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Bigger savings from biogas

By optimizing its biogas use, a Virginia utility saves energy and money while increasing the reliability of its nutrient removal process

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During the design of modifications to provide additional nutrient removal at its 57,000-m^3/d (15-mgd) Moores Creek Wastewater Treatment Plant (WWTP) to achieve Virginia's nutrient wasteload allocations, the Rivanna Water and Sewer Authority (RWSA; Charlottesville, Va.) realized that it would need to make additional improvements to its aeration and digestion facilities. The facility's anaerobic digesters were heated by waste heat from the gas engines used to power the aeration blowers. Digester heating needs at times would govern blower operation, adversely affecting nutrient removal performance. Seeking to maintain its nutrient removal capability, as well as the practice of beneficially using biogas generated onsite, RWSA began evaluating options for optimizing its digester heating process. The results of this evaluation have enabled RWSA to achieve significant energy savings, reduce greenhouse gas emissions, and improve treatment performance at its Moores Creek WWTP.

◄ **A combined heat and power system was installed to generate electrical power from biogas and provide digester heating. The system includes a gas-engine-driven generator equipped with engine jacket and exhaust-heat-recovery systems to provide hot water for digester heating.** Hazen and Sawyer

Existing conditions

The Moores Creek WWTP recently was modified from a conventional activated sludge plant to a five-stage enhanced nutrient removal (ENR) process to meet total nitrogen and total phosphorus allocations imposed as part of efforts to improve Chesapeake Bay. Residuals from the treatment plant are thickened and stabilized via anaerobic digestion before dewatering.

The existing facility relied on aeration blowers driven by gas engines and equipped with a system for recovering waste heat. This system was used to provide hot water to heat the anaerobic digesters and buildings onsite. Although they were powered by biogas from the digesters, the engine-driven blowers routinely used natural gas as a supplemental fuel to generate sufficient hot water for heating the digesters. Because of the need to meet digester heating requirements, this process occasionally resulted in excessive aeration, leading to less-efficient energy utilization and reduced performance in terms of nutrient removal potential.

Furthermore, the new five-stage ENR process depends on stricter aeration control for effective performance to achieve oxic, anoxic, and anaerobic conditions in the proper zones. Therefore, the occasional practice of using excessive aeration to improve digester heating was no longer feasible. Meanwhile, because of increased blower discharge pressure and substantial maintenance requirements, the existing aeration blowers had to be replaced.

Developing alternatives

Because the existing method of using digester gas was no longer compatible with the ENR treatment objectives, RWSA explored alternate uses for the biogas. To this end, RWSA considered four alternatives for using biogas at the Moores Creek WWTP:

Alternative 1. Continue the current practice of heating the digesters by means of recovering heat from new blowers driven by gas engines.

Alternative 2. Install new dual-fuel hot-water boilers to use biogas for digester heating. Excess biogas would be sent to new gas-engine-driven blowers.

Alternative 3. Install new dual-fuel hot-water boilers to use biogas for digester heating. Excess biogas would be flared.

Alternative 4. Install a combined heat and power (CHP) system for generating electrical power from biogas and recovered waste heat. Heat recovered through the CHP system would be used for digester heating, with supplemental heating provided by a hot-water boiler.

Under Alternative 1, the two existing gas-engine-driven blowers would be replaced with new engine-driven centrifugal blowers. In total, four new centrifugal blowers would be installed in the existing blower building – two driven by electric motors and two driven by gas engines. Digester and building heating would continue to depend on the gas-engine-driven equipment for hot-water generation at whatever quantity and quality could be furnished, based on blower operating conditions. In cold weather, the heating requirements for the digester process were expected to exceed the capability of the hot-water generation system, causing digester operating temperatures to fall below the recommended operating range. Such an event would require that RWSA sample and analyze its digested solids to demonstrate that it had achieved targets relating to Class B pathogen reduction.

Alternative 2 would include installation of two new hot-water boilers to provide supplemental heat for digestion. Hot water generated by the system would be designed to meet the overall anaerobic digestion heating demand during winter. Biogas in excess of that required for digester heating would be used to power two new gas-engine-driven process air blowers. As in the previous option, the engines would be able to run on digester gas or natural gas. Because waste heat from the engines could no longer be relied on to heat buildings under this alternative, new systems for building heating would be required for the solids pumping station and blower facilities.

One hot-water boiler was provided to supplement digester heating during cold weather. During winter, biogas from anaerobic digestion is used to fire the boiler. Hazen and Sawyer

Existing engine-driven blowers were replaced with high-speed direct-drive centrifugal blowers driven by electric motors. Hazen and Sawyer

Since optimizing the digester heating process at its Moores Creek Wastewater Treatment Plant, the Rivanna Water and Sewer Authority (Charlottesville, Va.) has achieved significant energy savings, reduced greenhouse gas emissions, and improved treatment performance at the facility. RWSA

Alternative 3 also would entail construction of two new hot-water boilers to supplement digester heating demand requirements. However, under this option, the existing engine-driven blowers would be replaced with four electric-motor-driven centrifugal blowers. Biogas in excess of that required for digester heating would be flared.

Alternative 4 would use a CHP system for generating electrical power from biogas and recovery of waste heat. The CHP system would include a gas-engine-driven generator equipped with engine jacket and exhaust-heat-recovery systems to provide hot water for digester heating. One hot-water boiler would be provided to supplement digester heating during cold weather. Individual heating systems would be provided to the buildings that house the solids pump station and the blower facilities. This option also would replace the engine-driven blowers with four centrifugal blowers driven by electric motors.

Analyzing costs, greenhouse gas emissions

Capital costs were estimated for each of these alternatives. Estimates included total project costs for new aeration blowers, blower motors and engines, boilers, gas piping, hot-water piping, a CHP system, and building heating, as applicable. Net present worth costs were developed, including 20-year life-cycle costs for electrical power for aeration and natural gas purchased for digester heating, operation of engine-driven blowers, or both uses. The results of the economic analysis are presented in Table 1 (p. 4).

Figure 1. Optimized monthly biogas utilization – 57,000-m³/d (15-mgd) design flow

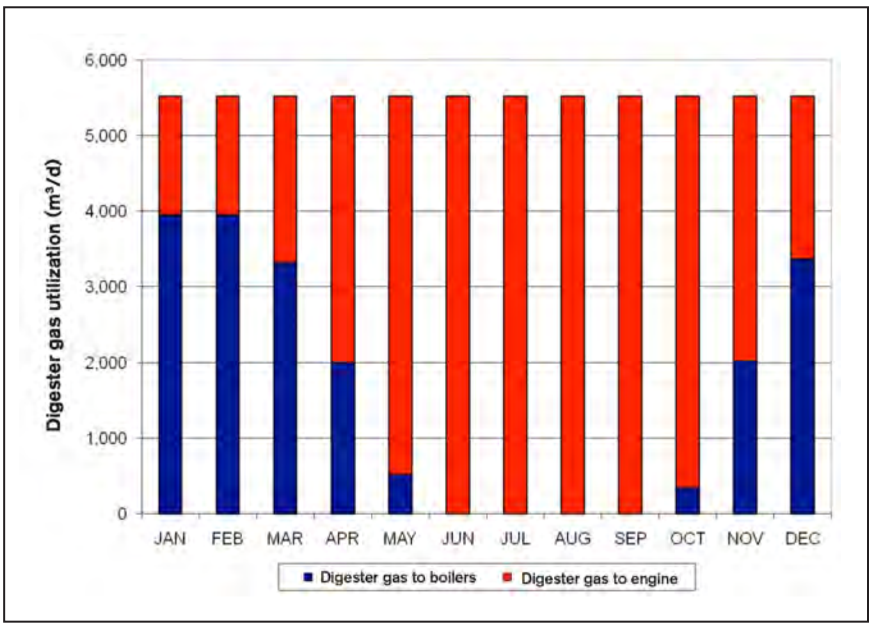
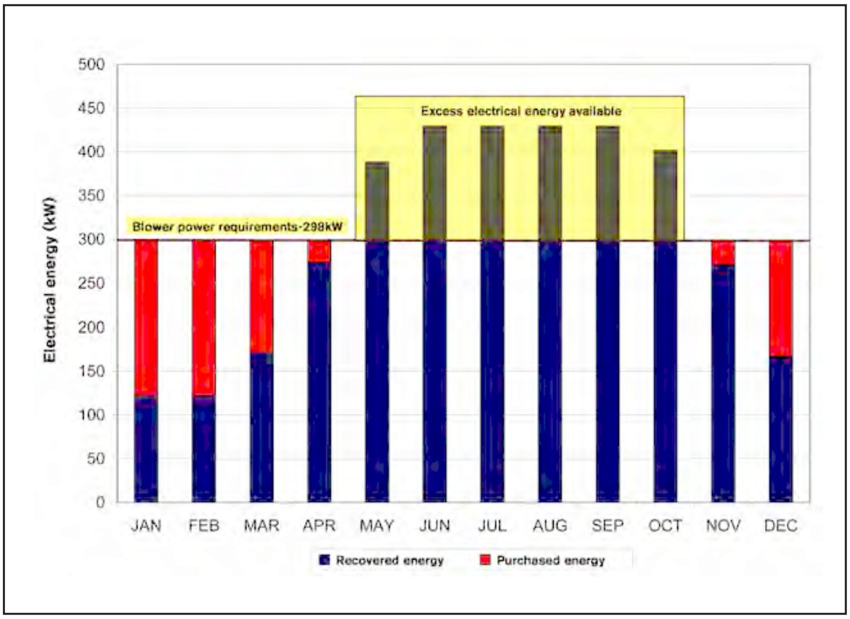


Figure 2. Recovered electric energy balance – 57,000-m³/d (15-mgd) design flow



Evaluating the alternatives

Alternative 1 would require year-round operation of both engine-driven blowers to generate sufficient heat for digester heating. Because the generated biogas would be insufficient to run both blowers during cold weather conditions, natural gas would have to be purchased to operate the blowers enough to heat the digesters. Under this alternative, digester heating would be dependent on the aeration system, and excessive operation of the engine-driven blowers for heat production would result in overaeration of the secondary treatment process. This outcome would be undesirable from the perspective of energy efficiency and process operations – as excessive aeration would impair denitrification and phosphorus removal performance.

Alternatives 2, 3, and 4 would decouple digester heating and aeration, improving efficiency of the aeration and nutrient removal processes. Alternative 3 would result in lower utilization of biogas, because excess gas would be flared. Alternative 4 would enable optimal use of biogas, depending on the season. For example, the evaluation indicated that the most cost-effective benefit would be realized by sending most of the biogas to the hot-water boiler for digester heating from December through March and directing all biogas to the CHP system from June through September (see Figure 1, p. 3). Under this seasonal operating protocol, excess electrical power beyond that required for aeration would be available from the CHP system from May through October (see Figure 2, above). The CHP system would be expected to provide more electrical power than required for aeration on an annual average basis, resulting in a net "credit" when estimating aeration energy costs.

Although Alternative 4 would have the greatest capital cost, the net present worth cost of this alternative would be nearly

Two categories of greenhouse gas emissions, known as Scope 1 and Scope 2, were calculated, and the potential carbon footprints of the four alternatives were compared. Scope 1 emissions included emissions from combustion of purchased natural gas, methane emissions from incomplete combustion of biogas, and nitrous oxide emissions from biogas combustion. Carbon dioxide emissions from biogas combustion were calculated but not included in the overall carbon footprint of each alternative, because these are considered biogenic and are excluded in existing greenhouse gas accounting protocols. Scope 2 emissions included greenhouse gas emissions associated with offsite generation of electrical power used to run the WWTP's aeration system. Table 2 (below) compares the relative carbon footprints of the four alternatives for using biogas.

Table 1. Net present worth (NPW) comparison

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Capital costs	$1,897,500	$2,428,800	$1,859,600	$2,884,200
NPW electric power costs	$0	$1,400,000	$3,266,000	($37,300)[1]
NPW natural gas costs	$2,077,000	$0	$0	$0
Total NPW cost	$3,974,500	$3,828,800	$5,125,600	$2,846,900

[1]Net savings.

Table 2. Comparison of total greenhouse gas emissions

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Scope 1[1] (Mg carbon dioxide/yr)	695	185	437	185
Scope 2[2] (Mg carbon dioxide/yr)	0	581	1377	–26
Total greenhouse gas emissions (Mg carbon dioxide/yr)	695	766	1814	159

[1]Scope 1 includes emissions from combustion of purchased natural gas, methane emissions from incomplete combustion of biogas, and nitrous oxide emissions from biogas combustion.

[2]Scope 2 includes greenhouse gas emissions associated with offsite generation of electrical power used to run the WWTP's aeration system.

During the design of modifications to provide enhanced nutrient removal at its 57,000-m³/d (15-mgd) Moores Creek Wastewater Treatment Plant, the Rivanna Water and Sewer Authority recognized that it would need to make additional improvements to its aeration and digestion facilities. The improvements were needed to maintain nutrient removal capabilities, as well as the beneficial use of biogas generated onsite. RWSA

25% lower than the next lowest option (Alternative 2) and would provide the greatest flexibility to optimize biogas utilization. This option also would have the lowest potential greenhouse gas emissions, because the Scope 2 emissions associated with purchased electrical power for process aeration would be reduced substantially. Furthermore, because the CHP system would provide more electrical power than would be required for aeration, the system could be considered a "credit" in terms of greenhouse gas emissions.

The preferred alternative

Ultimately, RWSA selected Alternative 4 because of its improvements related to overall energy efficiency at the Moores Creek WWTP. Five high-speed direct-drive blowers were installed in 2010 and have been in operation for approximately 18 months. The CHP system began operating in summer 2011. The energy-efficiency improvements at the WWTP already have achieved significant savings by reducing purchases of natural gas and electrical power while optimizing the use of digester gas, an economically and environmentally sustainable alternative energy product.

These improvements have reduced substantially the need to purchase natural gas, decreasing typical natural gas usage from 14.2 GJ/d (13.7 million Btu/d) in 2009–2010 to 2.0 GJ/d (1.9 million Btu/d) in 2011. Since the CHP system began operation, average energy consumption at the Moores Creek WWTP has decreased from a historical average of approximately 690 kWh per million liters of wastewater treated (2600 kWh per million gal treated) to 560 kWh per million liters treated (2100 kWh per million gal treated).

This reduction in energy consumption has occurred despite the switch to operating all electric-motor-driven blowers, replacement of the existing chlorine disinfection system with ultraviolet disinfection, and the additional energy loads associated with the pumping and mixing that occurs during the five-stage ENR process.

The energy improvements have benefited nutrient removal performance by eliminating the dependency of digester heating on operation of the aeration blowers and decreasing the amount of dissolved oxygen that is returned to the anaerobic and anoxic zones. The nutrient removal improvements have resulted in substantial reductions in the amounts of nitrogen and phosphorus discharged from Moores Creek WWTP to the Chesapeake Bay watershed. During the last 6 months of 2011, effluent total nitrogen and total phosphorus concentrations averaged 3.0 and 0.2 mg/L, respectively.

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