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Low Energy Gas Design - Considerations

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Agenda

- Basics
- Fuel Options
  - ➢Agricultural Gas
  - ➢Sewage Gas / Waste Water Treatment Plant
  - ➢Landfill Gas
  - ➢Coal Mine Methane
- Summary

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Basics

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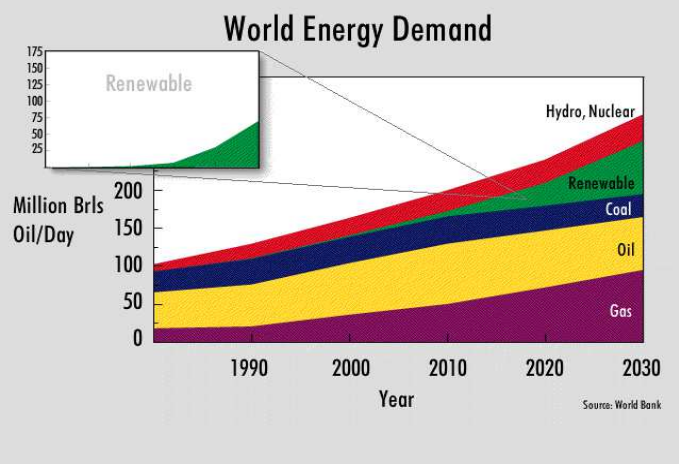
Renewable Energy Market Growth Projections



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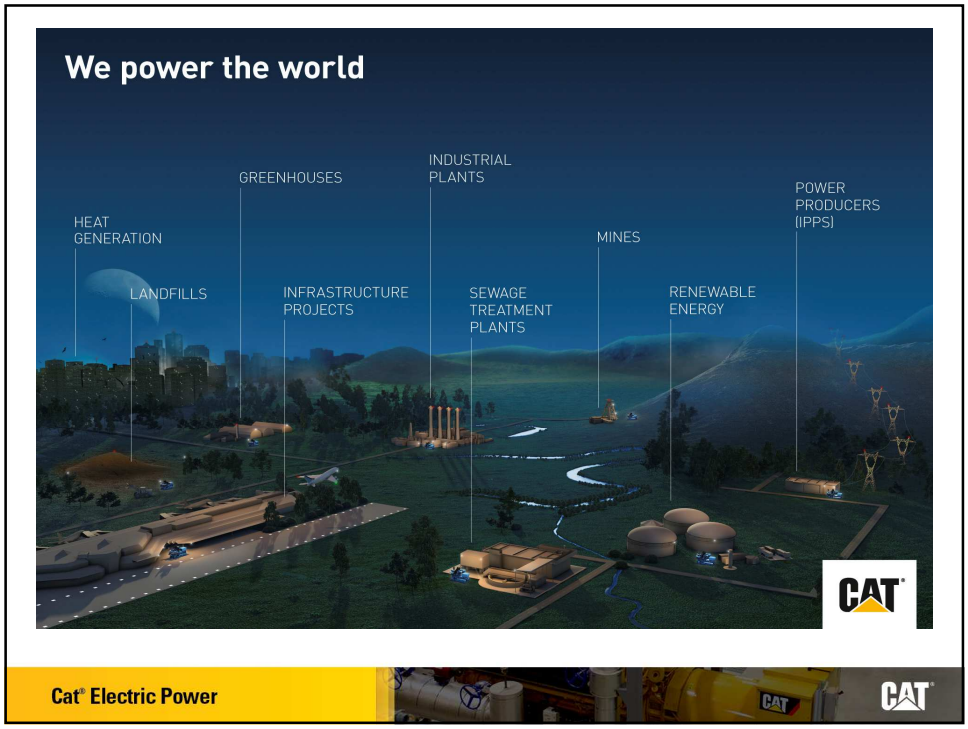
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MINES
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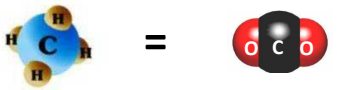
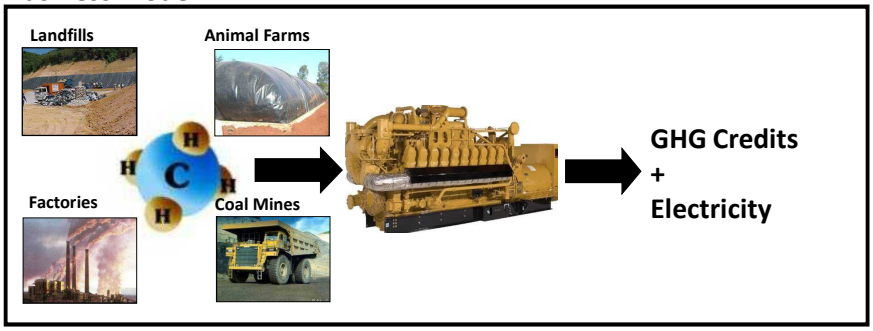
Sustainability: Methane Reduction

Global Warming Potential

1 Methane = 23 Carbon Dioxide



Business Model



Basic Considerations

Biogas compared to Natural Gas

- Higher Methane Number – lower risk of knocking
- Lower Heat Value is lower
- Higher contaminant load
- Larger Fuel Delivery System
- Accompanying gases often take part in combustion and lead to acids, deposits, abrasive particles

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Agricultural Biogas

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Extraction of ag biogas

- Breakdown of organic matter in the absence of oxygen
- E.g. $C_6H_{12}O_6 \rightarrow 3CO_2 + \mathbf{3CH_4}$
- Accompanying substances: hydrogen sulphide, moisture

Source	Biogas in m³ per ton	Methane
Maize Silage	202	52%
Rye	163	52%
Forage Beet	111	51%
Biowaste	100	61%
Chicken Dung	80	60%
Sugar Beet	67	72%
Pig Dung	60	60%
Cow Dung	45	60%
Grain	40	61%
Pig Manure	28	65%
Cow Manure	25	60%

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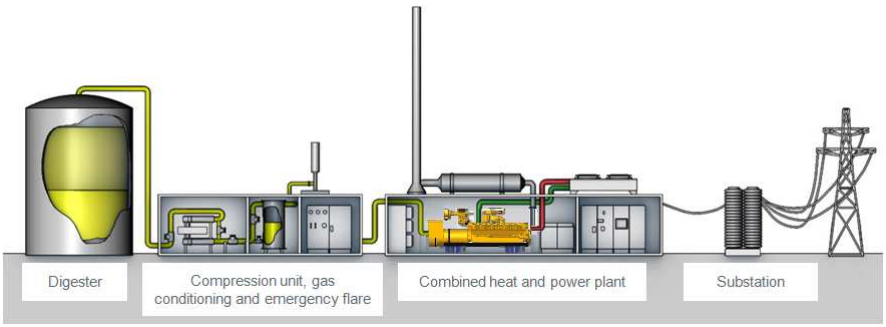
How ag biogas can be used

Extraction › Conditioning › Usage › Net entry



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Typical gas composition ag biogas

Compounds	Spread	Common
Methane (CH_4) in %	45-70	50
Carbon dioxide (CO_2) in %	25-55	50
Nitrogen (N_2) in %	0,01-5	~ 0
Oxygen (O_2) in %	0,01-2	~ 0
Hydrogen sulfide (H_2S)	25-500 ppm	150 ppm
Ammonia (NH_3)	0,01-2,5 mg/m³	0,7 mg/m³

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Typical ag biogas plants

- Use of manure and corn in a two step digester
  → Methane, CO_2, H_2S
- Engine heat to warm the digester and used for district heating
- Electrical power normally fed to the grid

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Challenges ag biogas

1. Humid biogas
2. High amount of hydrogen sulfide (H_2S)
3. Formaldehyde in exhaust gases

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Gas Dryer

1. Gas from fermenter
2. Gas cooled down / droplet separator
3. Gas heated up for transport to genset

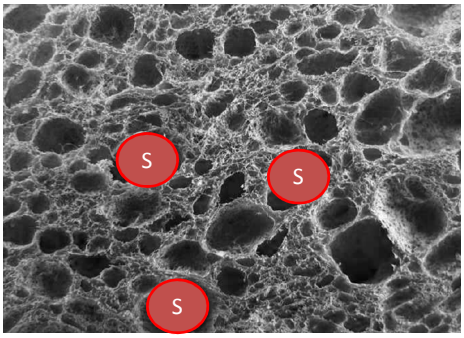
Activated Carbon Filter for Hydrogen sulfide (H_2S)

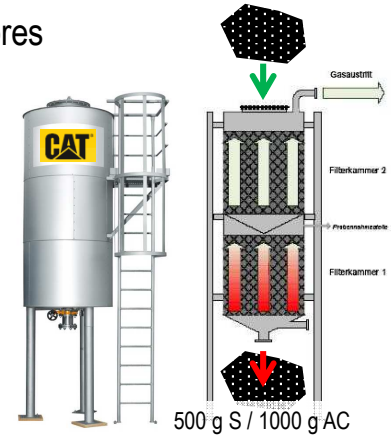
H2S → Gas engine → SO2 → Catalytic converter → SO3 → Heat exchanger → H2SO4 (Sulphuric acid)

- H_2S combusts to SO_2
- The catalytic converter oxidizes SO_2 to SO_3. SO_3 condenses as H_2SO_4 (sulfuric acid) in the exhaust gas heat exchanger
- Risk: Deposits, Corrosion, Significant reduction of Lube oil lifetime

Activated Carbon Filter for Hydrogen sulfide (H_2S)

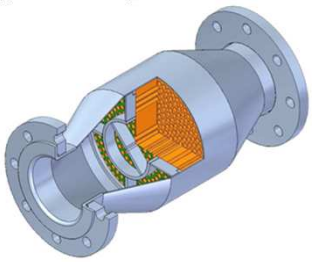
- $2\ H_2S + O_2 \rightarrow 2\ S + 2\ H_2O$
- Sulphur (S) is being collected in pores





Formaldehyde in exhaust gases

- Cancer-Causing
- Limit according to German guideline 60 mg/m^3
- Formaldehyde reduced: $HCHO + O_2 \rightarrow CO_2 + H_2O$
- Carbon monoxide reduced: $2CO + O_2 \rightarrow 2CO_2$
- Only with H_2S completely filtered
- Addition of an Oxi-Catalyst



Genset / Engine
3 x CG132-12

Segment / Fuel Type
Biogas

Customer / Operator
Biogas Göttingen GmbH & Co. KG
Stadtwerke Göttingen AG, Germany

Total Output
1,8 MWe

Installation / Commissioning
December 2011

With the heating system, close to the Göttinger tax office standing three gas engines with each rating of 600 kW from type CG132-12 , are generated annually by the combustion of biogas from the region 25 million kWh of heat and electricity for 5,000 homes. The produced biogas replaces 600 liters oil per day, so that spares the environment annually 10 000 t of greenhouse gases.

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Sewage Gas - Waste Water Treatment Plant

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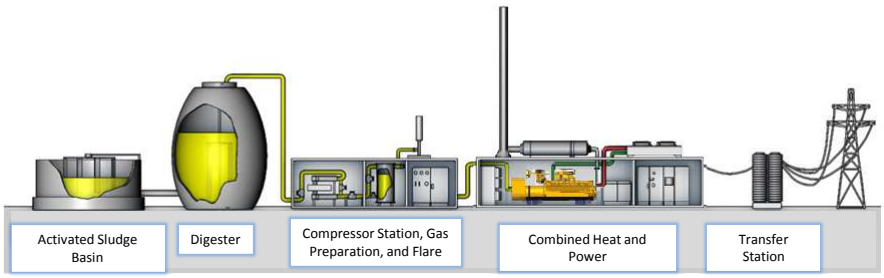
Extraction of sewage gas

- **Extraction:** Sewage gas is produced in the digestion towers of wastewater treatment plants
- **Step 1** Mechanical cleaning
- **Step 2** Biological cleaning
- **Step 3** Additional wastewater treatment
- **Step 4** Sludge treatment, the sewage sludge is digested inside the digestion towers. After 12-24 days **sewage gas results**
- Accompanying substances: hydrogen sulphide, siloxanes

How sewage gas can be used

Extraction → Conditioning → Usage → Net entry



Typical Sewage Gas Composition

Compounds	Spread	Common
Methane (CH_4) in %	50-75	65
Carbon dioxide (CO_2) in %	15-45	35
Nitrogen (N_2) in %	<1%	0

Further compounds	Amount
Hydrogen sulfide (H_2S) in ppm	10-10000
Siloxanes in mg/Nm³	30

- Heating value between 6-6,4 kWh/m³
- Variable methane contents due to several organic feed materials

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Challenges sewage gas

1. High Humidity
2. High amount of hydrogen sulfide (H_2S)
3. Siloxanes

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Siloxane Cleanup Skid

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Genset/Engine
7 x CG170-16 K

Segment/Fuel Type
Sewage Gas/Natural Gas

Customer/Operator
Melbourne Water Corporation, Australia

Total Output
9,8 MWe

Installation/Commissioning
2002

The plant can convert the emerging sewage gas to electricity so that the energy demand is satisfied. These gas gensets convert natural and sewage gas to 1.4 MW electricity each, at a temperature of 35° C. The thermal output accounts for 1.4 MW per engine as well.

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Landfill Gas

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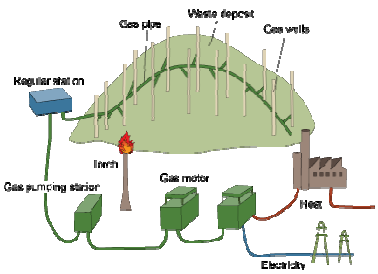
Extraction of landfill gas

- Digestion of organic waste in closed landfills.
- Within the useful life (15-20 years) of a landfill one ton of waste is producing 100-200 m³ (3500 – 7000 ft³) landfill gas
- Only the gas from the anaerobic non-stable methane phase and the stable methane phase can be used
- The composition of the landfill gas changes over the years (CH_4-content diminishing)
- The gas is extracted from the landfill through wells



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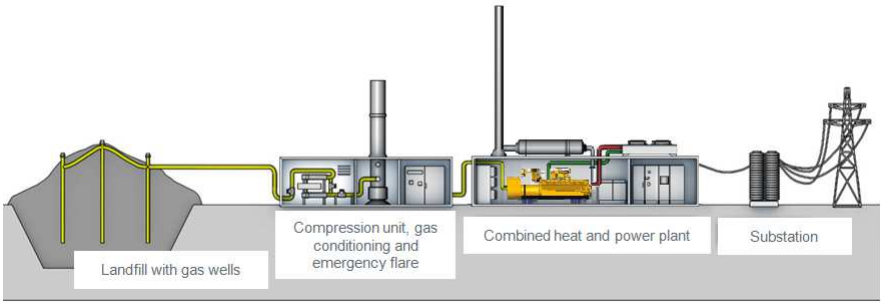
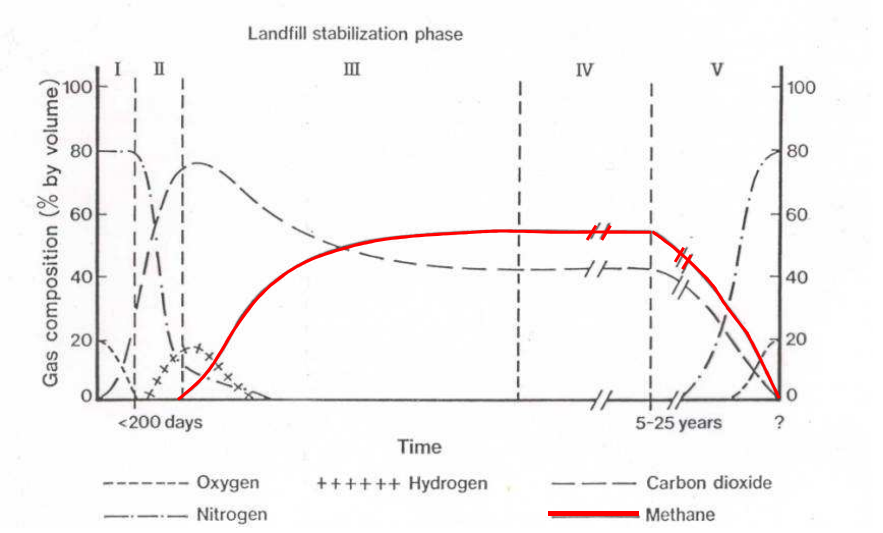
How can landfill gas be used

Extraction › Conditioning › Usage › Net entry



Gas production curve



Composition of Landfill Gas

- Typical composition of landfill gas

Compounds	Spread	Common
Methane (CH_4) in %	35-65	50
Carbon dioxide (CO_2) in %	20-45	27
Nitrogen (N_2) in %	10-35	23
Oxygen (O_2) in %	0-10	0

Further compounds	Amount
Ammonia (NH_3) in mg/Nm³	0-50
Chlorinated hydrocarbons (CKW) in mg/Nm³	10-600
Hydrogen sulfide (H_2S) in ppm	5-1000
Organic silicon compounds in mg/Nm³	3-300

Challenges of Landfill Fuel

1. High Humidity
2. High amount of hydrogen sulfide (H_2S)
3. Siloxanes

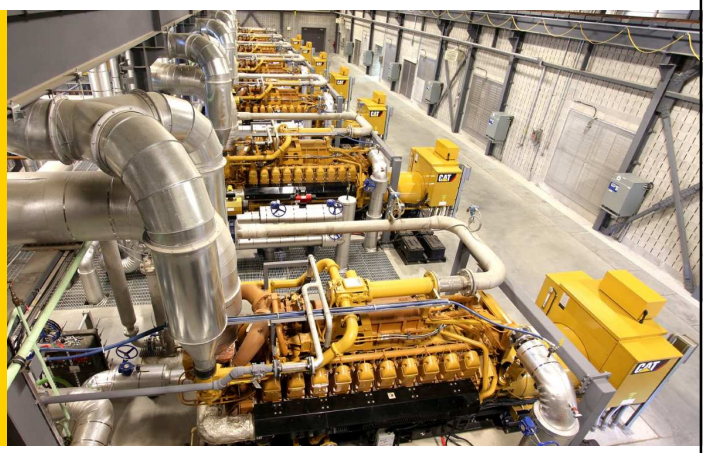
Genset/Engine
7 x G3520C

Segment/Fuel Type
Landfill Gas

Customer/Operator
EBI Energie, Canada

Total Output
9.4 MWe

Installation/Commissioning
2012



At its cogeneration plant, EBI Énergie pumps 4,500 standard cubic feet of methane per minute to six Cat® G3520C gas generator sets that convert the gas to electricity. The plant recovers jacket water heat from the engines to heat leachate treatment ponds in colder months.

EBI Énergie won and signed a 25-year agreement with Hydro-Québec to produce 9.4 MW of renewable electricity through 2036

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Coal Mine Methane

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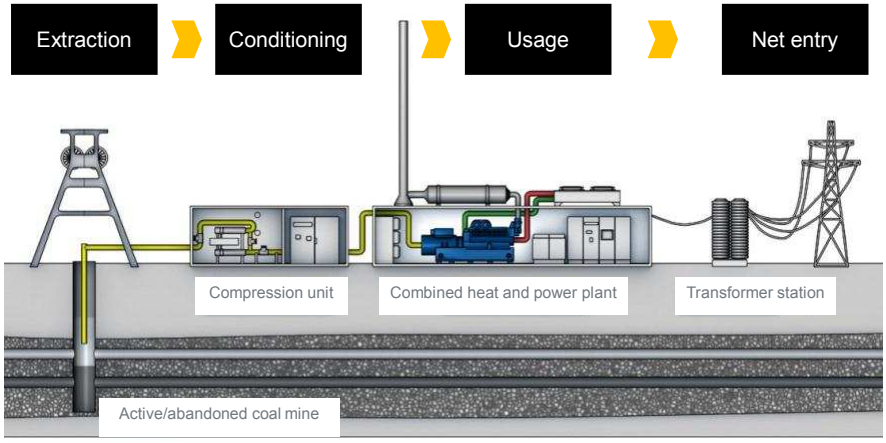
How can I use Coal Mine Gas?



Types of Coal Gas

1. Methane from unexplored coal beds
   - Coalbed methane **(CBM)**
   - Nearly natural gas quality
2. Methane from active underground mining
   - Coal Mine Methane **(CMM)** or Coalseam methane **(CSM)**
   - Coal Mine Gas out of active coal mining can be lean gas (<40% CH_4)
3. Methane exhausted from abandoned mines
   - Abandoned mine methane **(AMM)**
   - Hardly combustible due to high CO_2/N_2-shares
   - Methane content diminishes over time and can be below 30%

Composition

Compounds	CBM	CMM	AMM
Methane (CH_4) in $\%_{vol}$	90-95	<20-70	<20-80
Carbon dioxide (CO_2) in $\%_{vol}$	2-4	1-6	8-20
Carbon Monoxide (CO) in $\%_{vol}$	0	0,1-0,4	0
Oxygen (O_2) in $\%_{vol}$	0	7-17	0
Nitrogen (N_2) in $\%_{vol}$	1-8	4-40	5-60

- Global/regional differences for the methane content, e.g China extremely low CH4-content (down to 12%)
- The gas has to be analysed to its compounds before energetic utilization

Benefits of the use of Coal Mine Gas

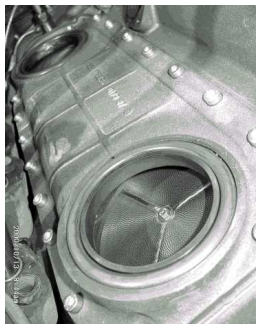
1. Save the environment by capturing and using methane
   - Methane is up to 25 times more powerful than CO_2 as a greenhouse gas
2. Financial benefits
   - Income from using Coal Mine gas to generate electricity and/or heat
   - Generation of CO2-certificates by avoiding methane emissions
   - Utilization of Coal Mine Gas can be required by law
   - Feed-in-tariffs for electricity generated out of Coal Mine Gas
3. Improve mine safety by preventing pit explosions (risk at 4-16% CH4)

Challenges of CMM

1. Difficulty of humid Coal Mine Gas
2. Dust loading of Coal Mine Gas
3. Danger of explosion
4. Fluctuating CH_4-contents
5. Low CH_4-contents from AMM

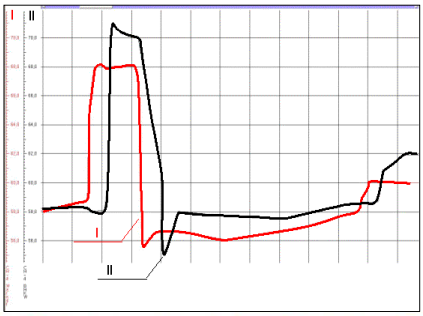
Danger of Explosion

- Installation of blaze barriers in front of the gas control train and inside the engine, that prevents the ignition of the gas mixture by a spark or a leaky valve
- Installation of Flame Arrestors in the engine



Fluctuating CH_4-contents

- A CH_4 sensor is installed at an early stage of the gas supply line in order to allow the gas mixer to adapt to the air gas ratio in time
- Gas storage tanks can be utilized to keep gas quality consistent



Low CH_4-contents from AMM

- For methane contents >40% no additional measurements required
- For methane contents between 30-40% installation of special gas mixer
- For methane contents <30% the differential pressure between gas and air gets heightened by the use of the low heating value kit in front of the gas mixer

Genset/Engine
60 x G3520C

Segment/Fuel Type
Coal Mine Methane

Customer/Operator
Jincheng Sihe Mine, China

Total Output
120 MWe

Installation/Commissioning
2008

This is the largest CMM project worldwide. It produces 120 MWe at 1060 meters altitude in a combined cycle steam turbine application creating a overall system efficiency of 80%. This site produces 840,000 MW hrs/yr sold to the utility with 2.9 MMTCO2e CERs that have an economic value of $45.3M/yr at $15 USD.

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Summary

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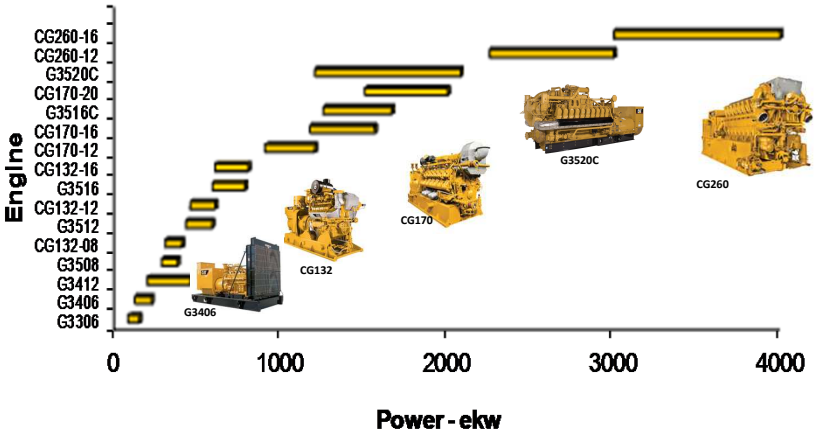
Wide Range of Low Energy Genset Products

- Products from 50-4,000 kW
- Over 12,900 MW of gas product in service



Fuel specification guidelines

- **Heat Value**: 13.8 – 23.6 MJ/Nm3 (350 – 600 Btu/scf).
- **Heat Value**: Down to 10.8 MJ/Nm3 (275 Btu/scf) with special factory request
- **Methane %**: Min methane content is 30%-45%, depending on other fuel constituents
- **Methane Number**: Min Methane Number of 120-130 (Detonation Margin)
- **Natural Gas**: Landfill units are capable of operation on Natural Gas with special factory request

Contaminant Limits

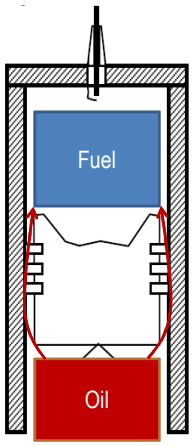
Fuel Contaminant	G3500 Series		CG Series	
	mg/MJ of Fuel	Approx. PPM*	mg/MJ of Fuel	Approx. PPM*
Halides (as Cl)	19	230	0.55	7
Sulfur (as H_2S)	57	730	12.2	155
Siloxanes (as Si)	0.56	9	0.11	1.6
Ammonia	2.81	72	0.17	4

*Based on 500 Btu/scf Fuel

Contaminant Problems

Lube Oil Monitoring

- Monitor Oil Quality Closely for Changes
- Higher sulfate ash content 0.5 - 1.0 wt. %
- More additives to ensure neutralization of acids (fluor, chlor, sulphur)
- Too many unused additives can lead to deposits in combustion chamber



Cat CG Series Service Plans

Value limit list for combustion properties

Gas quality	Low	Medium	High
Sulphur (total S) per 10 kWh	less than 2200 mg	less than 440 mg	less than 15 mg
Hydrosulfide (total H_2S) based on 10 kWh	less than 1500 ppm (corresponds to 0.15 Vol%)	less than 300 ppm (corresponds to 0.03 Vol%)	10 ppm (corresponds to 0.001 Vol%)
Chlorine and fluorine (Sum Cl and F) per 10 kWh	less than 100 mg	less than 20 mg	less than 2 mg
Ammonia (total NH_3) per 10 kWh	less than 150 mg	less than 30 mg	less than 2 mg
Humidity* (relative humidity φ) * at lowest temperature of the entire gas pipe system	less than 80 %	less than 50 %	less than 50 %
Silicon compounds (total VOSiC) per 10 kWh	less than 20 mg	less than 1 mg	0 mg

Example of service plans for CG260:

	Low	Medium	High
General overhaul	48.000 Oh	64.000 Oh	80.000 Oh
Minor overhaul	24.000 Oh	32.000 Oh	40.000 Oh

Questions?

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