficient lighting in two large areas of the plant (two separate projects, the second of which utilized government incentives).

In addition, we found and corrected a non-optimum condition in the electrical system, a transformer that had for years been lead out incorrectly and was producing non-nameplate voltage. Changes affecting electrical use at the regional plant are tabulated in Table 1.

Reductions at the Grand Traverse County Septage Treatment Facility
At the septage facility, the largest electrical consumption reductions stem from significant deviations from the designer-intended mode of operation (Table 2). The Facility provides preliminary treatment of hauled domestic septage prior to discharge to the collection system and ultimately final treatment and discharge to the environment from the regional plant. The septage facility was constructed as a membrane bioreactor with auto-thermophilic aerobic digestion (ATAD) for solids treatment. The facility receives less than the anticipated loading. CH2M HILL, with the owners' consent, has decommissioned the membranes, contrived a way to decant from the aeration vessels, and runs the system as a sequencing batch reactor. The facility meets its effluent quality targets but at much lower energy consumption and cost. Aeration use associated with the membranes is eliminated and membrane cleaning chemical use is eliminated. Unaerated time in the cycle allows for denitrificaton which improves total nitrogen removal,

reduces process air requirement through biological utilization of nitrate oxygen, and eliminates need for NaOH feed for pH control because of natural recovery of alkalinity.

Once we became confident after extended experimentation that we can successfully operate as a sequencing batch reactor, we further committed to the strategy. Influent to the septage facility is screened to a quarter-inch at the point where trucks are offloaded into an equalization vessel. As designed, influent was processed through a 0.5 mm screen as it was transferred from equalization to the bioreactor. That level of screening was intended to protect the Dynatec X-flow membranes (and inside-out tubular membrane). Decommissioning the membranes means we no longer need to screen to that degree. We fashioned a bypass and cut the 0.5 mm screen out of the flow schematic. This eliminates all run time on two electric motors, eliminates consumption (and re-treatment) of a spray water, and greatly reduces operational attention since this was a problem-intensive process.

The above changes are reversible. However, prior to resuming operation as an MBR, we would need to empty and clean the bioreactor after having run it without the 0.5 mm screening for some time.

CH2M HILL and our client are currently planning to install a decant mechanism to further facilitate SBR-like operation. The current method of withdrawing decant is make-shift. We remove it through the waste activated sludge withdraw pipe, which happens to be at a convenient elevation in the reactor. The decant must be pumped using a progressive cavity pump to a sump, then re-pumped into the plant's post EQ tank as effluent. The new decanters will eliminate these two pumping steps, saving electricity and reducing the maintenance requirement.

Another deviation from the originally envisioned operation at this plant is our preparation of biosolids as a bulk liquid rather than as a dewatered material. The electricity, chemical and disposal costs associated with belt filter press dewatering and landfilling would more than exceed our current cost for contract hauling and subsurface injection as a liquid. Operator effort is also reduced.

We use the second stage of the ATAD process, the nitrification/denitrification reactor (SNDR), as a biosolids storage vessel prior to land application. In this mode, we are able to refrain from mixing and aerating it until after it is over half full. This savings would not be possible if we were dewatering the material as designed because the biosolids would need to acclimate to a lower-temperature, lower-rate biology in the SNDR to become amenable to coagulation with polymer for dewatering (ATAD is a high-rate, high-temperature process that generates a dispersed biology resistant to flocculation). Another electricity-saving measure associated with solids handling was modification of control programming of the ATAD to give it more "turn-down" capability so it runs more efficiently when lightly loaded.

MANAGEMENT APROACH

After start-up of new processes (following modification of the regional plant to MBR and the construction of the septage facility), the first order of business was to identify and abate vulnerabilities to ensure treatment reliability. Then we turned attention to optimization. That effort began with recognition that energy consumption reduction is important – for global, local and personal reasons – and that it is possible. We don't harbor the common but false assumption that a plant's energy consumption rate is fixed into the design. We did not begin with an energy management plan or by setting any numerical goals. Any target would have been be arbitrary; we did not know how much savings there was to be had (and still do not), but were interested in discovering and developing any measure having a payback. We made energy consumption reduction an ongoing intention and a regular part of our process control work. The following principals apply:

Measurement We record consumption daily at multiple metering points and are accustomed to looking at trend graphs. Each bump or dip can be correlated to conditions or to choices we made. Measurement with an inductive amp meter reveals consumption of individual pieces of equipment under different conditions. For example, we measured energy use of permeate pumps while artificially varying suction head to simulate the impact of membrane fouling on energy consumption. We can now make knowledge-based judgments balancing membrane cleaning costs against the effect of fouled membranes on electricity consumption.

Big stuff first We often worked on the small and the large opportunities simultaneously, but were determined to at least keep working on the largest ones.

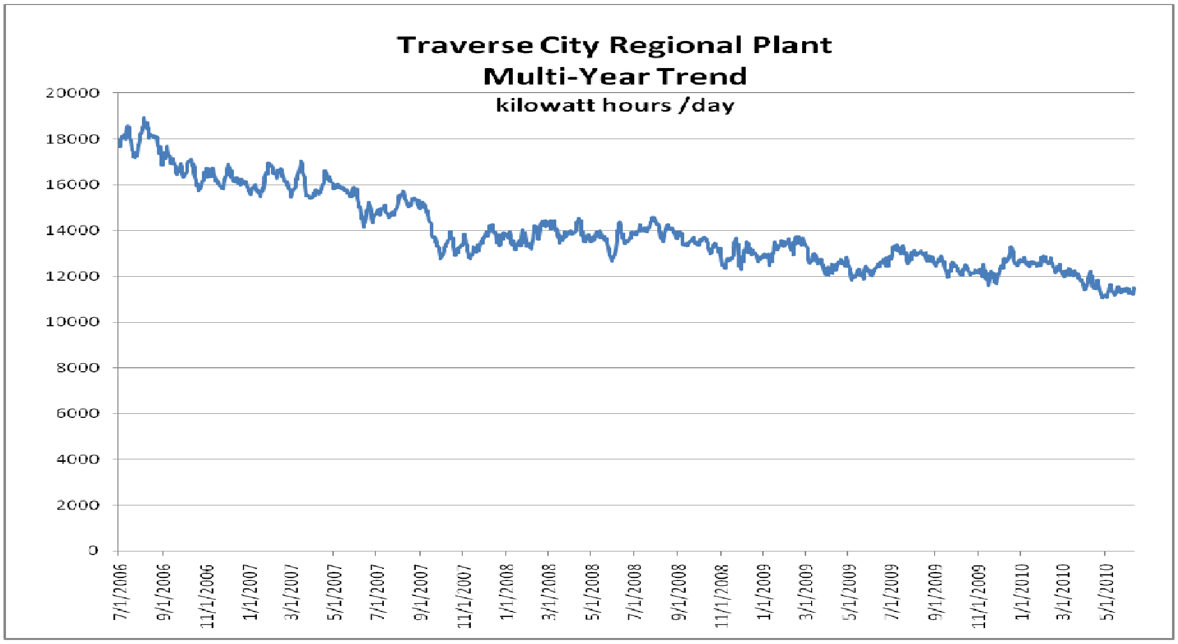
Make energy management part of ordinary work Energy use is an item on our weekly operations meeting agendas. We compare current usage data to last week, last month and last year. When there is an increasing trend or a bump in consumption, staff is compelled to know to what it can be attributed and to determine whether it is an acceptable energy expenditure or a new issue to address. Also, as we come to know the impact of each operational decision on energy use, opportunities to reduce become apparent. In addition to staff-wide meetings, energy use is also part of process control strategies established between operators and supervisors and one of the areas evaluated in employees' individual performance appraisals.

Use Knowledge Resources Staff invited the power company to make a presentation on the complicated rate structure – peak and off-peak, demand charges and power factor. Staff uses CH2M HILL engineers and sometimes vendors to help evaluate a contemplated project's challenges and payback.

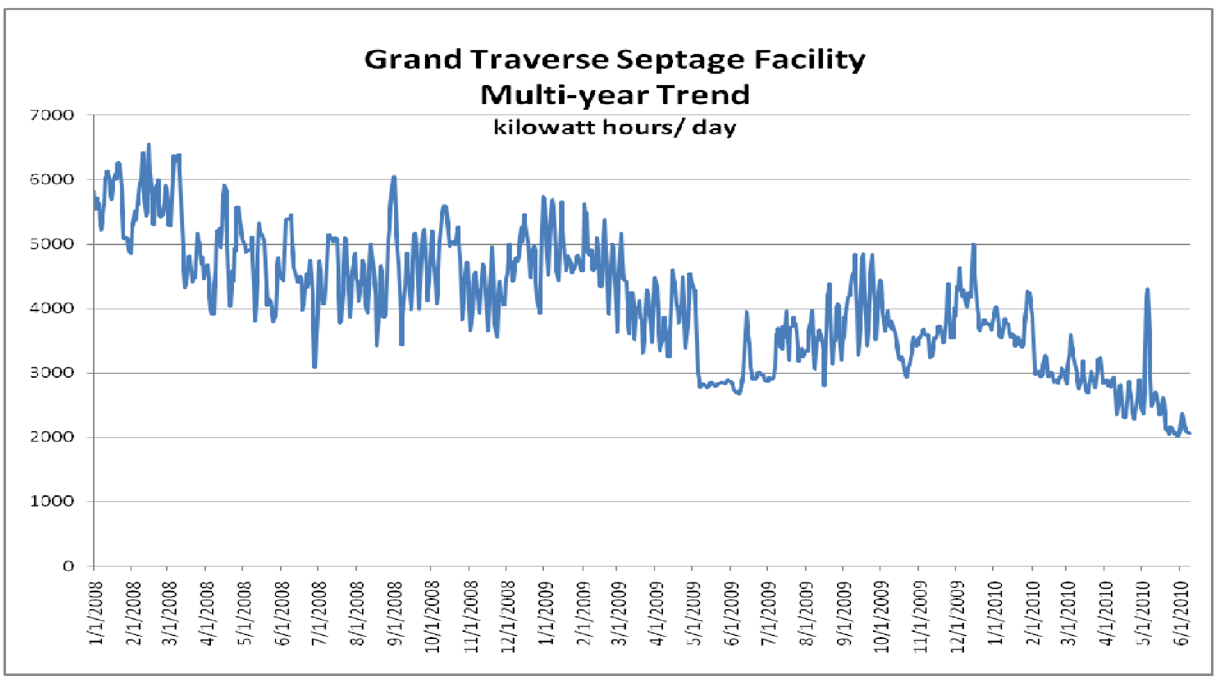
Regard energy as similar to a chemical feed – Energy is an ingredient; add just enough to accomplish the need. Mixing a biosolids tank or a digester beyond homogeneity is a wasteful practice similar to overfeed of a chemical (applicable to aeration and D.O, mixing in treatment vessels, and heating many process buildings any warmer than needed to prevent freezing)

SUMMARY AND CONCLUSIONS

The energy optimization process has returned notable results (Graphs 3 and 4, and Table 1). At the regional plant, we reduced energy consumption 32 percent over four years. The energy reduction efforts at the septage facility reduced consumption over 40 percent. For both faculties combined, the savings total more than $185,000 annually.



Graph 3



Graph 4

Table 1 Operational changes at the Traverse City Regional Wastewater Treatment Plant

Action	**Result/Decrease**
Reduced runtime of second return activated sludge pump	250,600 kWh/year
Installed new controllers on air distribution valves and shut-down timers on process air blowers	186,000kWh/year
Installed shut-down timers on digester mixers	41,600 kWh/year

Redesigned membrane vacuum system, reducing usage from two pumps, typically, to on-demand	65,000 kWh/year Reduces maintenance costs, noise and vulnerabilities
Quantified energy impact of membrane fouling for use in considering cleaning frequencies	10,000 kWh/year/psi
Use biosolids storage space for settling and decantation to concentrate biosolids instead of mechanical concentrator	9,000 kWh/year Decreases water, polymer coagulant, and labor demands
Replaced inefficient lighting	14,600 kWh/year
Re-tapped transformer after discovering out-of-spec voltage condition	Incremental improvement in efficiency of equipment powered by that transformer
Partnered with GE to facilitate programming changes for automated controls for GE Zenon® membrane system to reduce scour air blower runtimes	1,006,000 kWh/year 50 percent fewer run hours
Adjusted effluent service water use to reduce pumps	45,600 kWh/year
VFDs on return activated sludge pumps	175,200 kWh/year

Table 2 - Operational changes at the Grand Traverse County Septage Facility

Action	Result/Decrease
Partnered with auto-thermal aerobic digestion system supplier to make programming changes that provide greater turn-down capability and lower the maximum allowed speed	Allows turndown to 75 percent of normal pump speed
Reduced run time on storage nitrification/denitrification reactor mixers and aerators by operating only when at least half-full	49,400 kWh/year
Decant effluent (as in an SBR) instead using membranes	433,000 kWh/year Improves nitrogen removal, Recovers alkalinity and nitrate-borne oxygen Decreases membrane cleaning chemical costs
Cessation of use of 0.5mm screens	Eliminates all run time on two to three small motors. Reduced water use
Processing biosolids as liquid rather than dewatered biosolids	Saves electricity, polymer costs and tipping fees, eliminates need for construction of biosolids cake storage building