 <p data-bbox="662 640 844 682">CATERPILLAR</p>	
	<p data-bbox="889 716 1234 779">Landfill Gas Fueled Engine Technology</p> <p data-bbox="889 787 1079 877">Jeremy Elder Karl Grundemann December, 2007</p>

Topics

- Experience**
- Landfill Gas**
 - Contaminants
 - Clean Up
- Air Quality Regulations**
- Caterpillar Low Energy Fuel Generators - G3500**
- The Caterpillar Dealer**
 - Sales
 - Information
 - Parts
 - Service

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Experience With Landfill Gas

- First landfill gas generator sets installed in 1983.
- Over 800 MW of landfill product installed worldwide.
- Over 40,000,000 hours of operation on landfill gas



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Landfill Gas

- Landfill Gas
 - Produced by anaerobic decomposition of organic landfill waste material
 - Consists of
 - 45%-60% CH₄ (methane)
 - 35%-45% CO₂ (carbon dioxide)
 - 5%-10% N₂ (nitrogen)
 - Trace amounts of O₂ and other HC's
 - Contaminants
 - Low Heat Value (LHV) range :
 - 400-600 btu/scf (Natural gas is 920 Btu/scf)
- For every 1 million tons of Municipal Solid Waste (MSW):
 - 1.0 MW of electricity
 - 550,000 ft³/day of landfill gas

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Landfill Gas

CATERPILLAR METHANE NUMBER CALCULATION PROGRAM				Version 5.00	
Gaseous fuel analysis for : Example Landfill					
Date : 4/2/97					
METHANE	CH4:	50.000	HEPTANE	C7H16:	0.000
ETHANE	C2H6:	0.000	OCTANE	C8H18:	0.000
ETHYLENE	C2H4:	0.000	NONANE	C9H20:	0.000
PROPANE	C3H8:	0.000	CARBON MONOXIDE	CO:	0.000
PROPYLENE	C3H6:	0.000	CARBON DIOXIDE	CO2:	45.000
ISOBUTANE	ISOC4H10:	0.000	HYDROGEN	H2:	0.000
NORBUTANE	NORC4H10:	0.000	OXYGEN	O2:	0.500
ISOPENTANE	ISOC5H12:	0.000	NITROGEN	N2:	4.500
NORPENTANE	NORC5H12:	0.000	HELIUM	HE:	0.000
NEOPENTANE	NEOC5H12:	0.000	HYDROGEN SULFIDE	H2S:	0.000
HEXANE	C6H14:	0.000			
TOTAL (Volume %) : 100.000					
CATERPILLAR METHANE NUMBER: 145.2 ←					
COMPRESSIBILITY FACTOR: 0.997					
STOICH A/F RATIO (Vol/Vol): 4.765					
STOICH A/F RATIO (Mass/Mass): 4.719					
SPECIFIC GRAVITY (REL TO AIR): 1.010					
RELATIVE POWER CAPABILITY TO 905 BTU/FT3 (35.64 MJ/NM3) FUEL: 92%					
BTU/FT3 MJ/NM3					
LOWER HEATING VALUE: 456 17.96					
HIGHER HEATING VALUE: 508 19.99					
WOBBE INDEX: 454 17.88					

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Landfill Gas Contaminants

- Landfill gas contains corrosive contaminants
 - 4 categories of corrosive contaminants:
 - Sulfur compounds
 - Halide compounds
 - Acids
 - Silicon compounds

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Landfill Gas Contaminants

- Hydrogen Sulfide, H₂S
 - Forms sulfuric acid
 - Corrodes copper containing metals

- Halogenated Hydrocarbons
 - CFCs break down during combustion, releasing:
 - Chlorine
 - During combustion forms hydrochloric acid
 - Corrodes piston rings, cylinder liner, exhaust valves
 - Fluorine
 - Forms hydrofluoric acid
 - Eats engine

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Landfill Gas Contaminants

- Silicon
 - 2nd most common element on earth >> (Also common in landfills)
 - Causes corrosive wear
- Siloxanes
 - Common in cosmetics, cleaners, lubricants
 - Can be found in bio-gas and water vapor in the gas
 - Leads to deposits in combustion chamber
 - Buildup on valves can cause guttering, abrasive wear
 - Test for siloxanes

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Landfill Gas Clean Up

- Principal Goal Is To Protect The Engine
- Trade Off Between Capital Cost vs. Reduced Maintenance Intervals
- Fuel Pre-Treatment Design
 - Compromise
 - Fuel Good Enough To Allow Engine operation While;
 - Performing Reasonable Maintenance Regimen

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Landfill Gas Clean Up

Typical Fuel Gas Clean Up Components

- Inlet Scrubber And Fuel Filter
 - Remove Water Droplets and Trap/Remove Solids
- Demister
 - Oil Removal
- Gas To Air Cooler
 - Lowers temperature Of Compressed Gas/Removes More Liquids
- Gas To Gas Heat Exchanger
 - Pre-cools Gas Entering Gas Drier
- Gas Drier
 - Refrigeration Unit
 - Effectively Reduces Halogens And H₂S

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Air Quality Regulations

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Federal Emissions Standards

What are the EPA NSPS?

- NSPS (New Source Performance Standards) implement section 111(b) of the Clean Air Act (CAA) and are issued for categories of sources which cause, or contribute significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare.

- Standards apply to new stationary sources of emissions (sources) whose construction, reconstruction, or modification begins after a standard for those sources is proposed.

- Cover Stationary applications
- Form minimum US emissions requirements
- Local rules, if stricter, take precedence

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New Source Performance Standards

Proposed NSPS for STATIONARY SI ICE (10/16/2007)		2006	2007	2008	2009	2010	2011	2012
NOx / CO / NMHC		12-Jun	01-Jan	01-Jul	01-Jan	01-Jul	01-Jan	01-Jul
EPA SI NPRM Review		<Effective	Final					
RB Natural Gas **	>= 500 bhp		2 / 4 / 1			1 / 2 / 0.7		
	26 - 499 bhp			2 / 4 / 1			1 / 2 / 0.7	
LB NG & LB LPG **	>= 1350 bhp		2 / 4 / 1			1 / 2 / 0.7		
	500 - 1349 bhp		2 / 4 / 1			1 / 2 / 0.7		
	26 - 499 bhp		2 / 4 / 1			1 / 2 / 0.7		
R&M *	>= 500 bhp	3 / 4 / 1 - w/build date prior to 7/1/07						
	26 - 499 bhp	3 / 4 / 1 - w/build date prior to 1/1/08						
LFG/Bio/Ag	>= 500 bhp		3 / 5 / 1			2 / 5 / 1		
	26 - 499 bhp			3 / 5 / 1			2 / 5 / 1	
R&M	>= 500 bhp	3 / 5 / 1						
	26 - 499 bhp	3 / 5 / 1						
Emergency ***	> 25 bhp				2 / 4 / 1			
R&M	> 25 bhp	3 / 4 / 1 - w/build date prior to 1/1/09						
New SI, All fuels, all apps.	<=25 bhp				Mandatory Certification via Part 90			
R&M	<=25 bhp	Requirements of Part 90						
Gasoline & RB LPG	>= 500 bhp			Mandatory Certification via Part 1048				
	26 - 499 bhp			Mandatory Certification via Part 1048				
R&M	> 25 bhp	Requirements of Part 1048						

1. All new engines in this table, not listed as having a mandatory certification requirement, must be shown to be site compliant or may optionally be certified to this standard.
 - a. New Certified: No NSPS site test (local or state tests not prohibited) until R or M
 - b. New w/o Factory Certification: Initial compliance test, <500 bhp - no further test until R or M, >=500 bhp compliance test every 3 years or 8,760 hours.
 - c. R or M: Initial compliance test, <500 bhp - no further test until next R or M, >=500 bhp compliance test every 3 years or 8,760 hours.

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Low Energy Fuel Generator Sets

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Caterpillar G3500 Low Energy Fuel Generator Sets

- **230°F (110°C) Jacket Water outlet temperature**
 - Protects internal engine components from corrosion and from condensation of sulfuric and other acids
- **Positive crankcase ventilation**
 - With warmed intake air to prevent condensation and corrosion from blow-by gasses with fuel borne contaminants
 - Extends oil life



Caterpillar G3500 Low Energy Fuel Generator Sets

- **Corrosion resistant A/C core**
 - Match current Caterpillar corrosive fuel requirements
- **Oversized corrosion resistant fuel system for very low inlet fuel pressure**
- **Bright metals removed from areas that might contact fuel, blow-by with fuel borne contaminants**



Caterpillar G3500 Low Energy Fuel Generator Sets

Feature Basic Structure	G3516A	G3516A+	G3520C
Rating	810	925	1600
Efficiency	30.5	34.6	41.2
Exh Manifold	Wet	Dry	Dry
Air Flow	"U" Flow	"U" Flow	Cross Flow
Turbos	Rear Mounted	Rear Mounted	Front Mounted
Air Intake Manifold	Inboard	Inboard	Inboard
Exhaust Manifold	Inboard	Inboard	Outboard
Spark Plug Type	J-gap	J-gap	J-gap
JW Design Temp	230° F (110° C)	230° F (110° C)	230° F (110° C)
A/F Ratio Standard?	No	No	Yes
A/F Ratio Type Available	O ² Sensor Based	O ² Sensor Based	Charge Air Density
Detonation Sensors	1 per Side	1 per Side	1 per Cylinder
Methane % Adjust Capability	Manual	Manual	Automatic

Emissions Capabilities	G3516A	G3516A+	G3520C
Rated NO _x Emission	2.0	1.0	1.0, 0.5
Minimum NO _x Emissions	1.5	0.6	0.5
CO Emission Level, Nominal	1.9	2.7	2.5
CO Emission Level, Not to exceed	3.1	4.4	4.7

(G/bhp-hr)

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The Caterpillar Dealer...

Your Source for:

- Sales
- Information
- Parts
- Service



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The Caterpillar Dealers - Sales

- Generator Set Sales
 - Typical configuration: 1,600ekW, 4,160-volt, block heater, pre-lube pump, lube oil make-up, etc.
 - Balance of Plant Equipment
 - Radiator
 - › Round tube design
 - › No solder or gasket joints to fail or leak
 - › Robust to withstand higher temperatures and pressure.
 - › Large expansion tanks
 - › Low fan power and noise.
 - › Higher upfront cost and efficiency.
 - Exhaust Silencer – stainless?
 - Paralleling Switchgear
 - Enclosures

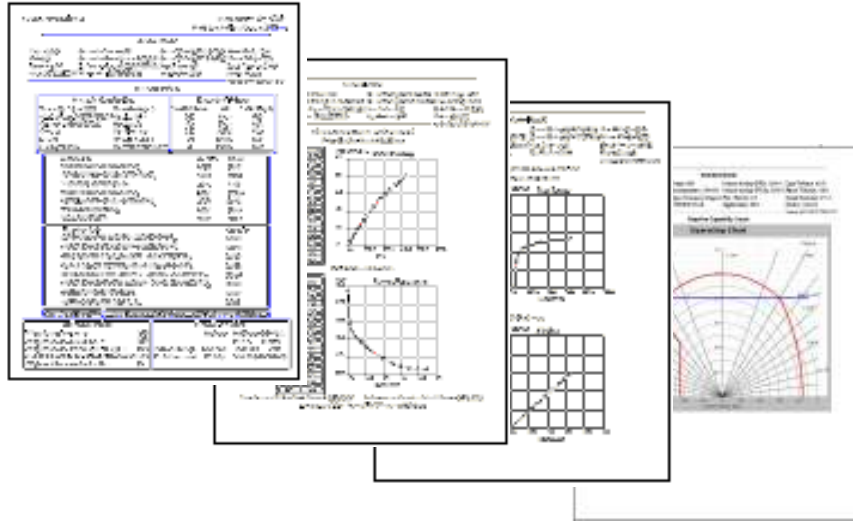
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The Caterpillar Dealers - Information



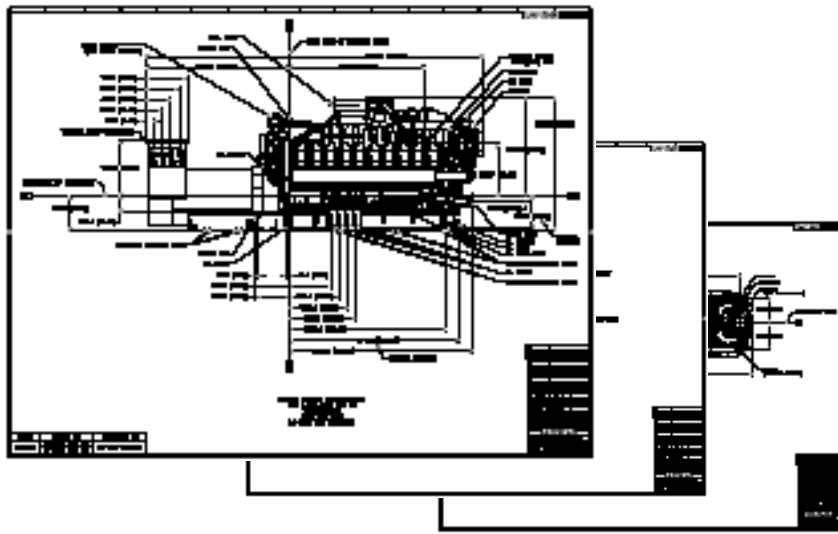
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The Caterpillar Dealers - Information



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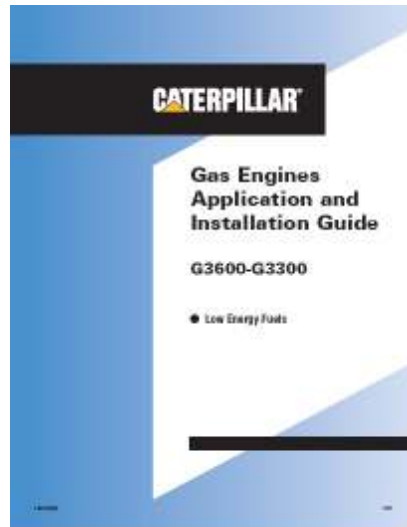
The Caterpillar Dealers - Information



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Application & Installation Guides

- Engine Room Design Considerations
- Mounting Systems
- Exhaust Systems
- Air Intake, Exhaust, Engine Room Ventilation, Crankcase Ventilation
- Vibration & Noise
- Cooling & Lubrication
- Fuel Systems
- **Low Energy Fuels**



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Application & Installation Guides

- Application & Installation Recommendations
 - Plant Layout Considerations
 - Access
 - Prevailing wind
 - Engine Room
 - Ventilation
 - Lighting
 - Water
 - Compressed Air
 - Keep Maintenance in Mind – lay-down area, drains
 - Portable A-frame hoist
 - Storage – Coolant, Oil

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Application & Installation Guides

- Application & Installation Recommendations
 - Things to avoid
 - Chilling the engine – condenses water/acid in crankcase
 - Fuel pressure fluctuations greater than 0.25 PSI – Instability
 - Fuel Processing / Clean-up
 - Crankcase Ventilation

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Application & Installation Guides – Contaminant Levels

		Standard Engine	Low Energy Fuel Engine
Sulfur Compounds as H ₂ S See footnote (1,2)*	mg H ₂ S/MJ ug H ₂ S/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.	

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The Caterpillar Dealer - Parts & Service Support

- Service indicators
 - Top End – Recession of exhaust valve stems. (~8,000 hr)
 - In-Frame – Increase in cylinder blowby, oil consumption, variation of or decrease in compression. (~24,000 hr)
 - Major – Power output, reduced oil pressure, wear metal analysis of the lube oil, noise, vibration. (~40,000 hr)

All of the above vary with fuel quality

- Inspect, Repair, or Replace
 - Ensure that the components are operating within the appropriate specifications.

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Thank you

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