Energy Efficiency in Municipal Wastewater Treatment Plants

Technology Assessment

Lawrence J. Pakenas, P.E.
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NEW YORK STATE ENERGY RESEARCH AND DEVELOPMENT AUTHORITY

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ENERGY EFFICIENCY IN MUNICIPAL WASTEWATER TREATMENT PLANTS

INTRODUCTION

Wastewater treatment plants consume large amounts of energy. They also have the capability to produce a fuel, biogas (a combination of methane and carbon dioxide), through anaerobic digestion of sewage sludge. A secondary treatment plant may use as much as 1500 to 1700 kilowatt hours (kWh) of electricity to treat one million gallons of sewage and manage the resulting sludge and residuals.[1]

Natural gas, fuel oil, and biogas are usually burned in boilers to provide heat energy for some sludge management practices and plant heating and cooling.

NYSERDA Estimates

The New York State Energy Research and Development Authority (NYSERDA) estimates that municipal wastewater treatment plants (WWTPs) in New York State consume about 1.5 billion kWh of electricity each year for sewage treatment and sludge management based on the predominant types of treatment plants, the results of an energy use survey, and recent trends in the amounts of electricity WWTPs use nationwide.[2]

According to NYSERDA estimates, 170 million therms of gas and 16 million gallons of fuel oil are used yearly for sludge processing and space heating.

Limited Incentive

There are more than 570 WWTPs in New York State, with 96 percent providing a minimum of secondary level of treatment.[3] Approximately 75 plants in metropolitan New York City and Long Island treat 60 percent of the State's total wastewater flow of 3.5 billion gallons per day.[3] Plants range from treating less than 100,000 gallons to more than 300 million gallons per day.[3] Some 15 million to 20 million gallons, or 1,000 dry tons of sludge, are produced by New York State WWTPs every day.[4]

While several reliable energy-saving technologies could be implemented at these WWTPs, most municipalities have had limited incentive to reduce energy costs. Electric utilities in New York State have encouraged demand-side management (DSM) to help control or lower energy costs and make energy available for new customers without constructing additional facilities.

Report Highlights

- Describes DSM opportunities for WWTPs in New York State;
- Discusses the costs and benefits of several DSM measures;
- Projects energy impact statewide of the DSM technologies;
- Identifies the barriers to implementing DSM at WWTPs; and
- Outlines one possible incentive that could stimulate widespread adoption of DSM by WWTP operators.

Wastewater treatment plants are unique. Each one is designed and operated differently. The information in this report, therefore, may not apply to all WWTPs under all situations and conditions.

The reader is cautioned to use this information as a general guideline and to confirm DSM opportunities at individual WWTPs using site-specific analyses.

DSM OPPORTUNITIES

DSM means actions that a utility may take to control or influence its customers' electricity use. For example, demand reduction is easily achieved using energy-efficient lighting, high-efficiency motors, electric-load controllers, and adjustable-speed drives.

DSM includes conservation, energy efficiency, and control of power requirements, and can include a redistribution of electricity use over time, usually a 24-hour day. Some DSM activities, however, may increase electricity use, contributing to load growth.

According to NYSERDA estimates, 170 million therms of gas and 16 million gallons of fuel oil are used yearly for sludge processing and space heating.

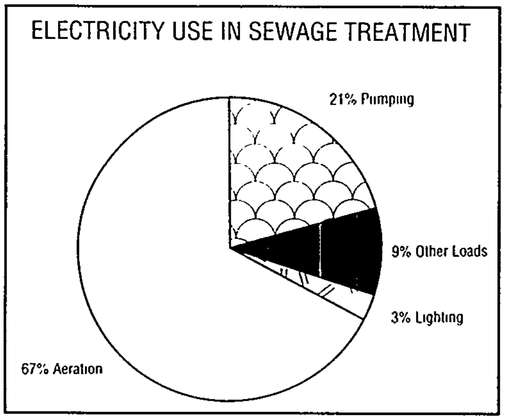

Figure 1. Typical percentages of total electricity used by various systems at an activated sludge treatment plant.

NYSERDA's Municipal Wastewater Treatment and Sludge Management Program defines DSM as any opportunity a WWTP has to reduce total energy *cost* and, in many instances, energy *use* by generating electricity on-site; reducing the amount of electricity purchased from the utility; shifting electricity use to off-peak hours; and, using alternative fuels and treatment technologies.

Outfall Hydropower

Installing a turbine-generator in the outfall pipeline or parallel to the pipeline of a WWTP to capture the energy of the flowing effluent may be feasible at some WWTPs. Technically, a head of only five feet is required to operate a water turbine; however, from 10 to 15 feet is the practical lower limit. The minimum head requirement will vary depending on the flow volume available.

On-site Generation

On-site generation would in most cases use an internal combustion engine-generator set or, when appropriate, gas turbine-generators. Fuel, natural gas or fuel oil, for the system could be purchased and/or produced by anaerobic sludge digesters (biogas), if available. Project economics would probably require cogeneration.

Electricity generated on-site would displace energy purchases from the utility, and heat from the system could be recovered for thermal load applications including sludge drying, digester heating, and space conditioning.

Aeration Efficiency

Sewage aeration at an activated sludge WWTP accounts for about 30 to 80 percent of the total plant electricity demand.[5] Figure 1 illustrates a typical energy-use distribution for an activated sludge plant.

Variations of the activated sludge process are commonly used for municipal wastewater treatment in New York State. Aeration electric demand and energy consumption could be reduced by using fine-pore diffused-air systems and aeration process controls, or lowering the sludge age (mean cell residence time or MCRT).

Time-of-Day Electricity Pricing

The future prices of electricity purchased from New York State utilities by WWTPs may vary over the course of a day using on-peak/off-peak rates or differential hourly rates. Some WWTPs are now subjected to on-peak/off-peak rates. Within certain operating constraints, many plants could achieve substantial energy cost savings by treating normal flows in off-peak hours when the cost of electricity is lowest.

At plants with excess process capacities, sewage treatment and sludge management would be mini-

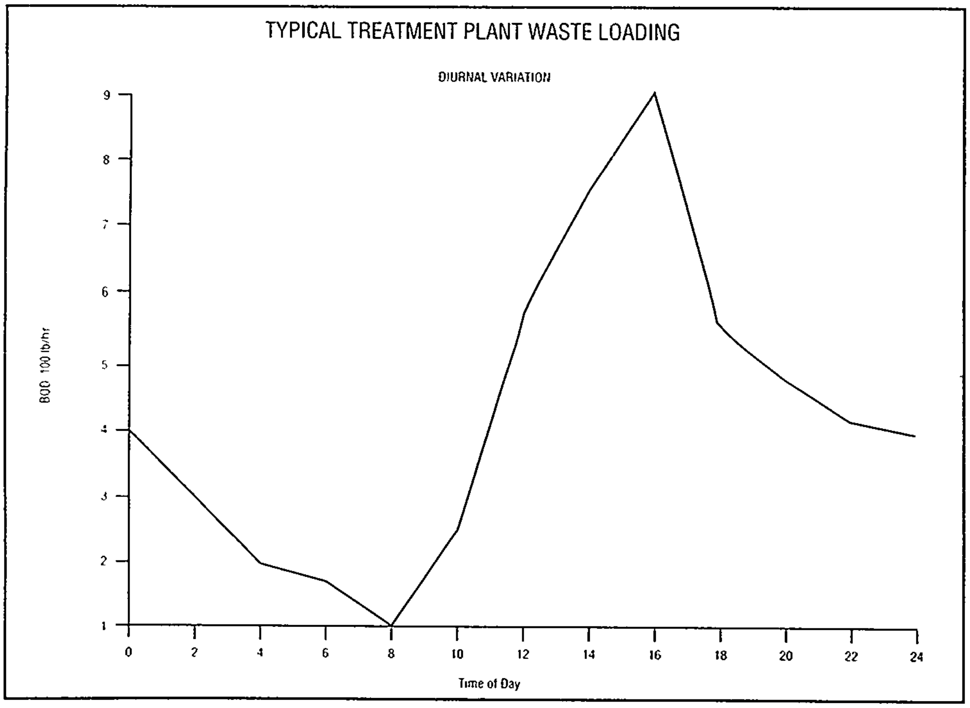

Figure 2. Variation in influent wastewater strength over 24 hours for a typical treatment plant.

mized during on-peak hours when electricity prices are highest. This WWTP operating method could challenge the WWTP operator.

The normal diurnal sewage flow pattern into a WWTP closely parallels an electric utility's system-demand and energy-cost curves; that is, rising in the morning to a peak that lasts into the evening before ebbing during the overnight hours as shown in Figure 2.

Storing Wastewater

Shifting electrical load from on-peak to off-peak hours, or levelizing electricity use throughout the day usually requires temporary storage of the influent wastewater either at the treatment plant site or within the sewerage system, and possibly sludge storage for batch processing.

Some sewerage systems are designed to collect and transport sewage so flows at the WWTP are reasonably constant. If there is no existing storage capacity, constructing new storage facilities specifically to process wastewater and sludge during off-peak hours may not be cost-effective.

The costs and benefits of wastewater storage and time-of-day electricity pricing need further development; these topics will not be included in the following analysis. A qualitative assessment of how time-of-day pricing may influence implementing DSM technologies appears in the conclusion.

OUTFALL HYDROPOWER

Turbines suitable for low-head effluent hydropower applications are generally custom-designed and manufactured by specialists in hydro-turbine construction.

The range of flows and heads at New York State WWTPs suggests that axial-flow tube turbines would be the preferred equipment. Several sewage-pump manufacturers offer "pumps as turbines," using an off-the-shelf wastewater pump converted to operate as a turbine. This standardized design and manufacturing approach never achieved its anticipated impact in the hydropower market, so current equipment offerings are limited.

Figure 3 illustrates an effluent hydropower concept. Treated sewage effluent, diverted from the outfall pipeline, passes through one or more turbine-generator units before flowing into the receiving water body.

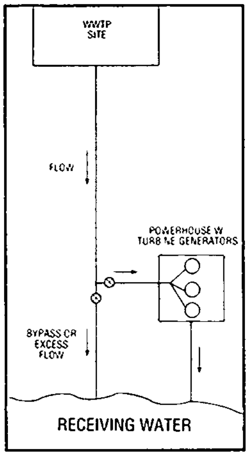

Figure 3. Diagram shows how a treatment plant's effluent could be diverted to a hydropower generating station to produce electricity.

The treated effluent could also flow through the shunted section of the outfall pipeline during times of hydropower system shutdown or excessive flows. Generated electricity is delivered to the WWTP via an independent transmission line that interconnects with the WWTP electric distribution system. The hydropower site also could be connected to the electric utility grid at the nearest access point.

Interconnections

Interconnection requirements are essentially the same whether the electricity is used by the WWTP or is sold to the utility. Each utility has general guidelines for interconnection and specific requirements for each project. Equipment would generally include transformer, meter, and protective relays.

Hydropower construction and operation are regulated through the Federal Energy Regulatory Commission. Federal agencies other than the U.S. Army Corps of Engineers would not normally be involved with an effluent hydropower project unless the energy was sold to the utility. New York State and local government agencies review the project, however, primarily for environmental impact and the potential for interfering with the WWTP's operation.

COGENERATION

Cogeneration appears ideal for a WWTP. Biogas fuel for generating power can be produced on-site using anaerobic sludge digestion. To increase the energy capacity of a system, the biogas could be supplemented with natural gas, if available. The electricity generated and recovered heat have many uses in the plant and any excess electricity could be offered for sale to the utility.

Internal combustion engines and generators are available that range from 10 to 6,000 kilowatts (kW). Small gas turbine-generators usually have output from 800 and 15,000 kW, but units with less than 50 kW of capacity could be feasible.[6]

Installations of 1,000 kW or less generally use engine-generators; gas turbines are preferred for capacities of 6,000 kW or more. Interconnection and regulatory requirements are similar to those described previously for effluent hydropower.

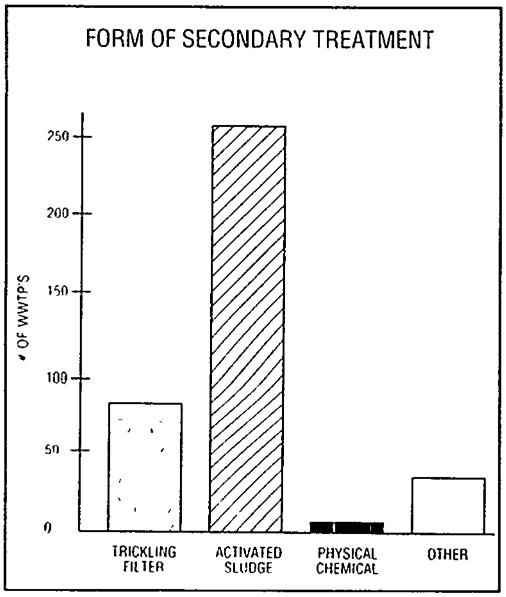

Figure 4. Number of treatment plants in New York State that use various forms of secondary wastewater treatment.

Waste Heat

Waste heat can be recovered for use in sludge management, and plant heating and cooling. Sludge management has become increasingly problematic and costly for many municipalities in New York State, particularly the disposal step. For example, sludge landfilling is no longer a matter of simply trucking the material to a local site a few miles away.

Before implementing beneficial use technologies, hauling sludge hundreds of miles to a special landfill at a cost of more than $300 per dry ton was not uncommon for upstate New York communities.[7]

In New York City, sludge management costs $250 million per year or about $220 per dry ton.[8] In general, the water content of the sludge has a direct impact on the cost of hauling, landfilling, composting, and pelletizing it. A lower water content means lower operating costs for these options.

Drying Method Choice

The drying-method choice often depends on the sludge's beneficial use designation or disposal option(s) available. Sludge drying can be done directly or indirectly. Smaller-sized WWTPs or those with low sludge volume often rely on drying beds to drain and evaporate water.

For larger plants, removing excess water

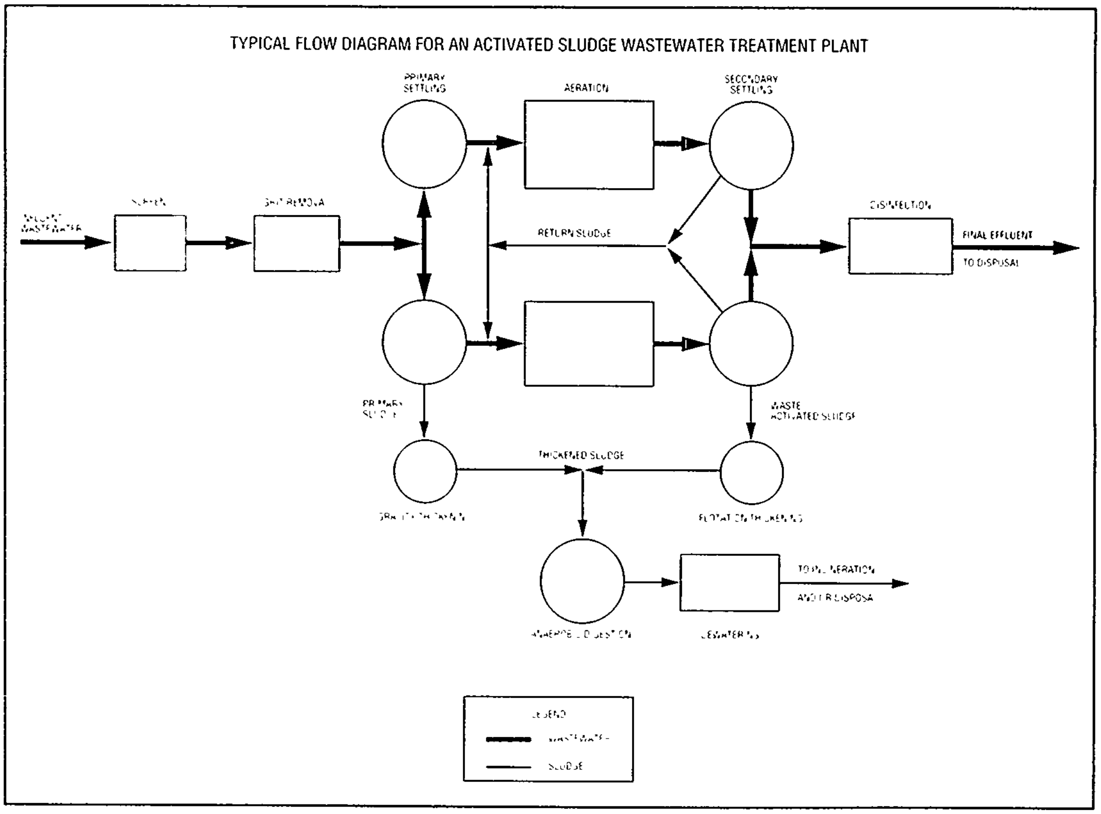

Figure 5. Diagram shows the layout and flow pathways for a typical activated sludge treatment plant.

after sludge dewatering usually involves heat drying. Heat energy for drying can be provided by fuel combustion in a boiler. The recovered heat from a cogeneration system or a sludge incinerator could also be used.

Manufacturers list steam, hot air, or a hot working fluid in their literature for operating most sludge dryers. Hot air is in direct contact with the sludge in a direct dryer.

Direct dryers reduce the moisture content of the sludge to about eight percent.[9] These units create a large amount of dust when operating but are preferred when producing a fertilizer or soil amendment from sludge.[9] Exhaust gas requires particulate removal and odor control.[9]

Indirect sludge dryers use steam or hot fluid to heat the interior dryer surfaces and hollow-shaft augers and agitators as the sludge passes over them. These units are relatively compact and dry large volumes of sludge to a 15 to 35 percent moisture content within a short time.[9]

There is little dust during dryer operation, and odor control and particulate removal requirements are minimal.[9] Indirect drying is the best choice to precede sludge incineration.[9]

This assessment focuses on steam-operated, indirect sludge dryers due to their compact design, relatively dust-free operation, and minimal pollution control requirements.

THE AERATION PROCESS

Aerating sewage via activated sludge is the predominant unit process for secondary wastewater treatment in New York State, as shown in Figure 4.[3] A typical activated sludge WWTP is shown in Figure 5.

Mechanical agitators mounted at the surface of the sewage vigorously churn the sewage like an egg beater, or a diffused air system installed on the floor of the aeration tank disperses small bubbles of air into the sewage for aeration.

In mechanical aeration, most of the oxygen transfer occurs when the sewage is thrown into the air by the aerators, as seen in Figure 6. Their oxygen transfer efficiency, expressed as pounds of oxygen transferred per horsepower-hour (lb. O_2/hp-hr), is 2.0 to 4.0 lb. O_2/hp-hr.[10] Diffused air systems are either coarse-bubble as seen in Figure 7, or fine-bubble, as shown in Figure 8.

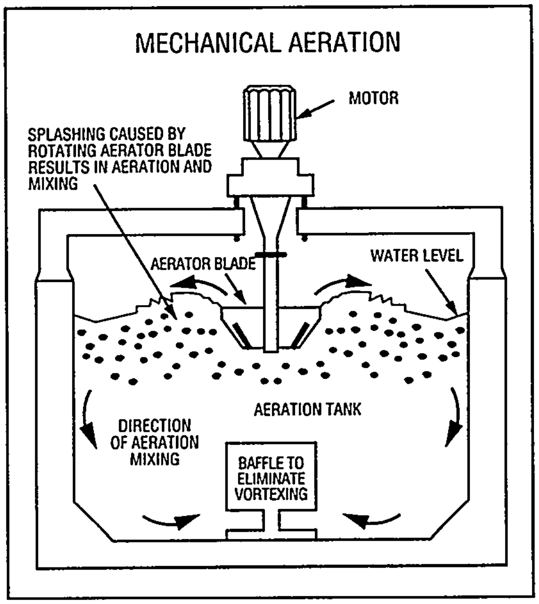

Figure 6. A cross-section of a typical mechanical aeration tank at an activated sludge treatment plant.

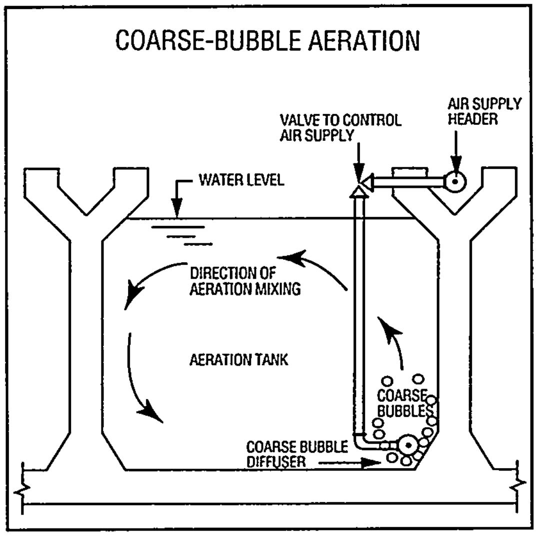

Figure 7. A cross-section of a typical coarse-bubble aeration tank at an activated sludge treatment plant.

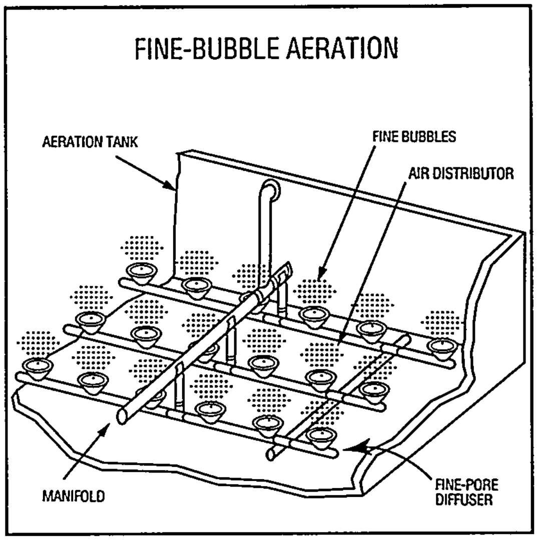

Figure 8. A cross-section of a typical fine-bubble aeration tank at an activated sludge treatment plant.

Bubbles Differentiate

The number of bubbles produced per unit volume of air and the bubble diameter differentiate the two systems. The smaller-diameter bubbles produced by the fine-pore system provide more surface area for better oxygen transfer efficiency than both coarse-bubble systems and mechanical aeration.

Oxygen transfer efficiency for coarse-bubble systems is about the same as mechanical aeration.[11] Fine-pore diffusers have an oxygen transfer efficiency of about 4.0 to 8.0 lb. O_2/hp-hr.[11]

Fine-Pore Systems

The capital cost of a fine-pore aeration system will probably be higher; however, the total annual cost for the system will be less than the annual cost of coarse-bubble aerators.[12] For example, the fine-pore system could reduce energy consumption from 40 to 50 percent, and overall life-cycle costs from 10 to 20 percent compared to other diffused-air systems.[12] Based on the oxygen transfer efficiencies given previously, energy cost savings using fine-pore diffusers compared to mechanical aerators will be similar. Actual cost savings will be site specific.

Oxygen Transfer Efficiency

The diffuser layout will affect oxygen transfer efficiency, aeration tank mixing, and energy use. Two typical diffuser arrangements are the spiral roll and the total floor coverage.

For the same aeration tank configuration and diffuser type, the total floor coverage will produce a higher oxygen transfer efficiency and use less energy than the spiral roll arrangement.[12] The spiral roll layout, however, provides better mixing of the aeration tank mixed liquor.[12]

Diffuser Maintenance and Cleaning

Fine-pore aeration systems may increase the maintenance requirements compared to other types of aerators, because fine-pore clogging in the air diffusers is a major problem. Diffuser fouling can occur on the air side and/or the water side.

On the air side, dust and dirt taken in by the air blowers or compressors could block the pores in the diffuser media. Air filters must be cleaned or changed frequently, and no unfiltered air can enter the system.

On the sewage side of the diffusers, biological solids in the mixed liquor could settle on the diffusers when the system is turned off or a biological slime layer could cover the pores. The aeration tanks must be drained periodically to expose the air diffusers and the accumulated biological deposits must be removed.

Sometimes cleaning diffusers requires only a strong spray from a hose; in other instances, diffusers must be removed for hand cleaning or replacing. Certain diffuser construction materials may not be compatible with some wastewaters. Pilot testing the diffuser in the actual wastewater stream would be necessary.

Sludge Age Reduction

Viable microorganisms that comprise the mixed-liquor suspended solids of an activated sludge process are in either the active stages of organic waste destruction and cell reproduction, or the endogenous phase of their life cycle. In both cases, oxygen is consumed by the microorganisms and energy must be expended to provide it.

Under usual operating conditions, the microorganisms in the system may have a mean cell residence time (MCRT, or sludge age) of 10 to 12 days depending on the type of sewage being treated, the level of treatment required, and the sludge-handling capability of the plant.

For a 12-day sludge age, approximately one-twelfth of the solids are removed from the system each day.

Shorter MCRT

If sludge age can be lowered from 12 days to three or four days, aeration energy will be significantly reduced because most of the normal oxygen requirement for endogenous decay will not be required under the shorter MCRT. The microorganisms will require oxygen for an average of only three days compared to 12 before they are removed from the activated sludge system.

The population of microorganisms in the mixed liquor will be active in waste assimilation and reproduction. Most will not enter the endogenous phase when oxygen is consumed but little or no waste is removed.

This operating mode uses less aeration

energy by reducing the potential for a "non-working" microbial population to develop in the aeration tanks. Furthermore, the sludge will be organically rich and should yield more biogas than 12-day sludge when anaerobically digested. If incinerated, the sludge should have a higher heat content.

Drawbacks

This concept has several drawbacks and costs. It cannot be used in WWTPs that rely on biological nitrification because the shorter MCRT is insufficient to sustain this process at normal wastewater temperatures. The short-MCRT solids will be more difficult to settle.

Alternatives to gravity settling may be needed and clarifiers may require chemicals to promote flocculation and reduce suspended solids in the final effluent to meet WWTP discharge permit requirements.

If one-third of the solids are removed from the system daily instead of one-twelfth, there is an increased potential for solids washout. In addition, the treatment plant and sludge management system must be capable of handling the increased sludge load.

Additional Costs

The added costs of chemicals and energy for processing greater quantities of sludge must be compared to the expected energy savings from reduced sewage aeration; increased methane production during sludge digestion; or lower auxiliary fuel consumption and more recoverable heat if the sludge is incinerated.

AERATION SYSTEM CONTROLS

In the activated sludge process, surface aerators or submerged air diffusers continuously disperse air into the aeration tanks to support the living biomass population and to maintain proper mixing. Due to oversized equipment, inefficient operation, or lack of controls, the amount of air delivered to the aeration basins is usually much more than required for mixing and biological activity.

This excess air represents wasted energy, and highly aerated sewage may lead to sludge settling problems and solids carryover into the plant effluent.

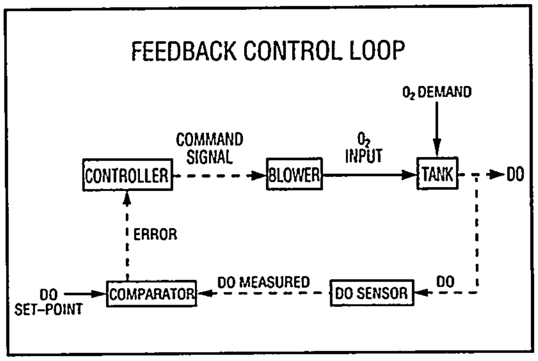

Figure 9. Diagram of a control loop for adjusting the operation of air blowers in relation to a dissolved oxygen concentration set point in a treatment plant's aeration basins.

Controls Research

According to research on the aeration process at WWTPs, the process has been controlled through continuous monitoring of sewage treatment variables and data feedback to a control center where programmable controllers or computers adjust the operation of the aeration equipment as shown in Figure 9.

For example, remote monitoring instruments periodically or continuously measure the mixed-liquor dissolved oxygen concentration in an aeration basin. The dissolved oxygen reading is used to automatically adjust operation of the aeration system in accordance with the data received by the controller and the requirements of good sewage treatment practice.

If an existing aeration system were retrofit with monitoring and automatic controls to maintain a setpoint concentration of dissolved oxygen in the aeration tanks, aeration energy could be lowered up to 30 percent.

Sensor Maintenance

Remote sensor biofouling as well as sensor placement may reduce the effectiveness of this energy-saving measure. Operators must spend the time to keep the sensors properly maintained and calibrated, and must be trained to work with the automatic system to avoid unnecessary override that might reduce energy savings.

DSM COSTS AND BENEFITS

Effluent Hydropower

The costs to construct an effluent hydropower project are extremely site specific, ranging from less than $1,500 to more than $8,500 per kW of installed capacity. The actual value of the purchased electricity displaced by effluent hydropower generation may be only $.06 per kWh or less, although the statewide average cost is $.09 per kWh.

This difference may be attributed to the unit cost of the energy replaced by effluent hydropower, which is the least expensive in the standard utility rate structure for the WWTP; some fixed charges for electric service will remain; and the cost of standby electricity needed by the WWTP when the hydropower is out of service.

Using $.06 per kWh as the statewide average value of avoided electricity purchases due to effluent hydropower generation, smaller effluent hydro facilities would not be economically attractive because their annual costs would be higher than $.06 per kWh.

An installed capacity of at least 300 kW would be required to keep annual costs for the hydro facility below $.06 per kWh. For example, a WWTP effluent flow of 60 million gallons per day (MGD) with a head of 50 feet or a flow of 200 MGD at 15 feet of head will provide a 300 kW generating capacity. WWTPs within the highlighted range of discharge flow and head conditions given in Table 1 may be able to construct and operate an effluent hydropower project for less than $.06 per kWh. Effluent hydropower installed at WWTPs outside this range of flow and head will generally not be cost effective at $.06 per kWh.

Low-flow/high-head and high-flow/low-head combinations may also be feasible. New technology developments in small-scale hydropower equipment over the past 10 years have lowered the cost of low-head hydropower.

For all WWTPs in New York State where effluent hydropower may be feasible, the total installed electric capacity of these sites would be about 4,000 kW.

Cogeneration

Figure 10 illustrates the energy requirements for trickling filter and activated sludge WWTPs as a function of plant influent flow rate. For WWTPs that use anaerobic sludge digestion, the resulting biogas could be used as a fuel for on-site cogeneration. By using all the biogas as a fuel, a typical trickling filter WWTP could meet its average energy requirements, including heating normally loaded digesters through cogeneration.

For an activated sludge plant, the biogas must be supplemented with natural gas (75 per-

TABLE 1

Effluent Hydropower
Kilowatt Output as Function of Head and Flow

DISCHARGE FLOW (MGD)	HEAD (FT)									
	5	10	15	20	25	30	35	40	45	50
10	5	10	16	21	26	31	37	42	47	52
20	10	21	31	42	52	63	73	84	94	105
30	16	31	47	63	79	94	110	126	142	157
40	21	42	63	84	105	126	147	168	189	210
50	26	52	79	105	131	157	184	210	236	262
60	31	63	94	126	157	189	220	252	283	315
70	37	73	110	147	184	220	257	294	330	367
80	42	84	126	168	210	252	294	336	378	420
90	47	94	142	189	236	283	330	378	425	472
100	52	105	157	210	262	315	367	420	472	525
110	58	115	173	231	288	346	404	462	519	577
120	63	126	189	252	315	378	441	504	566	629
130	68	136	205	273	341	409	477	545	614	682
140	73	147	220	294	367	441	514	587	661	734
150	79	157	236	315	393	472	551	629	708	787
160	84	168	252	336	420	504	587	671	755	839
170	89	178	267	357	446	535	624	713	802	892
180	94	189	283	378	472	566	661	755	850	944
190	100	199	299	399	498	598	698	797	897	997
200	105	210	315	420	525	629	734	839	944	1049

POTENTIAL ECONOMICAL FEASIBILITY

cent biogas/25 percent natural gas) as a cogeneration fuel to provide that plant's average energy requirements. These energy supply and demand relationships are shown in Figure 11.

Figures 12 and 13 show that the average annual cost of electricity generated by on-site cogeneration, using various combinations of biogas and natural gas as fuel, ranges from about $.023 to $.092 per kWh depending on how much biogas is available.

These estimates do not include alternative or back-up power supply, new buildings or power-

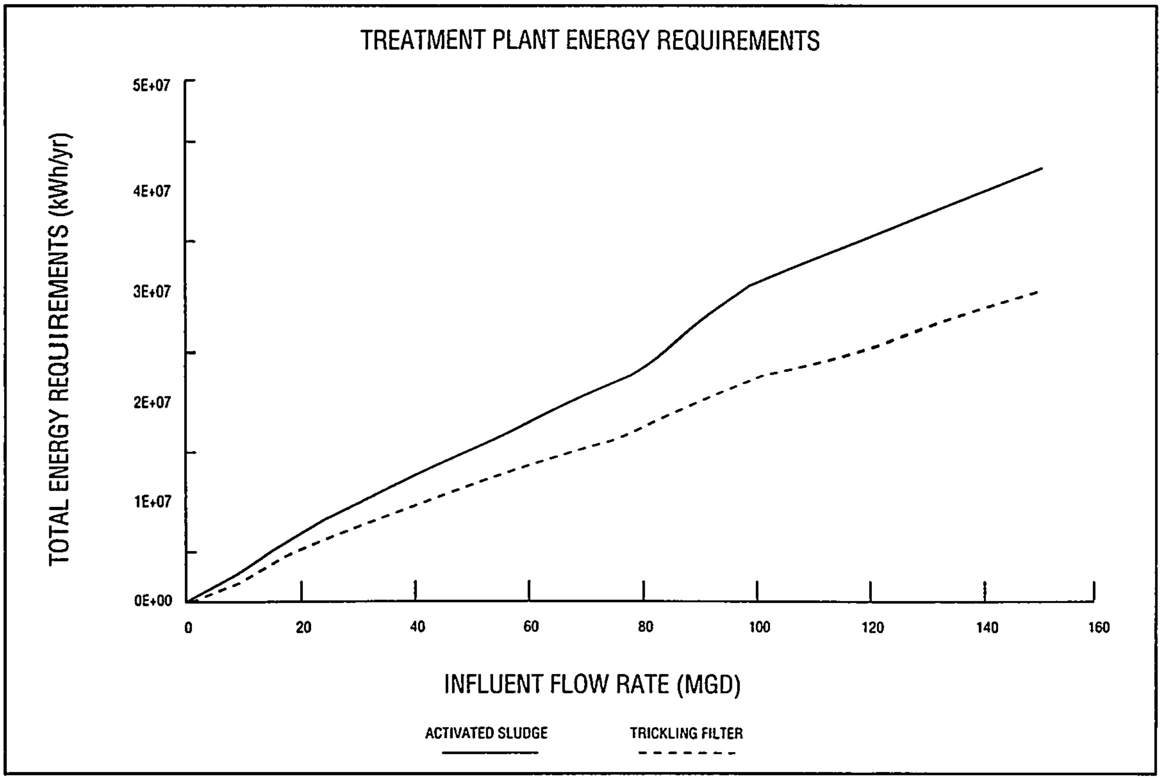

Figure 10. Graph shows the total amount of energy needed to operate a typical activated sludge or trickling filter treatment plant for a range of plant sizes.

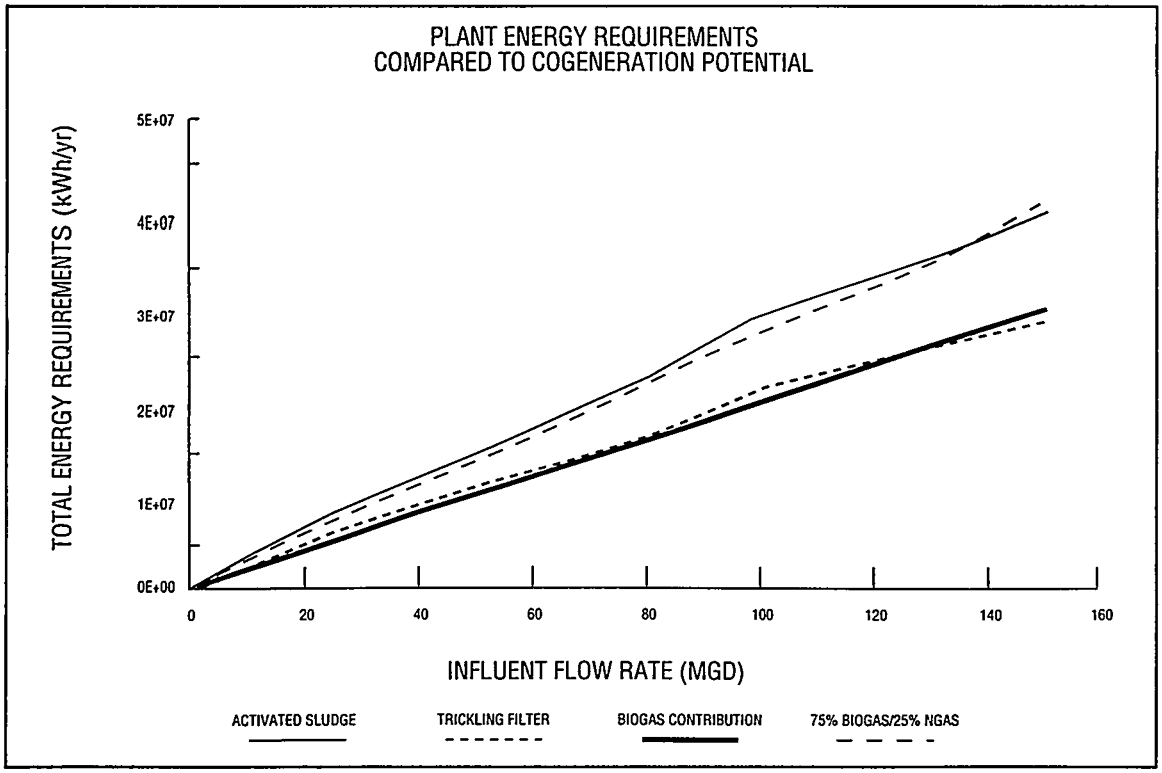

Figure 11. Graph shows that on-site cogeneration at treatment plants with sludge digestion could provide the energy needed to operate a trickling filter plant using only biogas as a fuel and an activated sludge plant when biogas fuel is supplemented with natural gas.

houses, and possible fuel clean-up and air pollution control equipment, which are all highly site-specific and could easily double the cost of generation.

The total installed capacity of cogeneration at all New York State WWTPs with anaerobic digesters would be about 85,000 kW if all biogas was recovered and used for fuel.

Gas-Turbine Cogeneration

Gas-turbine cogeneration offers an opportunity to produce steam by recovering exhaust heat. Using an electrical generating capacity of 3000 kW as the minimum for installing a gas turbine, a WWTP would need an average flow of at least 45 MGD to consider this cogeneration option.

Table 2 lists the annual cost for drying, hauling, and disposing of sludge for four WWTP sizes. The annual sludge management savings for drying sludge from 20 percent or 25 percent solids content to as high as 80 percent solids content are given in Table 3.

Fine-Pore Aeration

Cost estimates for constructing a fine-pore

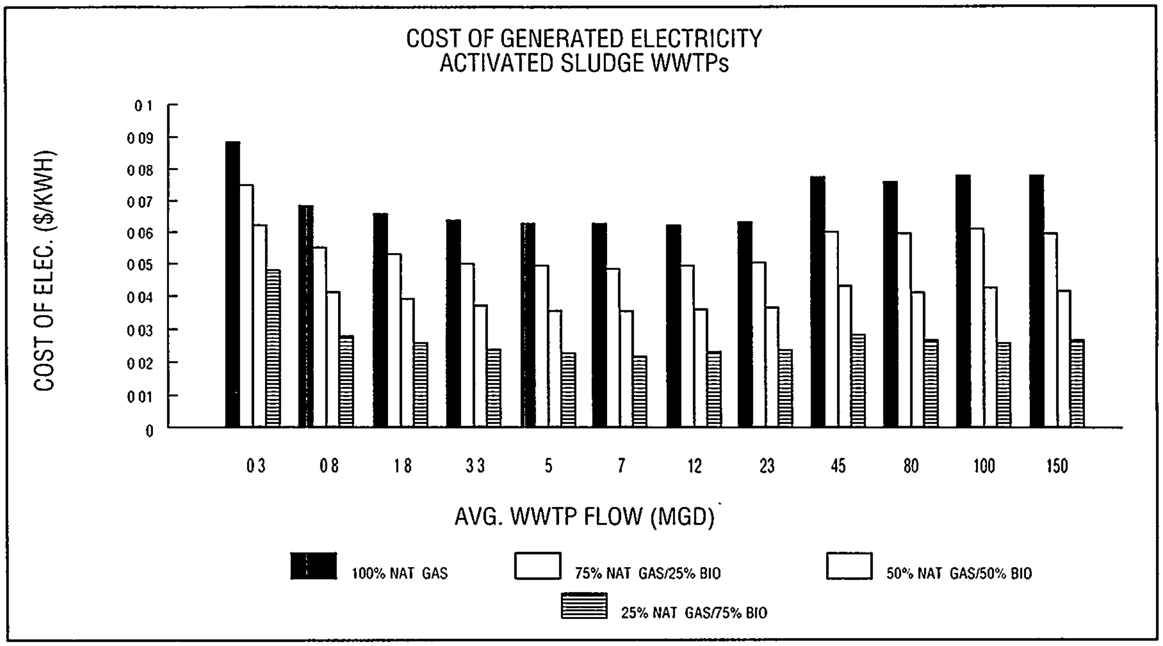

Figure 12. Graph shows the costs of electricity provided by on-site cogeneration for a range of activated sludge treatment plant sizes using various combinations of natural gas and biogas fuels.

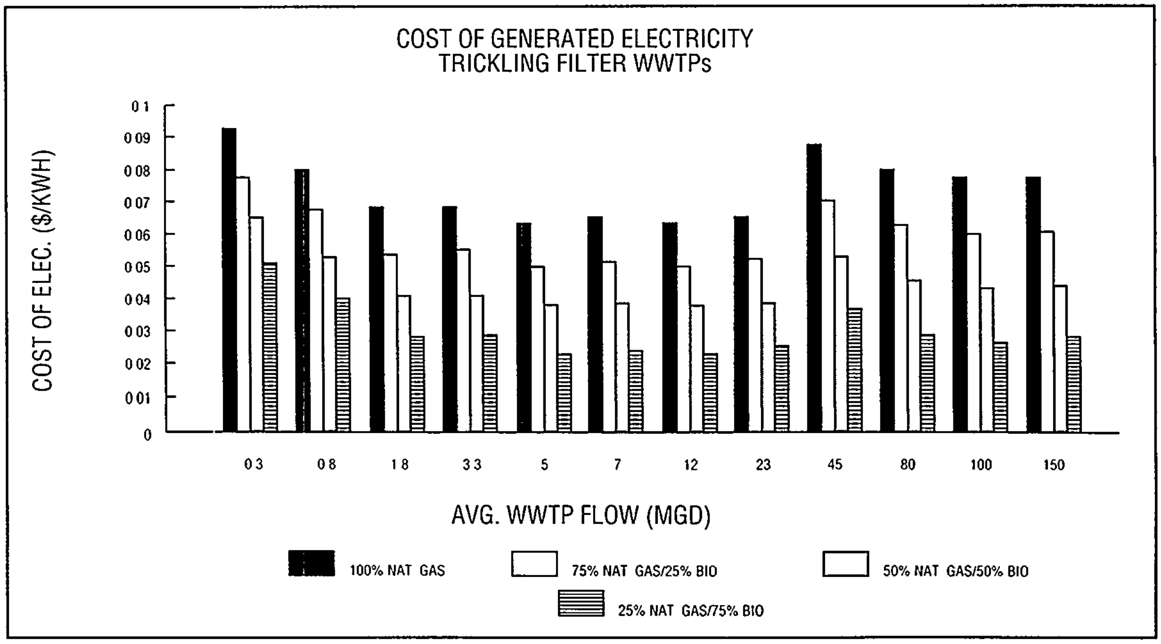

Figure 13. Graph shows the costs of electricity provided by on-site cogeneration in a range of trickling filter treatment plant sizes using various combinations of natural gas and biogas fuels.

aeration system fall into two distinct categories. For WWTPs with a flow of one MGD or less, the cost is about $35,000 per year per MGD. For the larger plants with capacities of five MGD or more, annualized capital costs are reduced $10,000 to $11,000 per MGD. The higher cost per MGD for the smaller WWTPs is due to a higher fixed percentage of total construction cost.

The installed cost of coarse-bubble aeration is lower than fine-pore systems.[12] Mechanical aeration is lower in initial cost than both the diffused air systems.[9] When operating at peak efficiency, the energy cost of fine-pore aeration would be 40 to 50 percent less than for coarse bubble or mechanical aerators.

The capital costs to retrofit coarse-bubble and mechanical aeration with a fine-pore system, and the estimated payback period based on energy savings, are listed in Tables 4 and 5.

Payback for replacing coarse-bubble with fine-pore aeration is five to seven years for most WWTPs. If mechanical aeration is removed to install a fine-pore system, the payback period would be four to five years.

As noted previously, smaller WWTPs have a much higher specific cost for installing fine-pore aeration compared to larger plants, resulting in a payback period two to three times as long.

Sludge Age Reduction

Decreasing the sludge age in an activated sludge wastewater treatment process will reduce the amount of oxygen required for sewage aeration but will increase waste sludge volume.

The additional biomass that has been removed from the aeration process must be properly managed, however, at increased cost.

The aeration cost will decrease and sludge management cost will increase to produce a net

TABLE 2

Sludge Drying, Hauling & Disposal Annual Costs

DEWATERED, DIGESTED, PRIMARY + ACTIVATED SLUDGE

Flow Rate (MGD)	20% Solids (cyd/yr)	20% Solids (tons/yr)	Hauling & Disposal ($/yr)	25% Solids (cyd/yr)	25% Solids (tons/yr)	Hauling & Disposal ($/yr)*	Drying, Hauling & Disposal ($/yr)**	40% Solids (cyd/yr)	40% Solids (tons/yr)	Drying, Hauling & Disposal ($/yr)	60% Solids (cyd/yr)	60% Solids (tons/yr)	Drying, Hauling & Disposal ($/yr)	80% Solids (cyd/yr)	80% Solids (tons/yr)	Drying, Hauling & Disposal ($/yr)
45	43,820	38,034	$3,651,278	35,056	30,427	$2,921,022	$3,302,226	21,910	19,017	$2,206,843	14,607	12,678	$1,598,297	10,955	9,509	$1,294,024
80	77,903	67,616	$6,491,160	62,322	54,093	$5,192,928	$5,695,732	38,951	33,808	$3,748,384	25,968	22,539	$2,666,524	19,476	16,904	$2,125,594
100	97,378	84,520	$8,113,950	77,903	67,616	$6,491,160	$7,223,873	48,689	42,260	$4,789,688	32,459	28,173	$3,437,363	24,345	21,130	$2,761,201
150	146,067	126,780	$12,170,925	116,854	101,424	$9,736,740	$10,540,057	73,034	63,390	$6,888,780	48,689	42,260	$4,860,292	36,517	31,695	$3,846,048

*If sludge was dewatered to 25% rather than typical 20%
**If 20% sludge was dried to 25% solids.

NOTES:
[1] Average hauling cost = $0.13/ton/mile; Average tipping fee for disposal = $70./ton.
[2] Assumes a 200 mile hauling distance.

TABLE 3

Annual Cost Savings for Sludge Drying

DEWATERED, DIGESTED, PRIMARY + ACTIVATED SLUDGE

	1	2	3	4	5	6	7	8	9	10	11	12	13
Flow Rate (MGD)	20% Hauling & Disposal ($/yr)	25% Hauling & Disposal ($/yr)*	25% Drying, Hauling & Disposal ($/yr)**	25% Dry vs. 20% Dew Savings [1] ($/yr)	40% Drying, Hauling & Disposal ($/yr)	40% Dry vs. 20% Dew Savings[1] ($/yr)	40% Dry vs. 25% Dew Savings [1] ($/yr)	60% Drying, Hauling & Disposal ($/yr)	60% Dry vs. 20% Dew Savings [1] ($/yr)	60% Dry vs. 25% Dew Savings [1] ($/yr)	80% Drying, Hauling & Disposal ($/yr)	80% Dry vs. 20% Dew Savings [1] ($/yr)	80% Dry vs 25% Dew Savings [1] ($/yr)
45	$3,651,278	$2,921,022	$3,302,226	$349,051	$2,206,843	$1,444,434	$714,179	$1,598,297	$2,052,981	$1,322,725	$1,294,024	$2,357,254	$1,626,998
80	$6,491,160	$5,192,928	$5,695,732	$795,428	$3,748,384	$2,742,776	$1,444,544	$2,666,524	$3,824,636	$2,526,404	$2,125,594	$4,365,566	$3,067,334
100	$8,113,950	$6,491,160	$7,223,873	$890,077	$4,789,688	$3,324,262	$1,701,472	$3,437,363	$4,676,587	$3,053,797	$2,761,201	$5,352,749	$3,729,959
150	$12,170,925	$9,736,740	$10,540,057	$1,630,868	$6,888,780	$5,282,145	$2,847,960	$4,860,292	$7,310,633	$4,876,448	$3,846,048	$8,324,877	$5,890,692

*If sludge was dewatered to 25% rather than typical 20%
**If 20% sludge was dried to 25% solids.

NOTES:
[1] Calculations based on cost to haul & dispose dewatered sludge minus cost to dry, haul & dispose dried sludge.
(For example: Column 4 = Col. 1 - Col. 3; Col. 6 = Col. 1 - Col. 5; Col. 7 = Col. 2 - Col. 5, etc.)
[2] Average hauling cost = $0.13/ton/mile; Average tipping fee for disposal = $70./ton.
[3] Assumes a 200 mile hauling distance.

cost savings for a broad size range of WWTPs as seen in Table 6.

Aeration System Controls

Aeration system controls could be applied to either surface aerators or diffused air systems, but are more likely to be installed on blowers or compressors that provide air to coarse-bubble or fine-pore diffusers. The capital cost of a control system for coarse-bubble aerators is higher than for fine-pore aerators.

A key component of the control system, variable-speed drives for blower or compressor motors, would be larger and more expensive for coarse-bubble aeration. According to control system manufacturers, WWTPs can expect an energy savings of at least 20 percent using automated control instead of manually operating aerators. Smaller WWTPs with less than one MGD of flow will probably not find aeration system controls economical.

The cost of the system controller and associated wiring is about the same for WWTPs in the size range of one to 20 MGD. This cost is about 60 percent of the total construction cost for a one-MGD WWTP but only 20 percent of the total for a 20-MGD plant. Payback periods for control systems installed at a one-MGD plant are five to 12 years depending on the type of aeration system and the expected energy savings.

A payback from energy savings of one to three years is possible for coarse-bubble aeration with controls, and two to four years with fine-pore control systems installed at WWTPs more than five MGD in size (Tables 7 and 8).

ENERGY IMPACTS STATEWIDE

Cogeneration

On-site cogeneration has no theoretical limits; it could be implemented at most New York State WWTPs assuming there are uses for the electricity and heat energy products. Cost data from Figures 12 and 13 show that cogeneration will probably be economical only if on-site anaerobic sludge digesters produce biogas for some or all the fuel, or the recovered heat has a high-value use such as sludge drying (Table 3).

Referring to Figure 11, it is assumed that cogeneration at trickling filter WWTPs, using biogas from anaerobic sludge digestion as fuel, will be cost-effective and can provide all the

TABLE 4

Retrofit Coarse Bubble with Fine Pore Aeration

Plant Flow (MGD)	Blowers & In-Tank Equipment ($)	Demolition ($)	Total Construction ($)	Annual Capital Cost ($/year)	$/MGD	HP Reduction (HP)	Annual Power Savings ($/year)	%	Payback Period (yrs)
1	$105,000	$9,000	$114,000	$10,800	$10,800	20	$11,760	29	9.7
5	$350,000	$37,000	$387,000	$36,500	$7,300	130	$76,400	43	5.1
10	$650,000	$78,000	$728,000	$68,700	$6,870	190	$111,700	35	6.5
20	$1,290,000	$154,000	$1,444,000	$136,300	$6,815	435	$255,700	41	5.6
50	$4,220,000	$360,000	$4,580,000	$432,400	$8,648	1,095	$643,800	43	7.1
100	$7,380,000	$690,000	$8,070,000	$761,800	$7,618	2,200	$1,293,400	43	6.2

Notes:
1. Annual capital cost based on 7% interest for 20 years bonding (.0944)
2. Power cost based on $.09/kWh

TABLE 5

Retrofit Mechanical with Fine Pore Aeration

Plant Flow (MGD)	Blowers & In-Tank Equipment ($)	Building & Air Piping ($)	Demolition ($)	Total Construction ($)	Annual Capital Cost ($/year)	$/MGD	HP Reduction (HP)	Annual Power Savings ($/year)	%	Payback Period (years)
1	$105,000	$130,000	$6,000	$241,000	$22,800	$22,800	25	$14,700	33	16.4
5	$350,000	$250,000	$25,000	$625,000	$59,000	$11,800	200	$117,600	53	5.3
10	$650,000	$370,000	$55,000	$1,075,000	$101,500	$10,150	400	$235,200	53	4.6
20	$1,290,000	$570,000	$100,000	$1,960,000	$185,000	$9,250	875	$514,400	58	3.8
50	$4,220,000	$1,100,000	$280,000	$5,700,000	$538,000	$10,760	2,275	$1,337,500	61	4.3
100	$7,380,000	$2,000,000	$550,000	$10,030,000	$946,800	$9,468	4,560	$2,680,900	61	3.7

Notes:
1 Annual capital cost based on 7% interest for 20 years bonding (.0944)
2 Power cost based on $.09/kWh

TABLE 6

Net Savings at SRT = 3 Days

Plant Flow (mgd)	Increased Solids Cost ($/yr)	Decreased Aeration Cost ($/yr)	Net Savings ($/yr)
1	7,010	8,800	1,790
5	35,100	43,500	8,400
10	70,200	86,400	16,200
20	140,400	173,400	33,000
50	349,400	433,300	83,900
100	698,800	866,600	167,800

electricity for plant operations and heat energy for maintaining temperature in the digesters.

It is assumed that cogeneration at activated sludge WWTPs will be cost-effective using biogas supplemented with 25 percent natural gas as fuel, and can provide the plant and digesters with the required amounts of electricity and heat energy.

About 130 of the WWTPs in New York State use either activated sludge or a trickling filter for wastewater treatment, and anaerobically digest sludge[3].

Using rule-of-thumb estimates for energy use per MGD of flow, these plants should use about 750 million kWh of electricity annually.[2] This energy represents about 85,000 kW of electric generating capacity that could be provided by cogeneration.

Approximately 270 million cubic feet of natural gas per year would be purchased as an auxiliary fuel.

Sludge Drying

Sludge drying produces energy savings by using less fuel for hauling and disposing the sludge. If the sludge solids content was doubled from 20 percent to 40 percent solids before hauling and disposing the material at a site 100 miles away, fuel savings would be about 2.7 million gallons per year based on a fuel use of 0.1 gallons per ton per mile.

Using 225 Btu/lb. for landspreading a 20 percent-solids sludge compared to 90 Btu/lb. for a 40 percent-solids material, an additional 800,000 gallons of fuel could be saved annually when landspreading a drier sludge product.

Effluent Hydropower

If effluent hydropower installations are limited to WWTPs with sufficient flow to generate about 300 kW of electric capacity, only eight treatment plants in New York State meet this criterion. The total electric capacity from

TABLE 7

Electrical Power Savings
Fine Pore Aeration with Controls

Plant Flow (MGD)	Power Cost No Controls ($/yr)	20% Annual Savings ($/yr)	25% Annual Savings ($/yr)	30% Annual Savings ($/yr)	Net Savings @ 20%	Net Savings @25%	Net Savings @ 30%
1	$29,400	$5,900	$7,400	$8,800	$4,300 (12.1*)	$5,800 (9.0*)	$7,200 (7.2*)
5	$102,900	$20,600	$25,700	$30,900	$18,300 (5.5)	$23,400 (4.3)	$28,600 (3.5)
10	$205,800	$41,200	$51,500	$61,700	$36,600 (3.7)	$46,900 (2.9)	$57,100 (2.4)
20	$367,400	$73,500	$91,900	$110,200	$67,700 (2.8)	$86,100 (2.2)	$104,400 (1.8)
50	$867,200	$173,400	$216,800	$260,200	$161,800 (2.8)	$205,200 (2.2)	$248,600 (1.8)
100	$1,728,200	$345,600	$432,000	$518,500	$328,200 (1.6)	$414,600 (1.3)	$501,100 (1.1)

Notes:
1 Net savings equals annual power savings minus O&M for control system
*Payback period (yrs)

TABLE 8

Electrical Power Savings
Coarse Bubble Aeration with Controls

Plant Flow (MGD)	Power Cost No Controls ($/yr)	20% Annual Savings ($/yr)	25% Annual Savings ($/yr)	30% Annual Savings ($/yr)	Net Savings @ 20%	Net Savings @25%	Net Savings @ 30%
1	$41,200	$8,200	$10,300	$12,400	$6,700 (8.4*)	$8,800 (6.4*)	$10,900 (5.1*)
5	$179,300	$35,900	$44,800	$53,800	$33,600 (3.7)	$42,500 (2.9)	$51,500 (2.4)
10	$317,500	$63,500	$79,400	$95,300	$58,600 (3.0)	$74,500 (2.3)	$90,400 (1.9)
20	$623,100	$124,600	$155,800	$186,900	$118,500 (2.2)	$149,700 (1.8)	$180,800 (1.5)
50	$1,511,000	$302,200	$377,800	$453,300	$290,700 (1.7)	$366,000 (1.4)	$441,500 (1.1)
100	$3,021,600	$604,300	$755,400	$906,500	$586,400 (1.4)	$737,500 (1.1)	$888,600 (0.9)

Notes:
1. Net savings equals annual power savings minus O&M for control system
*Payback period (yrs)

The value of displaced energy purchases is probably the key determinant for the economic feasibility of implementing DSM technologies at WWTPs.

these sites is about 4,000 kW assuming a 25-foot generating head is available at each site. Approximately 35 million kWh per year of electricity could be produced at these facilities with an energy cost savings of $3.1 million per year. If lower costs and/or a higher value for the electricity can be achieved so the minimum generating capacity becomes 85 kW per site, the statewide totals for electric capacity and energy will increase to 8,000 kW and 70 million kWh per year, respectively.

Aeration Process

Removing existing coarse-bubble and mechanical aeration equipment and installing fine-pore aeration systems at all WWTPs in New York State that use activated sludge could save from 300 million to 500 million kWh of electricity per year.

Sludge age reduction from 12 to three days could save from 100 million to 200 million kWh annually. Installing aeration system controls that automatically adjust the output of air blowers or compressors in response to the concentration of dissolved oxygen in the aeration tanks could further reduce electricity use from 100 million to 150 million kWh per year.

DSM BARRIERS

Maintenance and Backup Services

Operation and maintenance requirements, and backup electric service are two major factors that would affect the feasibility of on-site cogeneration. WWTP personnel may not be willing or able to perform either routine maintenance or major overhauls and repairs.

These services must then be provided under contract by an outside organization. Backup electric service will be required if most or all of a WWTP's electricity is provided by cogeneration. This backup service may be extremely costly if provided by the utility, and may double the overall cost of cogeneration.

Space Limits

Space limits are a major concern when evaluating sludge dryers. The dryers must be installed within existing structures between dewatering and residuals-processing equipment. The moist air discharged from a sludge dryer must be treated to remove the moisture, odors, and potential air pollutants before release to the atmosphere.

The high-flow/low-head conditions found at most WWTPs in New York State require large generating and related equipment to take advantage of effluent hydropower.

The high cost of this equipment drives up the cost of producing electricity that may exceed its value whether sold to the utility or used at the WWTP.

Mechanical aerators may be difficult to retrofit with fine-pore diffusers. The WWTP site may not be appropriate for constructing a new blower building close to the aeration tanks, and installing new aeration piping between the blower building and the tanks may be impaired by subsurface obstructions.

Process Monitoring

Lowering sludge age will require aggressive process monitoring at an added cost. The primary objectives of wastewater treatment, biochemical oxygen demand (BOD) and total suspended solids (TSS) removal, cannot be sacrificed in favor of energy savings. These treatment parameters must be watched closely through more frequent sampling and testing.

If sewage nitrification is required, the lower sludge age may not provide the proper ammonia removal and, therefore, might not be considered by some WWTPs unless a separate stage nitrification step is added.

Reducing sludge age increases the volume of sludge that must be processed. The existing sludge management facilities may not be able to handle the additional sludge, and new equipment and chemicals might be needed, adding to the cost of operating the WWTP at a lower sludge age.

Dissolved Oxygen Probes

The dissolved oxygen probes in the aeration tanks are the "weak link" in the use of aeration controls. The probes require careful selection, placement in the tanks, and constant calibration and maintenance. Many WWTP operators don't want to use aeration controls due to these requirements. Additional process monitoring is also necessary.

Operators must be sure that by reducing sewage aeration, while at the same time maintaining the proper dissolved oxygen concentration in the aeration tanks, they are providing adequate mixing of the tank contents.

Inadequate mixing can lead to sludge settling in the aeration tanks, reduced mixed liquor retention times, and lower oxygen transfer efficiency.

Installing low-energy equipment in aeration tanks for mixing and proper oxygen transfer may reduce the perceived risk of using aeration controls.

CONCLUSIONS

Effluent Hydropower

Effluent hydropower could be considered for any WWTP with a minimum plant flow of 15 MGD and a vertical drop in the outfall of at least 15 feet. Under these minimum conditions, however, the cost of electricity must be high enough to offset the cost of installing and operating the effluent hydropower system.

System installation costs could be lowered if plant personnel do some of the work and if "off-the-shelf" equipment, such as pumps used as turbines and motors used as generators, can be used. NYSERDA has published a manual to help calculate the energy potential of an effluent hydropower site.[13]

An effluent hydropower system would be constructed only when the value of the energy displaced exceeds the cost of the system. With effluent hydropower, there will be a delay between peak electricity demands at the WWTP and peak generating capability due to the time required for the high flows to be processed through the WWTP before reaching the effluent outfall. The lag time is usually six to eight hours.

On-site effluent storage in lagoons may permit additional flow release for electricity production during the times of high energy cost. Installing a hydropower facility in the influent pipeline would remove the supply and demand time lag; however, the cost to generate the power with untreated sewage may be higher than for treated effluent due to the need for special construction materials and equipment protection.

Cogeneration

Cogeneration is ideally suited for a WWTP, particularly where biogas fuel is available from anaerobic sludge digestion. There is an on-site use for the electricity and thermal energy products of cogeneration. Thermal energy may be used for building heating and cooling, hot water, and wastewater/sludge process needs such as sludge drying. Cogeneration can be installed at any WWTP, but site-specific project economics need to be carefully evaluated. NYSERDA has published four reports on using cogeneration at municipal WWTPs that may be consulted when considering cogeneration opportunities at a WWTP.[14]

Time-of-day energy pricing for WWTPs may provide an opportunity to offset high energy prices through DSM. For example, Niagara Mohawk Power Corporation (NMPC) has offered a special electrical service rate to a limited number of large industrial and commercial customers, including WWTPs, as a DSM incentive.

Under this service classification, the price of electricity purchased by these customers could change hourly based on a complex supply/demand formula. The customers are provided with an electricity price menu every day in the late afternoon that lists 24 hourly prices of electricity for the following day beginning at midnight.

The hourly prices are usually lowest during the late-night and early-morning hours of the day and highest in the late afternoon and early evening. Considerable energy cost savings are possible if electricity is consumed during the low-cost periods and avoided during the most costly hours.

If electricity and natural gas were subject to time-of-day pricing, the decision whether to operate a cogeneration system would be complex. While there could be significant cost advantages, the WWTP operator would need to compare the relative values and quantities of gas and electricity that would be displaced by cogeneration.

The analysis also would consider external costs that could be affected by the cogeneration system such as backup power supply and sludge hauling costs. While electricity cannot be stored directly, natural gas purchased at low prices could be stored at the WWTP for later use, reducing operating costs.

On-site cogeneration has no theoretical limits; it could be implemented at most New York State WWTPs, assuming there are uses for the electricity and heat energy products.

Aeration Process

New technology in diffused-air wastewater aeration systems provides a low-risk opportunity to reduce the cost of operating an activated sludge process at a WWTP. Conversion from coarse-bubble or mechanical aeration to a fine-pore system should lower the energy costs for sewage aeration by at least 25 percent.

Adding a feedback control system that monitors a treatment variable (e.g., dissolved oxygen) and automatically adjusts the operation of the fine-pore aeration system according to the reading of the measured variable could boost the energy savings to 35 percent or more.

Process controls require additional maintenance and frequent calibration that may discourage some WWTPs from considering automation. NYSERDA has published two reports on installing and testing fine-pore aeration systems at municipal WWTPs, and another report on using dissolved oxygen monitors to control aerator operation in an activated sludge process.[15]

Reducing Sludge Age

Reducing the sludge age in the aeration tanks at a WWTP has an energy benefit for the activated sludge process. At a lower sludge age, for example, three days, it is primarily the working biomass in the mixed liquor that is provided with oxygen by the aeration system. The non-working microorganisms are removed from the system as waste sludge.

This sludge should yield more biogas when anaerobically digested and should have a higher heating value when incinerated than older (e.g., 12-day) sludge. More sludge will be produced, however, and chemicals may be required to promote flocculation and settling.

Nitrification will not be possible at most WWTPs when sludge age is three days. This concept has a greater potential for lowering aeration energy costs at WWTPs than aeration controls. More evaluation and testing is needed, however, to confirm projected energy savings.

STATEWIDE ENERGY SAVINGS

The potential statewide energy savings for the DSM technologies discussed in this report are summarized in Table 9.

The value of displaced energy purchases is probably the key determinant for the economic feasibility of implementing DSM technologies at WWTPs. For example, producing 25 percent of a WWTP's electricity needs on-site using effluent hydropower may not be economical because the marginal cost of those displaced kilowatt hours is the least expensive in the rate structure.

TABLE 9

Statewide Energy Impacts of DSM Technologies

Technology	Energy Impact
Cogeneration	85 MW of Utility Power Displaced 0.27 TBtu Natural Gas per Year Purchased for Fuel Up to 3.5 Million Gallons of Fuel Saved per Year After Sludge Drying
Effluent Hydro	8 MW (16 MW Peak) of Utility Power Displaced
Fine-Pore Aeration	45 MW (90 MW Peak) of Utility Power Displaced
Aeration Controls	14 MW (28 MW Peak) of Utility Power Displaced
Sludge Age Reduction	20 MW (40 MW Peak) of Utility Power Displaced

The average cost for all electricity purchases may be $.09 per kWh but the marginal cost of the displaced energy may be only $.055 per kWh.[15]

Similarly, NYSERDA estimates that heat recovered from a cogeneration system and used to displace natural gas purchases for sludge digester heating may have a value of $7.00 per million Btu, while use of that same heat to dry dewatered sludge from 20 percent to 50 percent solids and offset weight-based sludge hauling costs may save the equivalent of $25.00 per million Btu.

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