Final White Paper

Characterization of the Installed Costs of Prime Movers using Gaseous Opportunity Fuels

Report Addendum

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For insertion into the “Reciprocating Engine”, “Gas Turbine” and “Microturbine” sections of the Technical Characterizations:

Opportunity Fuels

There are often supplementary costs involved with the installation of power generating equipment utilizing opportunity fuels. In particular, landfill gas (LFG) and anaerobic digester gas (ADG) require many additional considerations when compared with natural gas projects. Many companies offer special “biogas” models for certain engine or microturbine types, but these prime movers typically cannot handle the gas as it is produced, without some conditioning. The gas must be pressurized and pre-treated to some degree before it can be used as a fuel, at a cost that can vary greatly with equipment size and gas composition.

In the past, these gases have primarily either been used for heating purposes or flared. Recently, however, there have been efforts to utilize these waste gases as fuels for power generating equipment as distributed energy resources (DER) or combined heat and power (CHP) applications. Early attempts to utilize the gas for power were mixed, with several engines being severely damaged by hydrogen sulfide and siloxanes. However, effective pretreatment of the gas can help ensure project longevity by eliminating these harmful constituents so that it can be safely used as a fuel. Table 1 shows the average concentration ranges for the constituents of ADG and LFG, as well as natural gas, for comparison purposes.

Table 1. Typical Concentration Ranges for ADG/LFG, compared to Natural Gas

Constituent Gas	ADG	LFG	Natural Gas
Methane	40-65%	35-60%	87-96%
Carbon Dioxide	30-55%	30-50%	0.1-1%
Nitrogen	1-5%	2-10%	1-6%
Oxygen	0.1-1%	0.1-2%	0-0.1%
Ammonia	0.1-1%	0.1-1%	N/A
Hydrogen	<0.2%	<0.2%	0-0.1%
Hydrogen Sulfide	<0.2%	<0.2%	<0.2%
Siloxanes	<0.01%	<0.01%	N/A

Sources: EPA reports, Montgomery County MD Landfill data, Union Gas Natural Gas data

(Remove ADG/LFG from “Fuels” section)

In general, detectable H_2S levels must be brought down to around 200 parts per million before the gas is considered safe to use in an engine or microturbine, while siloxane levels must be brought down to below 5 parts per billion (virtually undetectable). Both of these components are almost always present in landfill gas and anaerobic digester gas from wastewater treatment plants, typically in numbers much larger than the engine threshold levels. While iron filters can effectively neutralize hydrogen sulfide, and carbon filters or chillers can eliminate siloxanes from the gas, these pretreatment technologies can be expensive to implement, often causing potential projects to be rendered uneconomical. Some landfills or treatment plants that have very low levels of siloxanes opt to not treat the chemical at all, although this has proved to be a risky endeavor. The initial quality of the gas and the size of the installation are key factors in determining how much gas pretreatment will cost.

Pretreatment Costs

A 30 kW microturbine and a 500 kW engine will typically require the same equipment for LFG/ADG pretreatment, only at a larger scale for the engine. Because all of the same components are required for the smaller unit, the cost per kW can be drastically higher. According to Capstone[1], a pre-treatment skid that pressurizes the gas and handles both hydrogen sulfide and siloxanes typically costs between $150,000 and $300,000 for a microturbine or small engine system, depending on size. This means that for a 30 kW microturbine, estimated pretreatment costs would be around $5,000 per kW. If the project size is doubled, this number quickly drops to about $3,000 per kW. For a 200-300 kW engine or microturbine installation, estimated pretreatment capital costs would range from $1,000 to $1,300 per kW, with larger sizes hovering around $1,000/kW. Table 2 summarizes the estimated capital costs for pretreatment equipment in ADG and LFG installations.

Table 2. Estimated Capital Costs for ADG and LFG Pretreatment, by Project Size

Size Range (kW)	Estimated Cost	Estimated $/kW
<60 kW	$150,000-$180,000	$3,000-$5,000 / kW
60-100 kW	$180,000-$215,000	$2,100-$3,000 / kW
100-200 kW	$215,000-$260,000	$1,400-$2,100 / kW
200-300 kW	$260,000-$300,000	$1,000-$1,400 / kW
>300 kW	$300,000+	$1,000-$1,100 / kW

Sources: DOE characterizations, manufacturer data, Resource Dynamics Corporation estimates

These costs are the estimated total installed cost for pretreatment equipment, when siloxanes and hydrogen sulfide must be eliminated. For farm-based ADG and some landfills, however, siloxanes are

[1] Telephone conversation, December 19, 2006.

not an issue. These exhaust gas constituents are typically produced by combusting waste gas when silicon compounds are present. These compounds are found in household products such as shampoo and cosmetics, commonly disposed of in both municipal wastewater and landfills. It is estimated that 40-50 percent of the pretreatment capital costs come from siloxane filters and associated equipment, with the balance for water removal, general particulate removal, and hydrogen sulfide filters. The waste from farm animals typically does not contain silicon compounds, so the anaerobic digester gas is completely free of siloxanes. Table 3 shows the effective pretreatment cost for farm-based ADG applications and landfills that opt not to include siloxane removal.

Table 3. Estimated Capital Costs for ADG and LFG Pretreatment, without Siloxane Removal, by Project Size

Size Range (kW)	Estimated Cost	Estimated $/kW
<60 kW	$80,000-$100,000	$1,600-$2,800 / kW
60-100 kW	$100,000-$120,000	$1,200-$1,600 / kW
100-200 kW	$120,000-$160,000	$800-$1,200 / kW
200-300 kW	$160,000-$180,000	$600-$800 / kW
>300 kW	$180,000+	$500-$600 / kW

Sources: DOE characterizations, manufacturer data, Resource Dynamics Corporation estimates

For Insertion into the "Engines" section only:

Modifications and Issues with ADG and LFG Engines

When the pretreatment costs are added to the estimated installed costs for ADG/LFG-powered engines, the total installed project cost is obtained. The capital costs for engines, derived from Department of Energy data for natural gas units[2], as well as independent research, must be slightly adjusted for lower-quality ADG and LFG fuels. With engines, up to 25 percent is added on to the cost of a natural gas unit, because adjustments must be made to the combustion unit, carburetors, manifolds, valves and piping to accommodate the low-Btu gas. For larger units (greater than 500 kW), lean burn technologies can be used, which eliminates the need for most engine adjustments, but they tend to cost more than traditional rich-burn units.   Also, for all engines, a heavier duty compressor is typically required, and the power output can be degraded for smaller, non-turbocharged units, because of the lower Btu content in the gas. Tables 4 and 5 provide typical power-only and CHP plant costs for 5 example engines, assuming that siloxane removal is part of the pretreatment process.

[2] Gas-Fired Distributed Energy Resource Technology Characterizations, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, October 2003.

Table 4. Estimated Capital Cost for Typical Reciprocating Engine-Generators using ADG or LFG in Grid-Interconnected Power-Only Applications

Cost Component	System 1	System 2	System 3	System 4	System 5
Nominal Capacity (kW)	100	300	1,000	3,000	5,000
Cost ($/kW)					
Equipment					
Genset Package	500	420	440	520	530
Pretreatment Equipment	2,400	1,100	1,000	950	900
Interconnect/Electrical	250	150	100	75	65
Total Equipment	3,150	1,670	1,540	1,545	1,495
Labor/Materials	330	250	155	110	105
Total Process Capital	3,480	1,920	1,695	1,655	1,600
Project and Construction and Management	75	55	50	45	30
Engineering and Fees	50	45	40	30	25
Project Contingency	35	30	25	25	25
Total Plant Cost ($/kW)	$3,640	$2,050	$1,810	$1,755	$1,680

Table 5. Estimated Capital Cost for Typical Reciprocating Engine-Generators using ADG or LFG in Grid-Interconnected CHP Applications

Cost Component	System 1	System 2	System 3	System 4	System 5
Nominal Capacity (kW)	100	300	1,000	3,000	5,000
Cost ($/kW)					
Equipment					
Genset Package	620	420	440	520	530
Heat Recovery	incl.	180	90	65	40
Pretreatment Equipment	2,400	1,100	1,000	950	900
Interconnect/Electrical	250	150	100	75	65
Total Equipment	3,270	1,850	1,630	1,610	1,535
Labor/Materials	450	350	260	230	220
Total Process Capital	3,720	2,200	1,890	1,840	1,755
Project and Construction and Management	85	75	65	65	60
Engineering and Fees	80	75	60	50	50
Project Contingency	45	40	35	30	30
Total Plant Cost ($/kW)	$3,930	$2,390	$2,050	$1,985	$1,895

For insertion into the "Microturbines" Section:

Modifications and Issues with ADG and LFG Microturbines

With ADG/LFG microturbine capital costs, about 10-15 percent is added compared to a natural gas unit, mostly due to higher compression demands and a slightly decreased power output. No modifications are required, but gas pretreatment is almost always necessary. The total costs for ADG/LFG microturbine power-only and CHP systems are provided in Tables 4 and 5.

(followed by tables similar to those made for engines)

For insertion into the "Gas Turbines" Section:

Modifications and Issues with ADG and LFG Turbines

Gas turbines are typically not used for ADG/LFG applications, because most projects are not large enough, and many equipment modifications are required, particularly in the combustion area. Since the gas is the working fluid in the turbine, some other adjustments, including turbine blade design and spacing, may be required for optimal functionality. Typically, about 50 percent of the cost of a natural gas unit is added when the equipment is modified for ADG or LFG fuels. Tables 4 and 5 provide estimates for typical power-only and CHP installations.

(followed by tables similar to those made for engines)