NEW PARADIGMS IN EFFICIENCY, EMISSIONS AND POWER COST IN LANDFILL GAS-FUELED GENERATORS

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ABSTRACT
Technological refinements have continuously improved the performance and durability of gas-fueled engines in the landfill industry. Today, the benefits of an intensive national effort to increase gas-fueled reciprocating engine generation efficiency are reaching the landfill gas-to-energy market.

The latest-generation gas engines, incorporating technologies developed with the U.S. Department of Energy Advanced Reciprocating Engine Systems (ARES) program, attained commercial status in 2002. These lean-burn, electronically controlled units, designed for extended-duty service in distributed generation, deliver 1 to 2 MW of capacity and are capable of 43 percent mechanical efficiency, with NO_x emissions rated as low as 0.5 g/bhp-hr without exhaust aftertreatment, and maintenance costs 40 percent lower per kWh than for traditional landfill gas engines. Now, enhancements for the special demands of LFG are bringing these technologies into the landfill industry.

Landfill gas versions are designed to resist corrosion and to deliver the maximum performance from low-Btu fuels. Changes include the use of non-corrosive metals in strategic wear areas, elevated jacket water temperatures to prevent condensation of caustics, enhanced crankcase ventilation to remove caustics from the system, and modifications to enhance fuel flow and enable full rated power production on low- and variable-Btu gases. The benefits for operators include reduced unscheduled downtime with less hands-on attention, extended service intervals, lower parts-replacement costs, consistent power output, and emissions compliance. Those and other benefits add up to lower generating costs per kWh, greater kWh output from the available gas, and more profitable power production.

Experience to date in commercial service in the United Kingdom and Canada, and in product-reliability verification units, demonstrate that these advanced gas generator sets deliver reliable electricity at highly competitive cost and in full compliance with applicable air-quality regulations.

BENEFITS OF LANDFILL-GAS-TO-ENERGY
Landfill-gas-to-energy embodies the ideal solution to an environmental problem: It turns a nuisance waste into a product with a practical use and economic value.

Still, since it became a common practice in the 1970s, landfill energy projects have challenged operators to generate reliable electricity at competitive cost. Reciprocating engines that were used to generate power proved vulnerable to contaminants inherent in landfill gas. Hydrogen sulfide (H_2S) and halides combine with water inside the engine to form weak acids that corrode components. Traces of siloxanes from products like detergents, shampoos and cosmetics create silicon dioxide deposits on spark plugs and cylinder components, diminishing engine efficiency and contributing to increased engine maintenance costs.

To meet these challenges, operators have installed extensive fuel filtration systems and have shortened intervals for basic maintenance and overhauls in an effort to minimize accelerated wear and tear. These measures, while effective from a mechanical perspective, add cost to what is often a challenging profit equation. Also, power density for gas engines has been limited due to exhaust gas temperatures and detonation issues.

To be viable, landfill energy projects must produce electric energy both at a profit for the operator and at market-competitive prices. The ideal engine-generating system would operate at high electrical efficiency while requiring a minimum of special fuel treatment and maintenance measures to achieve maximum service life.

Today, the landfill-gas-to-energy industry stands on the edge of a new paradigm in engine-generator set performance, efficiency, and emissions compliance. In particular, advanced engine-generator technology developed for the fast-growing distributed generation market is making its way into landfill applications.

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These natural gas-fueled distributed generation units deliver mechanical efficiencies as high as 43.5 percent (with water pumps), maintenance costs per kWh at 40 percent lower than for conventional technology, and out-of-engine NO_x emissions as low as 0.5 g/bhp-hr. They have already proven themselves in a variety of distributed generation and combined heat and power (CHP) applications in North America and worldwide.

In October, 2004, the advanced gas generator set technologies will be available with enhancements specifically designed for the landfill market. These include design changes to protect engine components against landfill gas contaminants, thus eliminating the need for elaborate fuel-treatment systems and special maintenance and service practices.

Now under evaluation at landfill installations North America and Europe, these engines are versions of the first commercially available products developed through a formal research program involving collaboration between the United States government and major engine manufacturers.

MARKET GROWTH

Landfill-gas-to-energy is an important and growing component of North America's power generation mix. The U.S. Energy Information Administration, part of the Department of Energy, in its *Annual Energy Outlook 2004 with Projections to 2025*, states, "Generation from municipal solid waste and landfill gas is projected to increase by nearly 9 billion kilowatt-hours, to about 31 billion kilowatt-hours (0.5 percent of generation) in 2025."

Landfill energy is environmentally attractive for its beneficial use of a waste product. Some electric utilities include landfill generation in their portfolios of renewable (or "green") electricity sources.

For all its advantages and potential, landfill-gas-to-energy still must deal with marketplace realities. The cost of admission to the market includes equipment that produces reliable power, in compliance with increasingly strict air-quality regulations, and at prices competitive with those of other power suppliers.

Engine performance is the linchpin of a landfill-gas-to-energy system. Key engine attributes are power density, fuel efficiency and ease of maintenance and service – all critical components of life-cycle cost, which in turn affects the price of electricity and the owner's profitability.

High-quality diagnostics and control are essential, as fuel with variable heating value and varying levels of contaminants and inert gases can change engine operating parameters abruptly and frequently. Advanced electronic controls enable engines to adjust for ambient and operating conditions automatically, without costly hands-on operator attention. Self-diagnostics greatly simplify and speed up service and repairs, helping to reduce both scheduled and unscheduled downtime.

GROWTH IN DISTRIBUTED GENERATION

Many of those same attributes are essential to reciprocating engines in the growing distributed generation market, of which landfill energy operations are a part. Economic and market forces have coalesced to change the dynamics of how electric power is produced, sold and delivered to end users. Electric utilities are now recognizing the value of distributed generation as a viable and permanent part of the energy-supply picture.

In recent years, utilities in various parts of the United States and Canada have experienced capacity shortfalls, sometimes posing a threat of rolling blackouts. A key virtue of distributed generation is that it enables utilities to deploy new capacity much faster and at far lower cost and financial risk than for building large-scale, centralized power plants. Distributed generation has the added benefit of forestalling construction of new high-voltage transmission lines, which are also expensive and have become more politically difficult to site and permit.

Of more immediate and everyday concern to power users are temporary declines or fluctuations in voltage affecting sectors of utility distribution grids during times of high demand. Today's high-value business equipment requires consistent power quality. Voltage fluctuations can seriously damage or disrupt computer systems and reduce the performance and service life of industrial machinery. Distributed generation systems, placed at strategic locations on the grid, support local distribution system voltage.

End users also stand to benefit from distributed generation where power markets are opening to competition and to concepts such as real-time pricing. In such cases, a business able to produce power on demand can gain a valuable hedge against market price volatility, or profit from the sale of energy on power exchanges.

In its 2002 *North American Generator Set Markets: Distributed Generation 10-Year Forecast* the Frost & Sullivan market consulting firm has forecast that distributed generation in North America will grow significantly in the next eight years. The firm projects cumulative shipments of distributed generation equipment to grow from 23 GW in 2002 to some 323 GW in 2012. The firm further notes that the U.S. Department of Energy's Office of Power Technologies has set a goal to enable distributed generation to account for 20 percent of new generating capacity in the United States by 2010.

ADVANCED ENGINE TECHNOLOGY

The rise in distributed generation has helped drive interest in landfill energy. It has also helped drive an increase in privately and publicly funded research projects aimed at developing cleaner, more efficient, lower-cost small-scale generation sources. Most of the research attention has focused on gas-fueled reciprocating engines because of their simplicity, flexibility and emissions performance. Advances in engine technology pursue three basic objectives:

- Reducing installed cost, making it easier for financial decision makers to justify initial investments in equipment.
- Reducing long-term operating expenses, thus driving down the cost per kilowatt-hour of electric energy.
- Limiting engine exhaust emissions, making it easier for users to comply with air-quality regulations

A key driving force for better engine-driven generator sets is the U.S. Department of Energy's Advanced Reciprocating Engine Systems (ARES) program. ARES involves a consortium of world-leading engine manufacturers, universities and research laboratories in a multi-year effort to develop a new generation of high-efficiency, low-emission natural-gas engines (see Figure 1). The basic goal of ARES is to produce gas engines with:

- Installed cost from $400 to $450 per kW.
- Thermal efficiency of 50 percent – a 30 percent improvement over historically available reciprocating engines.
- NO_x emissions at 0.1 grams per brake horsepower-hour or less when operated on pipeline natural gas – a 95 percent reduction over today's typical gas engines.
- Maintenance costs per kilowatt-hour equal to or lower than for today's gas equipment.

FIGURE 1
ARES PROGRAM OBJECTIVES
(FOR ENGINES OPERATING ON PIPELINE-QUALITY GAS)

	Timeframe for Commercial Products	**Thermal Efficiency**	**NO_x Emissions**
Current	N/A	38-40%	2.0 g/bhp-hr
Phase 1	2004-2005	44%	0.5 g/bhp-hr
Phase 2	2007-2008	47%	0.1 g-bhp-hr
Phase 3	2009-2010	50%	0.1 g-bhp-hr

Generically speaking, ARES-based engines are electronically controlled units in lean-burn configurations, able to achieve extremely low NO_x emissions without aftertreatment. Under ARES, manufacturer and supplier teams strive to improve engine performance using advanced materials, new fuel handling and processing systems, and advanced ignition and combustion systems.

REACHING COMMERCIAL MARKETS

Gas engines developed through ARES began reaching commercial markets in the last quarter of 2001. They will have near-term and positive effects worldwide on energy usage and air quality in a wide range of distributed generation applications, including landfill energy, peak shaving, utility load management and CHP.

The ARES-based engines available today are in 16- and 20-cylinder configurations, operating at 1500 rpm/50 Hz, 1200 rpm/60 Hz or 1800 rpm/60 Hz, with ratings up to 2.1 MW. In the near future, 12-cylinder configurations will be available.

These engines' high power density – up to 105 kW per cylinder – means fewer generator sets are needed for the same power demand. That, in turn, means fewer interconnects, less ancillary equipment, and less installation labor, thus reducing first cost and providing a quick return on investment. The engines are capable of brake mean effective pressure (BMEP) above 19.8 bar, a 40 percent improvement over the 14 bar engines of just a few years ago, enabling better fuel consumption and higher power densities in the same envelope.

A leaner fuel mix reduces combustion temperatures and thus drives down NO_x formation in the engine. Efficient turbochargers that increase airflow to the cylinders help to lean the fuel mixture. The leaner air-fuel ratio also limits risk of detonation – an uncontrolled, explosive combustion of fuel that reduces efficiency and, if severe enough, can damage cylinder components.

ARES-based technology meets the challenge of combusting the lean fuel mix efficiently and reliably. Many earlier lean-burn engines used prechamber systems, which add design, material and manufacturing costs, require maintenance, and leave joints that create potential leak paths for coolant and fuel. Pre-chambered engines require higher fuel pressures (45 psi/310 kPa) and are particularly sensitive to ignition system fouling from siloxane contaminants in untreated landfill gas. As such, they are susceptible to increased maintenance and service.

The ARES-based engines are designed to operate reliably and efficiently with minimal hands-on operator attention. They have an open-cylinder design using a high-energy spark plug for ignition.

The low-pressure fuel system (0.5 to 5 psi/3.5 to 35 kPa) allows them to fit in the broadest range of distributed generation settings and adapt well to the low-pressure fuel delivered in landfill applications. A digital microprocessor control automatically and precisely regulates engine governing, air/fuel ratio and ignition, resulting in optimum fuel economy with stringent control over NO_x emissions.

A technologically advanced air/fuel ratio control maintains NO_x within tight tolerances, under all ambient and load conditions. Rather then regulating the air/fuel ratio based on complex "weather station" measurements of ambient conditions, the ARES system regulates based on the single variable of charge air density as measured against the required load. This simple, low-maintenance design uses existing inlet air pressure and temperature sensors and does not require exhaust oxygen or humidity sensors. It is an active system, immune to changes in air temperature and humidity and requiring minimal maintenance and adjustment.

The open-protocol, SCADA-compatible control provides integrated management of major functions and includes comprehensive safety shutdowns and self-diagnostics. The gas engine control module, environmentally sealed in a diecast aluminum housing, is immune to vibration, insulated against electrical noise, and accurate at ambient temperatures from ⁻40 F to 250 F (⁻40 C to 120 C).

Detonation sensors monitor each cylinder and automatically retard timing on an individual-cylinder basis if detonation occurs. Lower NO_x formation and lower oil temperatures reduce oil nitration and oxidation, enabling 40 to 50 percent longer oil-change intervals. Heavy-duty components allow long, continuous service between top-end, in-frame and major overhauls.

MODIFICATIONS FOR LANDFILL SERVICE

In themselves, these ARES-based engine attributes stand to benefit landfill energy operators significantly. In addition, a model is being developed with design modifications specifically to meet the challenges of landfill fuels.

The model for the landfill industry is a 20-cylinder unit. A configuration for the 60 Hz market operates at 1,200 rpm, delivers 1,600 kW of capacity, and produces between 0.5 and 1.0 g/bhp-hr NO_x. A configuration for the 50 Hz market operates at 1,500 rpm, delivers 1,950 kW, and produces between 250 and 500 mg/Nm^3 NO_x. Both are capable of meeting existing or expected future landfill NO_x emission regulations anywhere in the world.

Like all of the new ARES-based engines, these units are built on a heavy-duty diesel-based platform designed for durability and to operate for up to 80,000 hours before major overhaul in typical distributed generation service (In landfill applications, overhaul intervals may vary with fuel quality). Mechanical efficiencies are 41.5 percent on the 60 Hz configuration and 40.6 percent on the 50 Hz configuration (at ISO 3046 conditions).

For landfill-specific duty, critical engine components have been modified to account for typical gas contaminants. This enables the generator sets to operate without intensive fuel treatment systems and the attendant maintenance costs and parasitic loads.

To protect critical engine components against corrosion from sulfuric and other acids, a specially designed cooling system elevates engine jacket water temperature from the traditional 210 F to 230 F (99 C to 110 C). This prevents water from condensing on engine components and forming sulfuric acid in the presence of hydrogen sulfide, or hydrochloric and hydrofluoric acids in the presence of halides. The elevated jacket water temperature also helps prevent condensation and acid formation in the lubricating oil, further protecting components and potentially helping to extend oil-change intervals. (Oil condemning limits in landfill service relate to total base number, or TBN, and total acid number, or TAN, rather than to oxidation and nitration as in pipeline-gas-fueled applications.).

Tests to date demonstrate that the higher jacket water temperature significantly reduces cylinder liner pitting and the acid corrosion of cylinder components, crankshafts, bearings and other critical wear parts.

As further protection against acids, bright metals (aluminum and unprotected steel) have been eliminated from certain components. The aftercooler cores, made from aluminum in the standard engines, are made of stainless steel in the landfill versions. Main and connecting rod bearing have brass instead of steel-backed aluminum material.

A crankcase ventilation system provides an additional line of defense against corrosion. A low-pressure pump ejects blowby gases and draws in fresh, filtered air. Thus when the engine is idle or shut down for maintenance and repair, crankcase components are not exposed to acid-forming gases and water vapor.

The engines have a low-pressure fuel system inherently well suited to landfill service – they readily operate on fuel pressures as low as 0.5 psi (3.5 kPa) without the need for fuel compressors. A specially designed two-stage, high-volume air intake system enables efficient air flow and minimizes heating of charge air, increasing the density of the air/fuel charge to the cylinders for maximum efficiency and optimum performance. The units' already oversized fuel-control valve is significantly larger in the landfill versions, enabling higher fuel flow rates.

Special engine modifications also account for the presence of siloxanes in the fuel. Valve and valve seat angles have been increased to prevent formation of hard deposits that could allow combustion gases to escape and erode engine performance.

PHOTO 1
LANDFILL GAS GENERATOR SET AT THE HARTLAND LANDFILL IN VICTORIA, BRITISH COLUMBIA

PERFORMANCE IN THE FIELD

The net effect of the special landfill modifications is to drive down operating costs and increase maintenance and service intervals.

By design, the ARES-based engines have longer intervals for oil changes, spark plug replacement, valve adjustment, and top-end and major overhaul. When compared with traditional lean-burn gas engines, they experience 40 percent lower maintenance costs per kilowatt-hour.

Experience thus far shows that maintenance costs for the new ARES-based engines at a given site should approach 40 percent lower than those for traditional lean-burn units in a similar application.

To date, ARES-based generator sets in the special landfill configurations have been deployed at sites in Canada and the United Kingdom.

<u>Cardiff, Wales</u>

One ARES-based engine-generator set has operated in continuous duty at each of two landfill sites in southern Wales. The two independent sites, near Cardiff, receive primarily domestic waste from the area. The landfilled areas range from five to eight years old and have just recently begun producing sufficient gas to support power production.

The generating equipment was installed by a UK-based electric company. The electric output is sold to the national power grid as part of a renewable energy obligation under the UK's green energy program.

Fuel energy content is typical of landfill gas at 45 percent methane, but siloxanes are relatively high, reflecting the site's high domestic waste content. Fuel passes through a 0.5 micron particulate filter and a coalescing filter for water separation (fuel humidity is typically 80 percent). Location of the generator set near the wellhead reduces the fuel pipe run and keeps the fuel temperature from dropping, thus keeping moisture entrained.

The utility chose the 50 Hz/1,500 rpm ARES-based configuration primarily for its high power density and low installed cost. To date, the units' efficiency has been slightly better than nominal ratings, and maintenance costs have been significantly lower than would have been expected for traditional lean-burn engines. The operator will monitor the engines' performance over time to gather more meaningful long-term data on efficiency, reliability, and maintenance expense.

<u>Victoria, British Columbia</u>

A 60 Hz/1,200 rpm ARES-based engine was commissioned in February 2004 at the Hartland landfill, operated by the Capital Regional District and located just outside British Columbia's provincial capital. The landfill receives municipal solid waste from a population of roughly 400,000.

Until the power generating system went online, the landfill gas had been flared. At present, plans call for the installation of a second ARES-based unit as gas volumes increase and as gas wells are added in new areas of the site.

The fuel is treated with refrigerant chilling and coalescing filtration for removal of moisture and siloxanes. The fuel treatment scheme allows for the addition of an activated carbon filter for further siloxane removal, should that become necessary. Fuel hydrogen sulfide levels are relatively low because for several years the site has refused to accept gypsum, a common source of sulfur in landfill gas. Chlorides, fluorides and siloxanes are present in variable quantities.

Independent power producer Maxim Power Corporation of Calgary, Alberta, installed the landfill-gas-to-energy system. The electric energy output (continuous duty at 1.6 MW) will be sold to BC Hydro for that company's Green Power program.

PHOTO 2
POWER GENERATION STATION AT THE HARTLAND LANDFILL SITE

Maxim chose the ARES-based unit for its high power density (80 kW per cylinder) and its projected low ownership costs versus conventional technologies. The unit's expected 42 percent mechanical efficiency is some 20 percent greater than for a traditional lean-burn unit of comparable power rating. The owner also cited a significant advantage in the engine's low-pressure fuel system, which eliminates the need for gas compressors and their attendant costs.

CONCLUSION

Advancements in reciprocating gas engine-generators stand to help landfill-gas-to-energy operators reduce unscheduled downtime, extend service intervals, and lower maintenance costs while delivering consistent power output and complying with emissions standards. Those and other benefits add up to lower generating costs per kilowatt-hour, greater energy output from the available gas, more profitable power production and, in the long run, a potentially greater role for landfill gas in the world's electric power generation mix.