

# THE POWER OF DIGESTER GAS

# As this California utility demonstrates, biogasderived electricity can reduce our dependence on foreign fuel supplies

Mark McDannel and Ed Wheless

here are many benefits in using wastewater and solid-waste management byproducts to generate electricity. These byproducts are low-cost sources that can provide enough local power to displace imported power, thus reducing the expense and environmental consequences of burning fossil fuels.

The County Sanitation Districts of Los Angeles County (CSD) has a long history of using biogas to produce electricity. In 1938, digester-gas-fueled onsite internal-combustion engines provided all the power a CSD treatment facility needed. It was so successful that the facility was disconnected from the local electric utility. Ever since, CSD has pursued the economic and environmental benefits of "waste gas." At wastewater treatment plants, CSD personnel use digester gas to generate the electricity needed for plant operations. At landfills, CSD personnel use landfill gas to generate electricity and then sell it to the local power utility.

CSD currently conveys and treats an average of 1.97 million  $m^3/d$  (520 mgd) of wastewater, and about 35% of the reclaimed water is suitable for reuse.

CSD is considered an industry leader in implementing projects that recover and use waste management byproducts (see Table 1, p. 38). Using these byproducts enables CSD to manage its energy resources effectively, conserve fossil fuels, reduce air emissions, and substantially lower costs. Altogether, CSD facilities produce about 127 MW of electrical power via digester gas (23 MW), landfill gas (63 MW), and solid waste (40 MW). The organization sells 97 MW of this power to Southern California Edison Co. (Rosemead, Calif.) and uses 29 MW onsite for daily operations (see figure, p. 39). Several of its water reclamation and solid-waste facilities lack onsite power generators, however, so CSD buys another 12 MW of power from Southern California Edison for its use.

CSD's wastewater treatment plants provide advanced primary, secondary, and in some cases

The Lancaster (Calif.) Water Reclamation Plant sends approximately 60% of its digester gas to a 250-kW microturbine to generate electricity for onsite use.

### **Large-Scale Effort**

CSD — a special-purpose, nonprofit organization formed under the 1923 County Sanitation District Act - currently provides wastewater and solid-waste-management services for more than 5 million people in a 2072-km<sup>2</sup> (800mi<sup>2</sup>) area of Southern California (consisting of 78 cities and unincorporated territory). Its wastewater management system includes 2124 km (1320 mi) of trunk mains, 46 pump stations, and 11 water reclamation facilities with a total design capacity of 2.37 million m<sup>3</sup>/d (625 mgd).



Table 1. CSD's Power-Generating Facilities

Facility	Power-generation technology (fuel type)	Net power production
Joint Water Pollution Control Plant	Combined-cycle gas turbine with waste-heat recovery (digester gas)	22 MW
Valencia Water Reclamation Plant	Internal-combustion engine facility with waste-heat recovery (digester gas)	0.4 MW
Puente Hills Landfill	Steam boiler/turbine power plant (landfill gas)	46 MW
Palos Verdes Landfill	Steam boiler/turbine power plant (landfill gas)	3 MW
Spadra Landfill	Steam boiler/turbine power plant (landfill gas)	7 MW
Puente Hills Landfill	Gas turbine generator (landfill gas)	1 MW
Puente Hills Landfill	Internal-combustion engine facility (8 MW capacity, operating at 6 MW February 2006; landfill gas)	6 MW
Commerce Refuse-to-Energy Facility	Mass burn/steam turbine plant (refuse)	10 MW
Southeast Resource Recovery Facility at Long Beach	Mass burn/steam turbine plant (refuse)	30 MW
Calabasas Landfill	Microturbine power plant (landfill gas)	250 kW
Lancaster Water Reclamation Plant	Microturbine with waste-heat recovery (digester gas)	200 kW
Palmdale Water Reclamation Plant	Fuel cell with waste-heat recovery (digester gas)	225 kW
Total generating capacity		126 MW

CSD = County Sanitation Districts of Los Angeles County.

tertiary treatment of domestic and industrial wastewater. Wastewater solids are conveyed to regional processing centers, where they are anaerobically digested. The digester gas generated consists of about 60% methane and 40% carbon dioxide. CSD has found several ways to convert this gas into electricity.

# Total Energy Facility

The Joint Water Pollution Control Plant (JWPCP) in Carson, Calif., is CSD's largest wastewater treatment plant. It processes up to 1.32 million m<sup>3</sup>/d (350 mgd) of wastewater and all the solids generated both onsite and at five treatment plants located upstream along the San Gabriel River. Because JWPCP treats so much solids, it can produce enough digester gas to meet more than 90% of its electrical requirements.

In the mid-1970s, JWPCP was an advanced primary treatment system that used digester gas to heat digesters, pump wastewater, and generate about half of the plant's electrical needs in reciprocating gas engines that were more than 20 years old. The local power utility supplied the rest of the electricity, and slightly more than half of the digester gas was sold to a nearby oil

Meanwhile, a CSD project team was designing a secondary treatment system for half of the plant flow, which would increase power demand dramatically. CSD decided to develop a new

power-generation facility to meet this demand, so the project team compared spark- and compression-ignition reciprocating engines, simple-cycle gas turbines, steam boilers, and combined-cycle gas turbines. Reciprocating engines were efficient and inexpensive but were rejected because their high air emissions were unacceptable to the local permitting agency. The steam boiler and simplecycle gas turbine were rejected because of their low thermal efficiencies.

Ultimately, CSD decided to build the Total Energy Facility, which uses combined-cycle gas turbines to produce both electricity and steam. The steam heats digesters and drives a steam turbine that generates more electricity. The facility, which cost about \$45 million to build, was completed in the early 1980s. Federal and state grants covered 95% of the costs, partly because of the advanced generation efficiency. The facility includes three fuel-gas compressors, three gasturbine generators, three dual-pressure heat-recovery steam generators, and one steam turbine generator. The gas turbines were standard natural-gas-fired turbines with a custom-configured fuel system specifically designed for lower-Btu digester-gas fuel. Special design features include

- larger fuel nozzles to deliver the required fuel volume,
- "black start" capability via diesel fuel,
- water injection to reduce nitrogen oxide (NOx) emissions, and

the ability to mix digester gas with natural gas to meet JWPCP power loads when digester-gas production is low.

Normally, two of the three gas turbines operate continuously, each producing about 6.5 MW of electricity. The third turbine is a standby unit. Together with the 2.5 MW generated by the steam turbine, the facility provided enough power (14 MW on average) between 1986 and 2001 to operate the entire JWPCP and sell a slight excess to the local power utility.

The digester-gas pretreatment system includes venturi scrubbers to remove particulate, filters to remove oil and grease, and cooling coils for the initial stage of moisture removal. A refrigerant gas chiller and dehydration unit downstream of the fuel-gas compressors removes essentially all moisture from the high-pressure digester gas (2689 kPa [390 lb/in.2]). Clean, dry digester gas then is combusted in the gas turbines. Pretreating the gas prevents potential operating problems, reduces plant maintenance and equipment downtime, and improves overall plant efficiency. During this period, the two-turbine system achieved up to 98% availability with an overall thermal efficiency near 40%.

In 2001, CSD began repowering the generating facility to increase its power-generation capability dramatically. The original gas turbines were upgraded to increase turbine output from 6.5 to 9.9 MW per unit. Not counting the 746-kW (1000-hp) fuel-gas compressor power draw, the

simple-cycle units each generate 9.15 MW. Since this upgrade, annual average power production has been 20.5 MW.

A new steam turbine also is being added that will increase power production from turbine waste heat to 7.1 MW. The once-through heatrecovery steam generators also are being replaced with conventional drum boilers, which are easier to clean. When completed, the facility will be able to produce 26 MW (net) under normal plant conditions (two operating units).

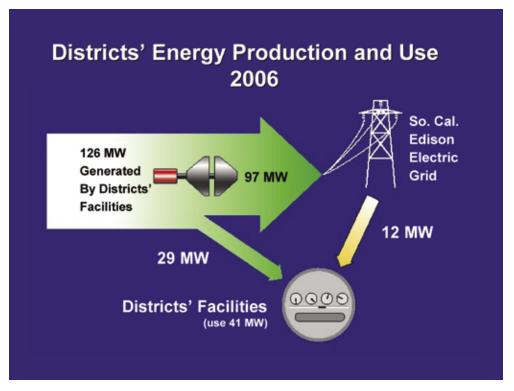
The cost of power production from the facility is about \$0.02/kWh. When compared to current power costs (\$0.12/ kWh), the facility saves more than \$15 million per year.

# **Internal-Combustion Engine Cogeneration** Facility

The Valencia (Calif.) Wastewater Reclamation Plant (WRP) is part of the Santa Clarita Valley Joint Sewerage System, which provides wastewater treatment for Santa Clarita Valley. Valencia provides tertiary treatment for about 64,300 m<sup>3</sup>/d (17 mgd) of wastewater and has solids-processing facilities designed to manage all solids generated by the joint sewerage system. Digester gas is used to heat digesters and generate electrical power via an internal-combustion engine facility.

Valencia's cogeneration facility has two major components: a 500-kW, spark-ignited, four-stroke internal-combustion engine generator and a heatrecovery steam-generator system (which recovers waste heat from engine exhaust gas and the engine-jacket water system). It is designed to run on one fuel (digester gas) and produce less than 0.9 g/bhp-h of NOx emissions (the permit limit). Digester gas is pretreated via an iron-sponge system to remove sulfur compounds but is not treated for particulate and moisture removal. Pretreated gas is compressed to 483 kPa (70 lb/ in.2) before entering the engine fuel system.

The cogeneration facility was constructed in 1987 as part of Valencia's solids-processing facility expansion contract; grant funding covered





The 250-kW fuel cell at the Palmdale (Calif.) Water **Reclamation Plant** has an internal reformer, so digester gas can be injected directly into it.

96% of the construction cost (about \$1 million). Average digester-gas production used to be about 306 m<sup>3</sup>/h (180 ft<sup>3</sup>/min); as a result, the engine did not reach full capacity but did approach 70% availability. By 2001, the unit was operating near 400 kW with an availability of 80%.

The engine has had some mechanical problems related to the precombustion chamber and jacket-water leakage. Because of this, its age, the lack of spare parts, and continuing concern with air emissions, CSD is considering replacing the unit with a modern engine, microturbines, or a cleanup facility that would produce pipelinegrade natural gas for sale.

#### **Microturbine Cogeneration Facility**

The 56,800-m<sup>3</sup>/d (15-mgd) Lancaster WRP provides primary and secondary treatment (aerated oxidation ponds) and serves about 160,000 people. More than 1136 m<sup>3</sup>/d (300,000 gal/d) receive advanced treatment (chemical coagulation to reduce phosphate and dual-media filtration) before being sent to Apollo Lakes Regional Park.

Lancaster's digesters generate about 238 m<sup>3</sup>/h (140 ft<sup>3</sup>/ min) of gas containing 55% methane. Before the microturbines were installed, 90% of this gas was flared, and 10% was used in a boiler to provide heat for the digesters.

CSD installed a 250-kW microturbine in 2005 (see Table 2, below). A microturbine is a small combustion turbine (basically a small jet engine) designed to drive a generator, which produces electricity. Microturbines offer several

potential benefits for WRPs:

- They can operate on digester gas.
- Most emit low levels of air pollutants.
- They produce a hot exhaust gas that can be used to heat the digesters.
- They do not require extensive operator training (the units operate unattended, and maintenance can be contracted out).

Now, 55% to 60% of digester gas is used in the microturbine to generate 198 kW (net) of electricity for use onsite. The microturbine has an integral waste-heat recovery system (turbine exhaust gases heat water, which, in turn, heats the digesters), so the existing boiler is only for backup. The design net electrical- and thermalcycle efficiency is 51%.

The system's total cost was \$720,000, of which 40% was funded by a grant from the California Public Utilities Commission. At the target ca-

Table 2. Summary of Microturbine Design and Performance Parameters

Gross power production (kW)	250
Net power output (kW)	225
Electrical efficiency (LHV)	32%
Combined heat and power efficiency	51%
Nitrogen oxide emissions	9 ppm at 15% oxygen
Capital cost	\$684,000
Cost recovered from California PUC	40%
Annual power purchase savings	\$225,000
Estimated cost of power production: total	\$0.043/kWh
Operation and maintenance	\$0.016/kWh
Capital recovery	\$0.027/kWh

**Table 3. Summary of Fuel-Cell Design and Performance Parameters** 

Gross power production (kW)	250
Net power output (kW)	225
Electrical efficiency (LHV)	47%
Combined heat and power efficiency	73%
Nitrogen oxide emissions (ppm)	<0.3
Capital cost	\$1.9 million
Cost recovered from California PUC	50%
Annual power purchase savings	\$227,000
Estimated cost of power production: total	\$0.093/kWh
Operation and maintenance	\$0.019/kWh
Stack replacement	\$0.016/kWh
Capital recovery	\$0.058/kWh

PUC = Public Utilities Commission.

pacity (90%), the power-production cost is projected to be \$0.043/kWh, of which \$0.016 is for operations and maintenance (O&M) and \$0.027 is for capital recovery. At 90% capacity and the average 2004 retail electricity cost (\$0.127/kWh), microturbine operations are calculated to save \$225,000 per year in retail electric purchases.

The microturbine system includes a gas-pretreatment process to remove siloxanes; it cools digester gas to subzero temperatures (as low as -29°C [-20°F]). The chiller design was based on CSD research showing that gas cooling could remove siloxanes to nondetectable levels.

## **Fuel-Cell Cogeneration Facility**

The 36,000-m<sup>3</sup>/d (9.5-mgd) Palmdale WRP provides primary and secondary treatment (aerated oxidation ponds) and serves about 100,000 people. Up to 22,700 m<sup>3</sup>/d (6 mgd) of effluent is reused to irrigate crops.

Palmdale's digesters generate about 136 m<sup>3</sup>/h (80 ft<sup>3</sup>/min) of digester gas containing 55% methane. Before the fuel cells were installed, 85% of this gas was flared and 15% was used in a boiler to provide heat for the digesters.

Fuel cells offer the same benefits for WRPs as microturbines and have lower (near zero) air emissions but cost significantly more to install. A fuel cell uses the electrochemical reaction between hydrogen and oxygen across a membrane to generate electricity directly. Because electricity is generated without combustion, virtually no air pollution is produced.

Before methane can be used in a fuel cell, it must be reformed into hydrogen. Palmdale's 250-kW molten carbonate fuel cell has an internal reformer, so digester gas can be injected directly into it (see Table 3, above).

The fuel cell uses 70% to 80% of the digester gas produced to generate 225 kW (net) for use onsite. The system includes a waste-heat recovery system, in which water is heated by fuel-cell exhaust gases to provide all necessary heat for the digesters. The design net electrical- and thermal-cycle efficiency is 73%.

The fuel cell requires protection from several contaminants found in digester gas, including chlorine, siloxanes, and sulfur (primarily in the form of hydrogen sulfide). This is accomplished by pretreating the gas in a fuel skid that includes filtration, refrigeration, and three activated carbon vessels (one containing coconut shell carbon, one containing activated carbon, and one containing impregnated carbon).

The system's total cost was \$1.9 million, of which 50% was funded via a grant from the California Public Utilities Commission. Power-production cost at target capacity (90%) is projected to be \$0.093/kWh, of which \$0.035 is for O&M, and \$0.056 is for capital recovery. Scheduled replacement of the fuel-cell stack accounts for \$0.016 of the O&M total. At 90% capacity and the 2004 retail electricity cost (\$0.128/kWh), fuel-cell operations are projected to save \$227,000 per year in retail electricity purchases.

#### **Proven Effectiveness**

Since 1938, CSD has been using biogas and biomass to generate green power. Its success demonstrates that biogas and biomass can be used safely and reliably as low-cost fuels for power-generation technologies (steam boiler-turbine generators, gas turbine generators, internal-combustion engine generators, microturbines, and fuel cells). Using the waste gases and refuse as fuels conserves fossil fuels, reduces air emissions, and provides substantial economic benefit.

Mark McDannel is a supervising engineer and **Ed Wheless** is a division engineer at the County Sanitation Districts of Los Angeles County (Whittier, Calif.).