CATERPILLAR®

DEALING WITH LANDFILL FUEL: EVALUATING FUEL TREATMENT OPTIONS

Michael A. Devine
Gas Product/Marketing Manager
Electric Power Division

2006

ABSTRACT

Dealing with fuel contaminants in landfill-gas-to-energy systems is essentially a matter of economics: weighing the costs of removal against the benefits of improved service intervals, performance and reliability. This paper highlights the most common contaminants found in landfill gas and describes the effect they have on engine component life, the cost of power generation, and engine emissions and emission control techniques.

Users have options when dealing with landfill gas contaminants. These range from dealing with contaminants before they get to the generating equipment, to selecting engines designed to operate with the contaminants. The external control option requires installation of equipment to reduce fuel contaminants, in exchange for higher ancillary equipment capital and maintenance costs. The internal engine control option involves engine manufacturers' design innovations in component metallurgy and other techniques that limit acid formation and keep engines operating safely.

The most favorable approach for a given application depends on factors such as gas composition, local emissions requirements, local power market conditions, and the site owner's performance and reliability expectations. Case studies at North American landfills illustrate extensive field experience with engines using internal modifications to limit the effects of corrosive fuel contaminants.

OVERVIEW

When challenged with the fuel contaminants in landfill-gas-to-energy projects, there are two fundamental approaches: pre-treat the fuel for improved service intervals, or operate an engine that is designed to minimize the impact of contaminated fuels and accept an increase in maintenance. Either way it all comes back to the economics of the project.

INTRODUCTION

There are two basic approaches for dealing with fuel contaminants in landfill-gas-to-energy projects. The first is to pretreat the landfill methane, taking out many of the contaminants to produce fuel that meets the engines' operating requirements. The second is to forego all but the simplest pretreatment and install engines specially modified to burn impure fuel, yet still deliver acceptable component life and maintenance intervals.

Neither choice is universally better than the other. The most favorable approach for a given application depends on various factors: gas composition, emissions limits at the site, local power market conditions, and the site owner's performance and reliability expectations. In the end, the choice typically boils down to economics: The winning approach is the one that delivers, all things considered, the lower cost per kWh.

While fuel pretreatment has a longer history and more name recognition in the landfill-gas-to-energy market, engine designs that deal with fuel contaminants internally have a 20-year track record of effectiveness. Those designs have improved steadily and are available on even the most technologically advanced, high-efficiency gas engines on the market. Therefore, any landfill-gas-to-energy project developer can benefit from analyzing and comparing both approaches in light of site-specific conditions.

LANDFILL FUEL CONTAMINANTS

For users considering gas engines for power generation, fuel quality has been a key concern since the dawn of the landfill-gas-to-energy industry. Landfill fuel contaminants, if not dealt with, will cause a wide range of engine problems. Contaminants of greatest concern are:

Sulfur compounds. During combustion cycle, sulfur compounds – notably hydrogen sulfide (H2S) – break apart and combine with available water (the primary compound created in the combustion process) to form a weak sulfuric acid. If left unattended, this acid can severely damages aftercooler cores, bearings, and any copper-containing engine components.

Halides
When halogenated hydrocarbons (chlorofluorocarbons, or CFCs) are oxidized in engine combustion, they release chlorine and fluorine, which in turn unite with water from the combustion process to form hydrochloric (HCl) and hydrofluoric (HF) acids. These acids, if not taken care of properly, will attack piston rings, cylinder liners, exhaust valve stems, valve guides and other critical wear parts.

Water vapor
Water vapor is not considered to be harmful when entrained as a vapor in the fuel at quantities below the point of saturation. (In fact, about 10 percent of the engine exhaust is water vapor.) However, water vapor in the fuel can combine with organic compounds common in landfill fuels during the combustion process to form organic acids like sulfuric, hydrochloric or hydrochloric acid. Even the carbon dioxide (CO_2) can combine with water to form carbonic acid. These acids may attack engine components. There does seem to be a relationship between the amount of water vapor in the fuel and the amount of sulfur, halides and (some species of) siloxanes that enter the engine through the fuel. Lower amounts of water vapor in the fuel have proven to be better.

Silicon crystals
Microscopic silicon (sand) crystals can travel with the landfill gas, agglomerate during combustion, and form larger particles that cling to exhaust valve faces and seats.

Siloxanes
These substances, commonly found in household products like shampoo, cosmetics and detergents, break down during combustion and lead to hard silica (SiO_2) and silicate deposits in combustion chambers, exhaust manifolds and exhaust stacks. In the cylinders, deposits on valve faces lead to grinding action and increased valve seat wear.

Chipping of the silicate deposits accumulated in the combustion chamber can lead to severe valve damage. This occurs when a thick deposit chips away, leaving a gap through which hot combustion gas flows while the valve is closed. It can also occur when a loose chip from the combustion chamber gets trapped in a closing valve as it exits the cylinder. The resulting blowtorch effect melts part of the valve, a phenomenon commonly referred to as guttering.

In many cases where siloxanes are present in the fuel, siloxane buildup on cylinder heads and on pistons physically reduces cylinder volume and increases the compression ratio, driving up cylinder pressures and carbon monoxide (CO) emissions.

IMPACT OF FUEL CONTAMINANTS

The effects of contaminants on the engine depend on a number of factors, including engine component metallurgy, exposure time and rate, engine operating temperature, and the brake mean effective pressure (BMEP) of the engine.

With minimal or no fuel treatment, a standard natural gas engine operating on a typical landfill gas can suffer shortened cylinder head life by 50 to 75 percent or more when compared with a similar engine operating on pipeline natural gas. Lube oil life is shortened as well, through acidification and high levels of silicone in the oil from blowby of H2S and silicon into the crankcase.

Most successful landfill operators analyze their oil for silicon in addition to acids and other standard wear indicators of oil condition. In fact, silicon may dictate the oil change interval: Most landfill sites use 100 to 120 ppm silicon in the oil as a condemning limit. Spark plugs in landfill engines also require extra attention, mainly because of silicon deposits, which shield the electrodes and increase the voltage required to fire the plug. A higher level of siloxanes in the fuel typically translates into shorter spark plug life. In extreme cases, plug life can be reduced by as much as 90 percent.

Because each landfill fuel is different and subject to seasonal and even daily change, operators must customize maintenance programs – intervals for oil and filter changes, spark plug cleaning and replacement, top-end, inframe and major overhaul, and other tasks. This is best accomplished by collecting site maintenance and operating data, observing wear and degradation trends, and adjusting practices accordingly.

Generator set manufacturers will provide fuel-quality specifications that include recommended maximum levels of contaminants allowable in an engine to maintain optimum operating conditions. Fuel exceeding specified contaminant concentration recommendations would compromise performance and/or service life.

Table 1. Comparative Fuel Purity Specifications*

		Standard Engine	Low Energy Fuel Engine
Sulfur Compounds as H_2S See footnote (1,2)*	mg H_2S/MJ ug H_2S/Btu	0.43 0.45	57 60
Halide Compounds as Cl See footnote (1,3)*	mg Cl/MJ ug Cl/Btu	0 0	19 20
Ammonia	mg NH_3 /MJ ug NH_3/Btu	0 0	2.81 2.96
Oil Content	mg/MJ ug/Btu	1.19 1.25	1.19 1.25
Particulates in Fuel See footnote (1,4)*	mg/MJ ug/Btu	0.80 0.84	0.80 0.84
Particulate Size in Fuel:	microns	1	1
Silicon in Fuel See footnote (1,4)*	mg Si/MJ ug Si/Btu	0.1 0.1	0.56 0.60
Maximum Temperature	°C °F	60 140	60 140
Minimum Temperature	°C °F	-10 -50	-10 -50
Fuel Pressure Fluctuation	kPa ± psig ±	1.7 0.25	1.7 0.25
Water Content		Saturated fuel or air is acceptable. Water condensation in the fuel lines or engine is *not* acceptable. It is recommended to limit the relative humidity to 80% at the minimum fuel operating temperature.	

This chart is for purposes of illustration only. Fuel specifications may vary by engine manufacturer and/or engine model. For any specific landfill-gas-to-energy installation, the chosen manufacturer's fuel specifications should be consulted.

Exceeding the maximum contaminant values by a slight amount might simply reduce oil change or spark plug replacement intervals by some small amount. Accepting contaminant levels far in excess of the recommended levels might decrease oil change and spark plug maintenance intervals by quite a bit, and also significantly decrease the time to major service intervals like top end or in-frame overhauls. And not all contaminants have the same effect on an engine life. For example, if only H_2S greatly exceeds the recommended value, it might only have a major impact of the oil change interval, and not much of an effect on spark plug or overhaul life, while a very high level of siloxanes might lead to decreased oil, spark plug and overhaul schedules.

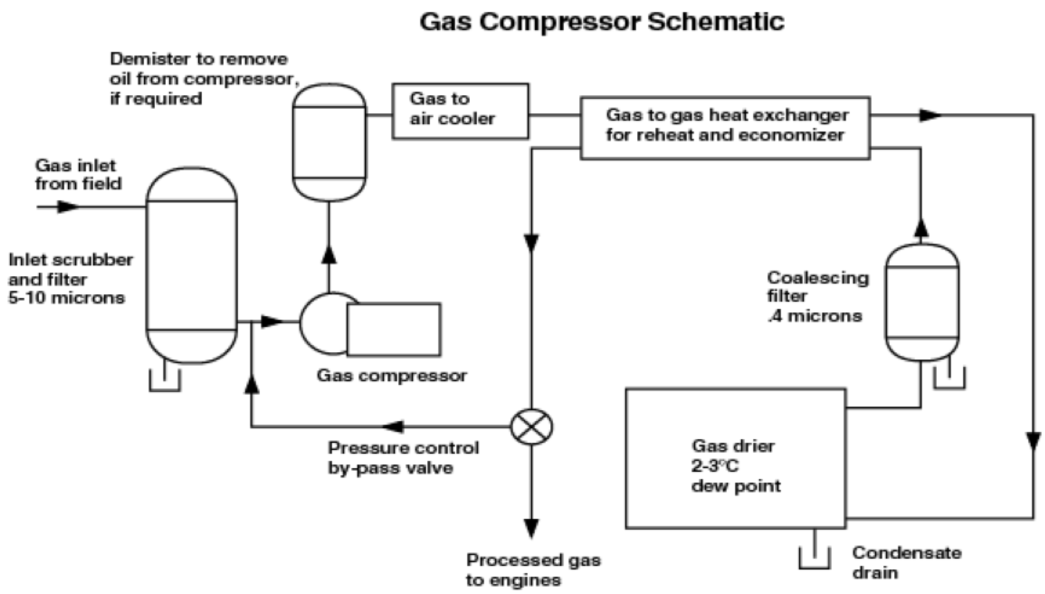
Not surprisingly, contaminant limits for landfill engines differ from those for standard engines (refer to Table 1). The recommended levels of contaminants in the chart are those that will allow the engine to achieve the designed service life represented in the manufacturers recommended maintenance schedule. Still, these recommended contaminant limits could help remove some trial-and-error from the development of proper maintenance programs and fuel delivery systems.

The chart lists maximum recommended fuel contaminants on a "contaminant mass/fuel heat value" basis rather than on a "contaminant mass/volume" basis. Assuming the same level of contaminant per unit volume of gas, a volume at 600 btu/ft^3 (22.4MJ/Nm^3) will have 50 percent of the contaminants of a volume at 300 btu/ft^3 (11.2MJ/Nm^3). When the contaminants are found in concentrations above the manufacturer recommended levels, higher contaminant levels per unit volume will have a significant impact on the service life of the engine.

As acids naturally form in the engine, it is important to use a type of lube oil in the engine that will "capture" these acids. The total base number (or TBN) is an indicator of the acid absorbing capability of an oil: the higher the TBN number, the better the acid neutralizing capability.

But higher TBN is not always better for a gas engine. An ash material is typically the oil additive used to neutralize acids, and high-ash oils are not recommended for natural gas engines. High levels of ash in lube oil will leave carbon deposits when combusted in natural gas engines that can cause premature wear and require an in-frame overhaul to replace the affected components. Therefore, users should look for an oil with the highest TBN recommended by the engine manufacturer, and use a scheduled oil sampling system to optimize the oil-change interval.

Figure 1. Landfill-Gas-To-Energy – Typical Fuel Treatment System



PROTECTING ENGINES

In protecting engine performance and longevity, there is no free lunch. Either basic approach – fuel pretreatment or the acceptance of reduced maintenance intervals with specially designed landfill engines – adds capital cost and affects long-term maintenance expense. The question is which option is the more economical for a given site.

Fuel pretreatment
A front-end gas processing (pretreatment) system can make up a significant share of a project's capital cost. The components must be chosen for function, reliability, and resistance to corrosive damage from the impurities they remove. In theory, pretreatment could deliver near pipeline-quality gas, but that is seldom if ever economical.

The pretreatment design usually requires a compromise: fuel good enough to enable reliable engine performance under a reasonable maintenance regimen. Figure 1 shows a typical gas pretreatment system. Every installation should include an inlet scrubber and fuel filter to remove water droplets from the gas and trap solid matter, and a gas compressor to deliver fuel to the engines at the necessary volume and pressure. Other gas treatment steps commonly include:

Demister: Removes oil from the gas stream in systems where oil is injected into the gas to lubricate the compressor.

Gas-to-air cooler: Lowers the temperature of the gas after it is compressed, thus reducing moisture and preventing condensation and attendant acid formation later in the fuel delivery system, or inside the engines.

Gas-to-gas heat exchanger: Precools the gas entering the dryer to reduce dryer power demand. The gas leaving the dryer is reheated later in the process by the gas-to-gas heat exchanger to prevent water from condensing downstream. These heat exchangers are typically made of stainless steel.

Dryer: An effective way to reduce halogens and H_2S in the gas. The device is usually a gas-to-liquid heat exchanger that uses a refrigerant. The gas is dried by chilling to a dew point of 36° to 37°F (2° to 3° C). Because halogens and H_2S are water soluble, reducing water content also reduces their concentrations. The dryer also reduces, to a lesser extent, some species of gas-borne siloxanes.

Coalescing filter: Removes any remaining water or oil droplets, and remaining solid matter down to 0.4 microns in size.

Condensate drain: Collects water removed from the gas. The water may be treated for discharge to a sewer system or, in some locations, reintroduced to the landfill to stimulate methane production.

An effective fuel treatment system helps reduce special maintenance demands on the engines but does require maintenance of its own. Every component in the treatment train needs service at intervals dictated by the characteristics of the fuel and the equipment make and model. Since the gas recovery project is only as reliable as the weakest link, all fuel pretreatment components need to be selected with the same attention to detail as the gas compressor, generator set or other system component.

Special engine design

In the mid-1980s, engine designers began looking at the demands of low-energy fuel applications (chiefly landfill and digester gas) and seeking ways to “harden” engines against fuel impurities. In essence, the engine designers accepted the realities of the corrosive fuels introduced to their engines and modified the design of critical components and systems to counteract the effects of many of these contaminants.

The resulting low-energy-fuel engines still require an inlet gas scrubber and gas compressor, and they may need other fuel-treatment steps under certain fuel conditions. In general, though, the engine modifications themselves were designed to counteract the effects of fuel-borne contaminants.

While modifications add to the capital cost of the engines, the capital and maintenance cost of pretreatment equipment can be reduced, sometimes significantly. Field experience demonstrates that the engines achieve acceptable maintenance and service intervals, and availability percentages that are highly competitive in the landfill industry.

The engine modifications have three basic strategies:

- Keep harmful substances from forming inside the engine.
- Make highly susceptible components corrosion resistant.
- Eject potentially corrosive gases.

Here are the specific modifications:

Optimized jacket water temperature. A two-circuit cooling system keeps the jacket water at 230°F (110°C), optimal for landfill service and well above the 194° to 210°F (90° to 99°C) range typical of standard natural gas engines.

The warmer jacket water temperature inhibits water vapor entrained in the exhaust gas and blow-by gases from condensing on the cylinder liners and on other internal engine surfaces, thus limiting the formation of acids and attendant corrosion. It also helps keep condensation and acid formation from reaching the lubricating oil, further protecting components and helping to extend oil-change intervals.

Tests to date indicate that the elevated jacket water temperature can improve oil life, significantly reduce cylinder liner pitting and the corrosion of other cylinder components, crankshafts, bearings and other critical wear parts without jeopardizing expected component life and maintenance intervals.

The elevated jacket water temperature is enabled by a higher coolant flow through the cylinder block, and by the addition of heat-resistant jacket water system and pump seals. In addition, the oil cooler is moved from the jacket water circuit to a lower-temperature auxiliary circuit. This keeps the oil temperature from exceeding its allowable limit of 210°F (99°C). The oil cooler thermostat begins to open at 200°F (93°C) to prevent the oil from being overcooled.

Corrosion-resistant materials. As further protection against naturally forming acids, the landfill-specific design minimizes the use of bright metals (copper and unprotected steel) in components likely to come in contact with the fuel or exhaust gases. For example, the aftercooler cores, made of copper alloys in standard gas engines, are made of stainless steel in the landfill versions to resist attacks from acids of sulfur, chlorine and fluorine.

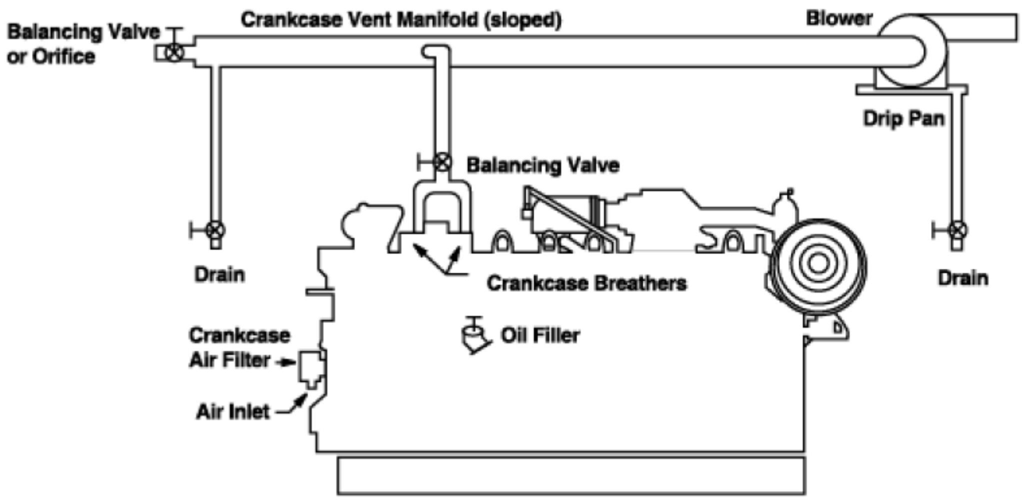
On precombustion-chambered engines, the ignition body that holds the prechamber into the cylinder head has higher corrosion resistance than in standard engines. Extensive field-testing has shown this component to be susceptible to corrosion unless the material is upgraded.

The balance of landfill cylinder head components are of a similar design as in standard engines, but materials may have been modified for longer life. The intake and exhaust valve materials, for example, have been modified for improved heat resistance, and the valve seat angles are optimized to minimize the formation of hard deposits. On some engines, a three-angle-shape valve face design combines long life with increased contact forces that combat deposits from higher-ash oils and other silicon deposits typical in landfill engines.

Crankcase ventilation. An additional line of defense against engine corrosion comes from a low-pressure air pump that draws warm, filtered air into the crankcase and evacuates harmful gases (see Figure 2). Thus when the engine is needed on line or has been shut down for maintenance or repair, the crankcase components are not exposed to condensing corrosive blow-by gases. Engine oil life will be improved as well.

Where ambient air is cool enough so that ventilation air itself might cause condensation in the crankcase, the inlet air can be preheated by passing it through a duct over the exhaust manifold.

Figure 2. Crankcase Ventilation System



COMPARING OPTIONS

Comparing the merits of external fuel pretreatment with merits of engines designed for landfill service requires a rigorous but relatively simple cost analysis.

The process begins with a fuel analysis, because that largely dictates the degree of fuel pretreatment that landfill engines will need. If the landfill has been in operation for awhile, multiple samples should be evaluated to understand the minimum and maximum methane content as well as the minimum and maximum contaminant levels expected in the fuel over time. If the landfill is a new installation, a landfill sample with an “educated guess” as to the methane content and expected fuel contaminant levels (based on the expected fill materials) should be evaluated. In general, the more contaminants there are in the fuel, and the larger their concentration, the greater the demands on the pretreatment system, and the greater its cost.

Based on experience, the pretreatment system designer can estimate the capital (installed) cost of the system as well as the expected maintenance cost of the components and the projected total ownership cost.

Based on the expected quality of the treated fuel, the generator set manufacturer will be able to project intervals for basic maintenance, as well as expected run times to top end, in-frame and major overhauls. This will enable a calculation of the total costs of maintenance, which will include service labor, components, and consumables (fluids, filters, etc.) cost over the project life.

Manufacturers with experience in landfill operation may be able to provide long-term maintenance contracts that guarantee a fixed maintenance cost per kilowatt-hour. Such contracts also can include guarantees covering uptime (as a percentage of total available operating hours) and emissions levels.

With these calculations complete, it is relatively simple to compare installed and ownership costs per kWh for the two alternatives. As a general rule – and especially where the cost difference is not compelling, it may be worthwhile to consider various intangibles. These include:

- Familiarity of in-house staff with the equipment they will be asked to maintain.
- The quality and availability of service and technical support (including time to deliver routine and emergency replacement parts)
- The comparative track records of the equipment suppliers (in particular, their direct experience in landfill-gas-to-energy projects).

CASES IN POINT

Elevated jacket water temperature technology has been in use in landfill applications since the mid-1980s, and many of the other landfill modifications have evolved since then. Altogether, these technologies (using Cat® engines alone) are at work on more than 920 MW of landfill gas projects installed since 1996.

The modifications are available on landfill versions of advanced gas engines developed through the U.S. Department of Energy Advanced Reciprocating Engine Systems (ARES) program and introduced commercially starting in late 2002.

These ARES landfill gas engines will be available in 12-, 16- and 20-cylinder configurations, operating at 50 Hz or 60 Hz, at speeds up to 1,500 rpm, with ratings up to 1,950 kW. A leaner fuel mix reduces combustion temperatures and drives down NOx formation. NOx ratings as low as 1.0 and 0.5 g/bhp-hr, 60 Hz (250 and 500 mg/Nm3, 50 Hz) are available without exhaust aftertreatment. A low-pressure fuel system (1.5 to 5 psi/ 10 to 35 kPa) makes the units adaptable to landfill gas service.

Here are a few examples of landfill-gas-to-energy projects driven by engines designed to tolerate landfill gases:

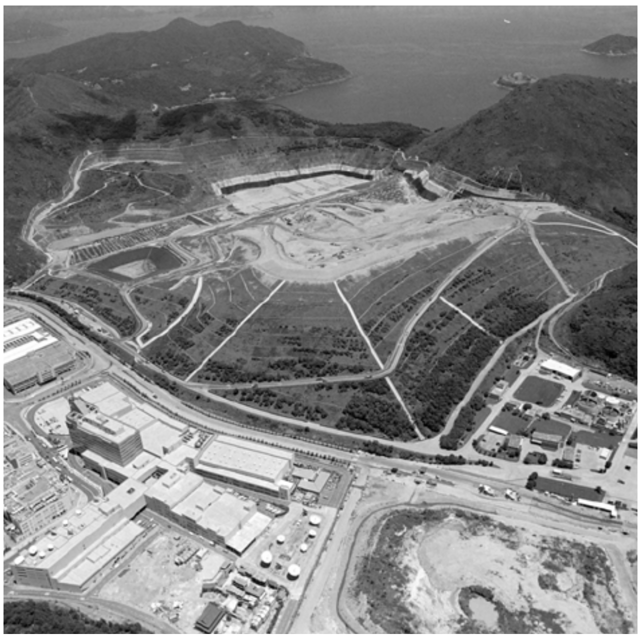
Seneca Meadows Landfill, Seneca Falls, N.Y.
This energy system, owned by Innovative Energy Systems of Oakfield, NY., began operating in 1996 and has been expanded three times to its current 11.2 MW capacity. The system uses 14 Cat G3516 generator sets modified for landfill service. As of 2004, the first three generator sets had run times of 68,000 hours, and management had projected that they could run 100,000 hours before major overhaul. In the fuel pretreatment system, methane at 3 psi passes through a chiller and into a glycol bath that removes halides, moisture, and particulates down to 0.1 micron. Overall energy plant NOx emissions are 1.3 g/bhp-hr, compliant with local air-quality standards.

Rhode Island Solid Waste Landfill, Johnston, R.I.
Ridgewood Renewable Power in July 2005 commissioned four Cat G3520C Low Energy generator sets, among the first such units shipped in North America. Each of these units is driven by an ARES-derivative 20-cylinder engine delivering 1.6 MW.

The system was installed by Milton Cat in Milford, Mass., which shared the operating risk by offering a performance guarantee and a fixed maintenance price per kWh under a comprehensive maintenance program. Emissions compliance is also guaranteed under the contract (the units are rated at 0.5 g/bhp-hr NOx).

South East New Territories Landfill, Hong Kong.
This site, operated by Green Valley Landfill Ltd., installed two Cat G3516 landfill generator sets in 1997. Each unit is rated at 970 kW, providing 1.9 MW of continuous power for the landfill infrastructure and an on-site wastewater treatment plant. The units operate in parallel with the local utility, exporting excess power to the grid. The generator sets have oversized radiators to compensate for tropical heat and humidity.

Management reports that the facility is online 99 percent of the time. Green Valley Landfill provides regular maintenance in-house; while top-end, in-frame and major overhauls are performed by The China Engineers, the local Cat dealer.



SUMMARY

Landfill-gas-to-energy system operators have a range of options for dealing with fuel-borne contaminants. Both fuel pretreatment systems and special engine designs that combat the effects of corrosive fuels have proven effective in multiple applications worldwide.

Because the relative costs and benefits of these basic options can vary greatly with site-specific conditions, operators should analyze both methods of fuel contaminant control as part of project planning. The “right answer” for any one project may well include a combination of fuel treatment options and optimized engine maintenance practices. To forego this analysis is to risk missing an opportunity to achieve the lowest practical capital and maintenance cost for the system.

ABOUT THE AUTHOR

Michael A. Devine is Gas Product/Marketing Manager for the Electric Power Group of Caterpillar Inc., based in Mossville, Ill. In his 30 years with Caterpillar, Devine has filled a variety of roles, including manufacturing, service engineering, electric power product and project management, and education and training. Involved with power generation since 1979, he has spent most of this time working to develop power generation products to serve the load management, distributed power, quality power and landfill-to-energy markets. He has traveled extensively, working on power projects and educating utility companies and power users worldwide on the benefits of Landfill, Digester, Distributed Generation and Cogeneration applications.

ABOUT

About Caterpillar
For more than 80 years, Caterpillar Inc. has been making progress possible and driving positive and sustainable change on every continent. With 2011 sales and revenues of $60.1 billion, Caterpillar is a technology leader and the world’s leading manufacturer of construction and mining equipment, clean diesel and natural gas engines and industrial gas turbines.

Web – www.catelectricpowerinfo.com
Online Community – www.catelectricpowerinfo.com/connect
Facebook – www.facebook.com/Caterpillar.Electric.Power
YouTube – www.youtube.com/CatPowerGeneration

EEWP0206-01