Connecting For Success...

ELECTRIC POWER DAYS 2017

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Consideration for Low Energy Gas Design

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Agenda

- Basics
- Sewage Gas
- Landfill Gas
- Agricultural Gas
- Coal Mine Methane
- Summary

Basics

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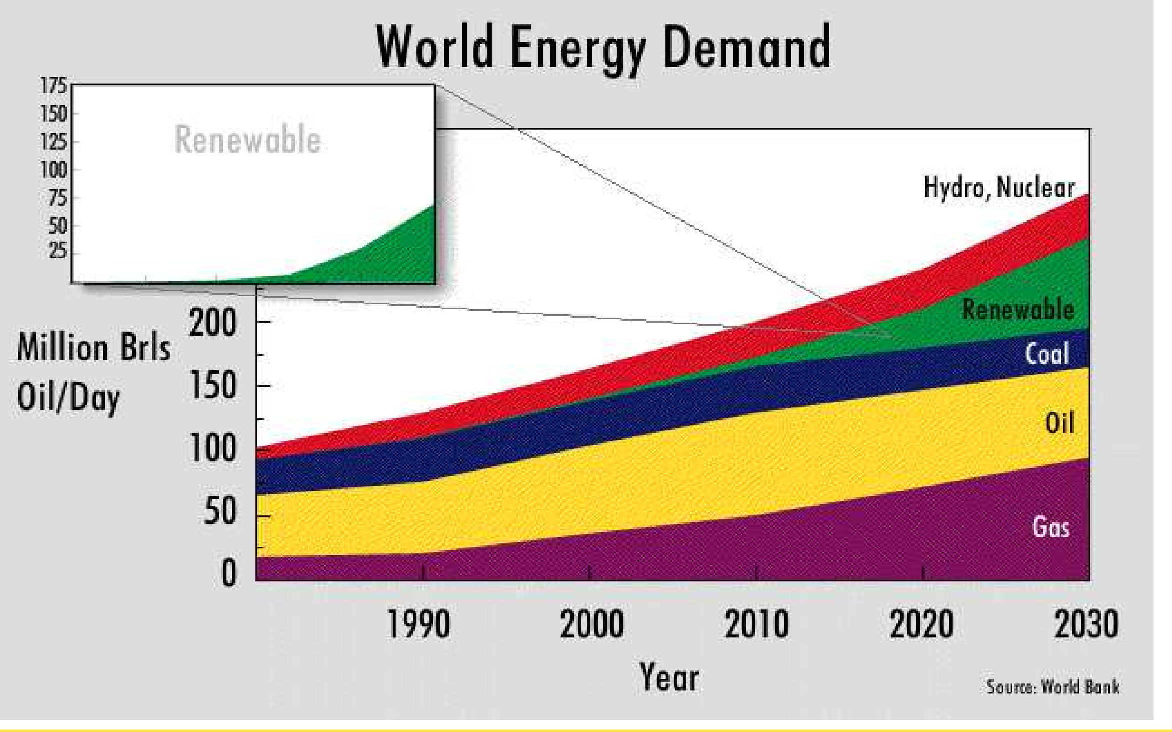
Caterpillar Inc. Sustainability Commitment

"Our vision is to contribute, through our diverse businesses, to a society in which people's basic needs are not only met but fulfilled in a way that sustains the environment."

Renewable Energy Market Growth Projections



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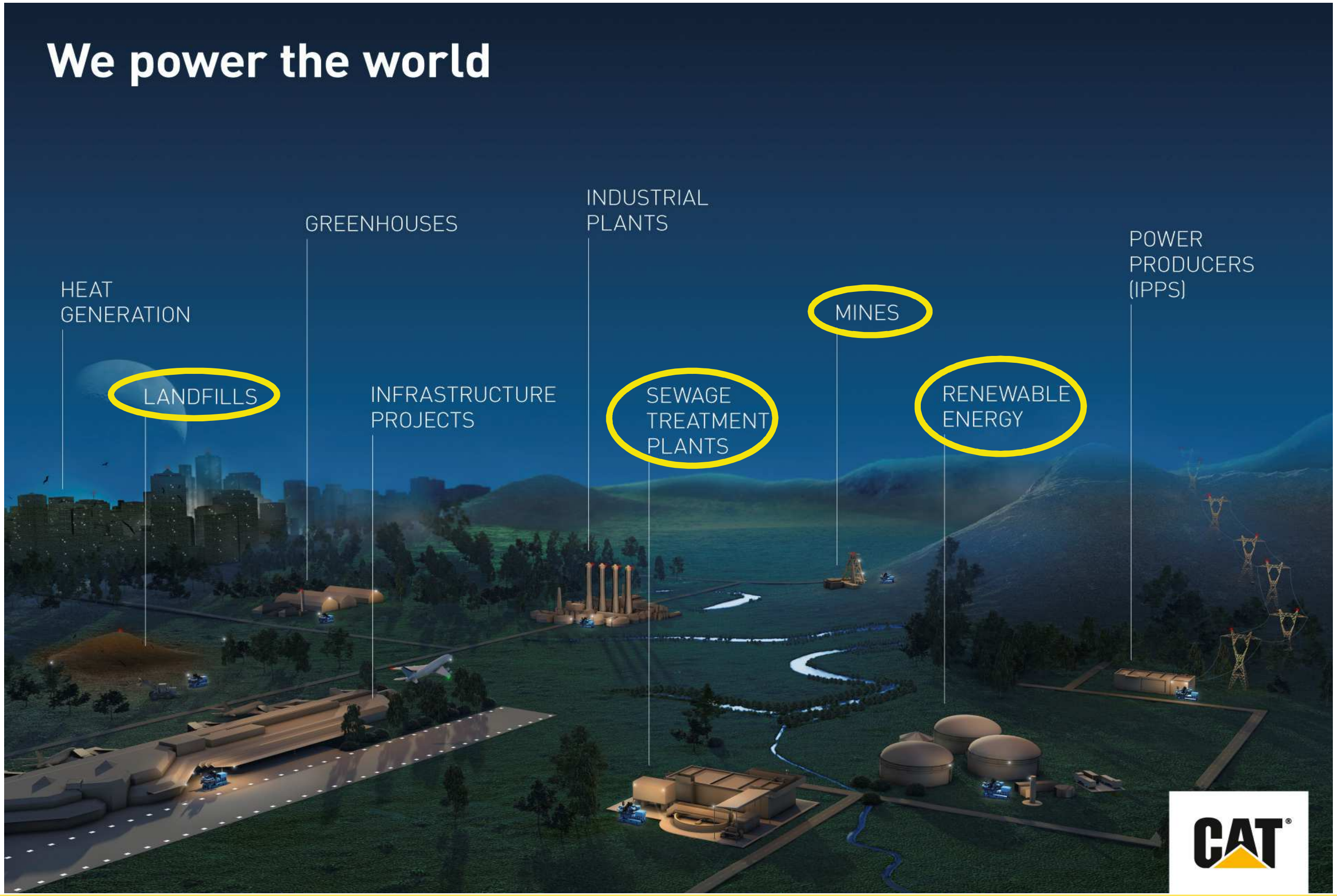

We power the world
HEAT GENERATION
LANDFILLS
GREENHOUSES
INFRASTRUCTURE PROJECTS
INDUSTRIAL PLANTS
SEWAGE TREATMENT PLANTS
MINES
RENEWABLE ENERGY
POWER PRODUCERS (IPPS)
CAT

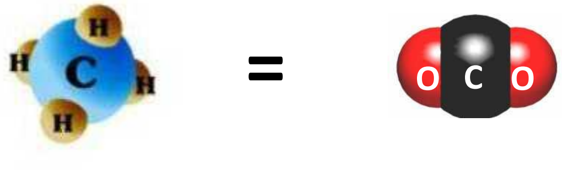
Renewable Energy Experience

- 1947- first Cat® **natural gas generator set**
- 1983- First **Biogas generator sets installed in Chicago, Illinois, USA**
- Today- **More than** 2 GW **of** Biogas **product installed** worldwide**.**
  - **adding about 200 MW/year**
- **More than** 55,000,000 accumulated hours **of operation on biogas.**

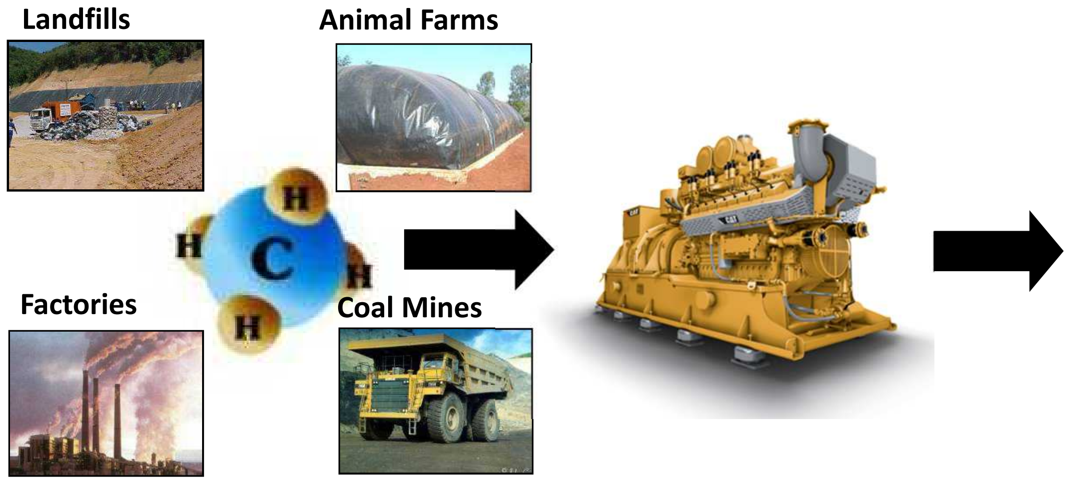
Sustainability: Methane Reduction

Global Warming Potential

1 Methane = **23 Carbon Dioxide**



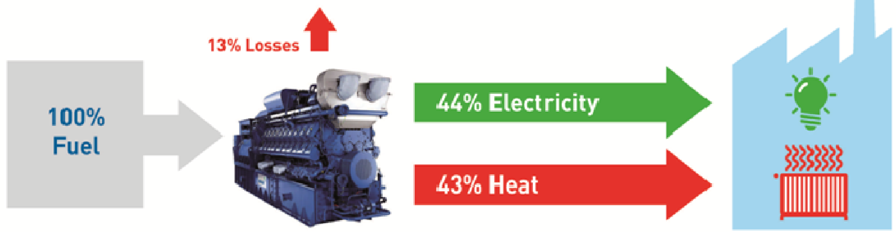
Business Model



GHG (Green House Gas) **Credits plus Electricity**

Input and output of a Gas genset

Renewable Gas



Basic considerations

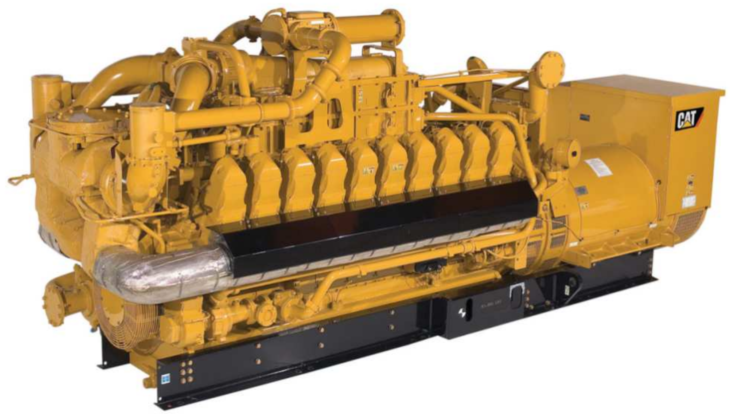
Biogas compared to Natural Gas

- Higher Methane Number – low risk of knocking (self ignition)
- Lower Heating Value compared to Natural Gas is lower
- Larger Fuel Delivery System required
- Higher contaminant load needs to be considered
- Accompanying gases and other compounds take part in the combustion process and lead to acids, deposits, abrasive particles

Basic Design Considerations

Modifications from Natural Gas Engine

- Corrosion Resistant Components (bearings)
- Mixture cooler design and Temp. (to avoid condensation)
- Spark Plugs (more frequent exchange intervals)
- Lube Oil extension (for longer exchange intervals)
- Gas train (lower inlet pressure and LCV, leads to larger dimensions



Sewage Gas

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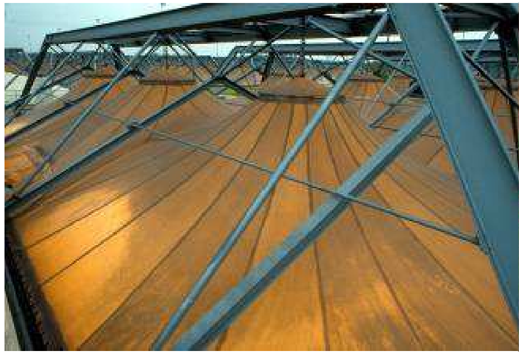
Extraction of sewage gas

Extraction: Sewage gas is produced in the digestion towers of wastewater treatment plants

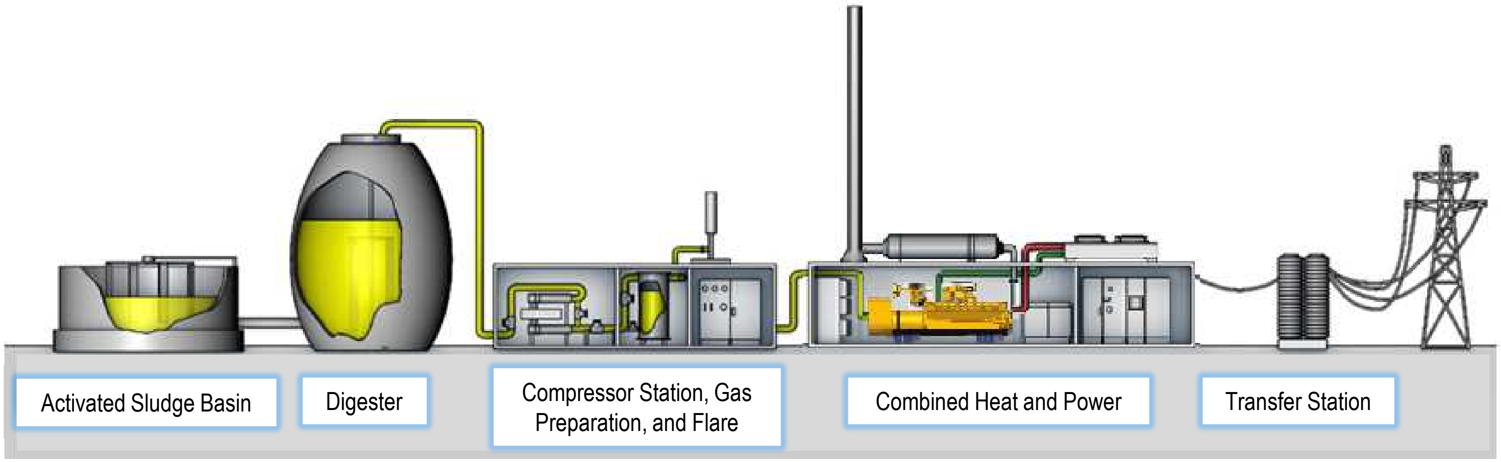
Steps of Waste Water Treatment:

- **Step 1** Mechanical cleaning (removal of solids)
- **Step 2** Biological cleaning (aeration tanks)
- **Step 3** Additional wastewater treatment
- **Step 4** After sludge dewatering it is then fermented within the digestion towers. After 12-24 days of fermentation the **sewage gas can be sucked off and stored in a gas storage tank**
- Accompanying substances: hydrogen sulphide, siloxanes



How sewage gas can be used

Extraction › Conditioning › Usage › Net entry



Typical sewage gas composition

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

Compounds	Range	Normal
Methane (CH_4) in %	50-75	65
Carbon dioxid (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

Challenges

Siloxanes in the sewage gas

- Silicon-containing compounds may damage the engine
  - Siloxane compounds are converted into SiO_2 (= Sand) which is creating deposits inside the combustion chamber.
  - A higher wear on the liners and valves occurs due to these deposits
  - Chipping particles may result blown through exhaust valves

Hydrogen sulfide in sewage gas (H_2S)

- H2S will oxidize to sulfur dioxide and sulphurous acid whilst the combustion process.
  - Corrosion of the engines and other metal parts
  - Lifetime of the lube oil deteriorates due to high sulfur content

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 self-demand is covered. These gas gensets convert natural and sewage gas into 1.4 MW electricity each. The thermal output from Jacket Water and Exhaust gas accounts for 1.4 MW per engine as well.

Landfill Gas

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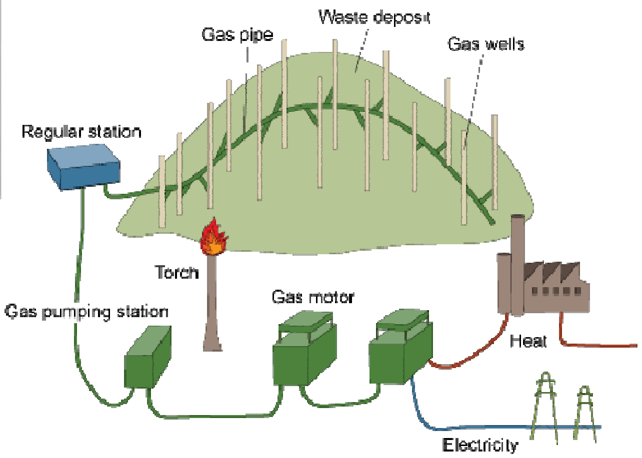
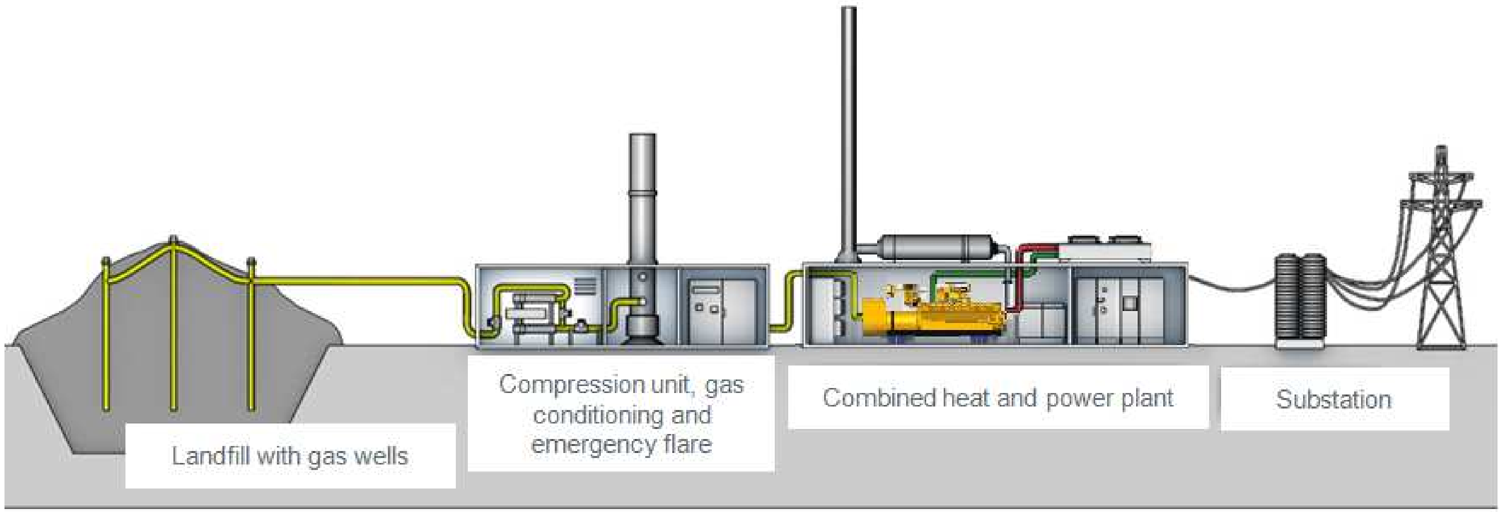
Extraction of landfill gas

- Anaerobic Digestion of organic waste in closed landfills
- Expected time frame to utilize LFG (15-20 years) of the organic landfill deposits, one ton of waste is producing about 100-200 m³ (3500 – 7000 ft^3) of landfill gas
- LFG is a mixture of CH4 and added air which is sucked via non-airtight sealing.
- The composition of the landfill gas may change over the years (CH_4-content diminishing)
- The gas is extracted from the landfill via wells which are connected with sucking blowers

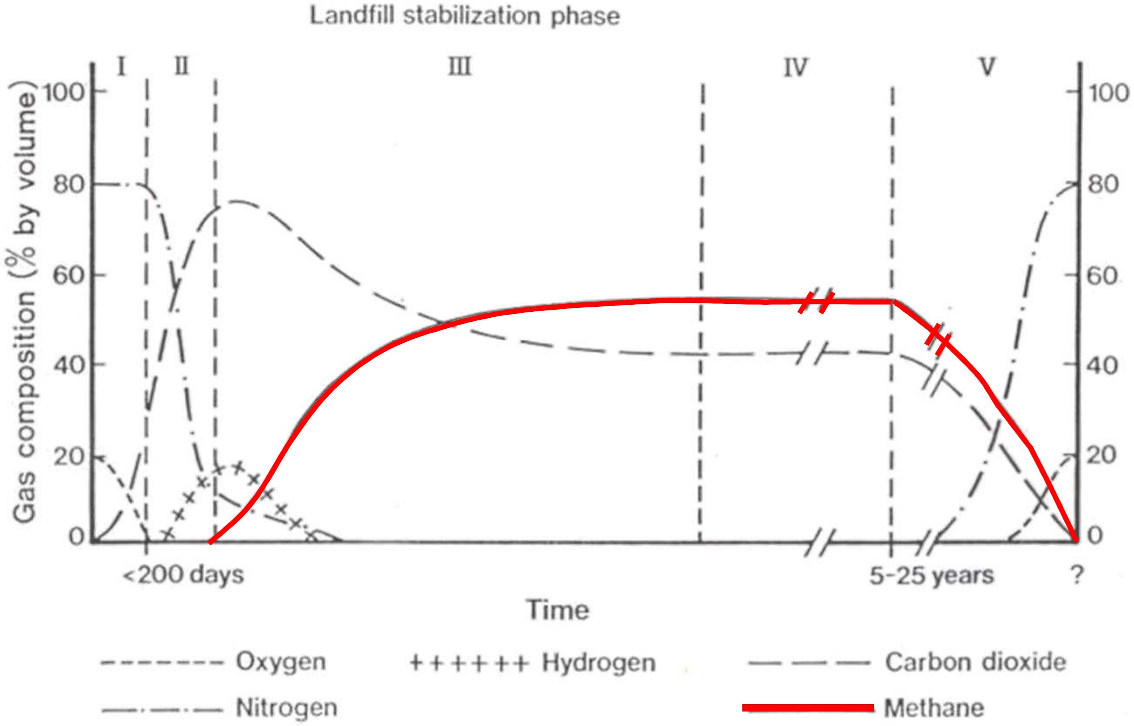


How can landfill gas be used

Extraction ❯ Conditioning ❯ Usage ❯ Net entry



Gas production curve



Composition of landfill gas

Typical composition of landfill gas

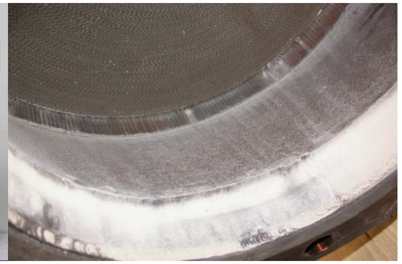
Compounds	Range	Usual
Methane (CH_4) in %	35-65	50
Carbon dioxid (CO_2) in %	20-45	27
Nitrogen (N_2) in %	10-35	23
Oxygen (O_2) in %	0-10	0

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 and solutions

- Halogenated hydrocarbons oxidize and hydrochloric acid or hydrofloric acid are formed
  - Acids lead to corrosion on bearings, cylinder linings, valve stems, valve guides and piston rings
  - Water wash, Gasdrying, Activated carbon filtering
- Silicon-containing compounds may damage the engine
  - A higher wear on the valves occurs due to silicon-containing deposits
  - Chipping particles may result into blown exhaust valves



Volatile organic silicon compounds (VOSiC)

In every combustion engine – independent of design, type and manufacturer organic compounds form:

$$Si_X O_Y (CH_3)_Z + O_2 \rightarrow SiO_2$$

- The chemical compound silicon dioxide, also known as silica, is the
- oxide of silicon, chemical formula SiO_2

Name	Abb.	Sum formula	CAS-Nr.
Tetramethylsilan	TMS	Si-(CH3)4	75-76-3
Trimethylsilanol	MOH	Si-(CH3)3-OH	1066-40-6
Hexamethyldisiloxan	L2	Si2-O-(NH3)6	107-46-0
Hexamethylcyclotrisiloxan	D3	Si3-O3-(CH3)6	541-05-9
Octamethyltrisiloxan	L3	Si3-O2-(CH3)6	107-51-7
Octamethylcyclotetrasiloxan	D4	Si4-O4-(CH3)8	556-67-2
Decamethyltetrasiloxan	L4	Si4-O3-(CH3)10	141-62-8
Decamethylcyclopentasiloxan	D5	Si5-O5-(CH3)10	541-02-6

Examples for VOSiC caused problems

Example

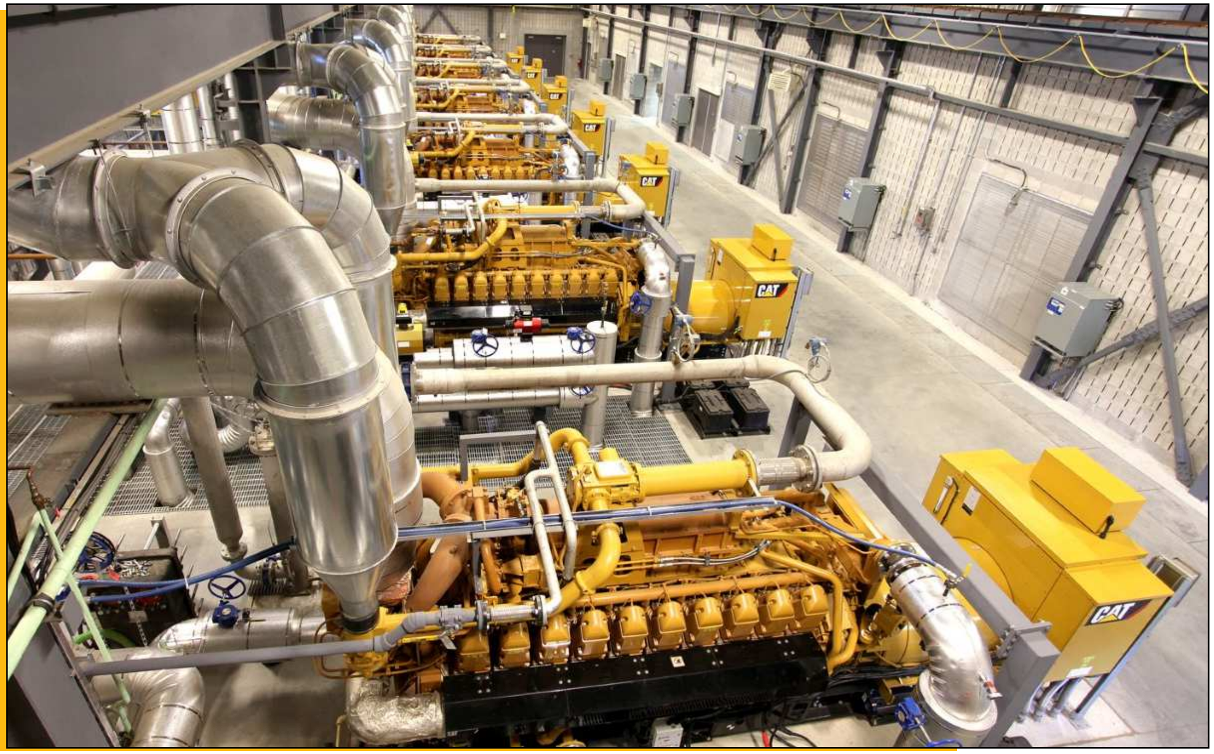
Genset / Engine
7 x G3520C

Segment / Fuel Type
Landfill Gas

Customer / Operator
EBI Energie, Canada

Total Output
9.4 MWe

Installation / Commissioning
2012



At its cogeneration plant, EBI Énergie blows 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 the leachate for water evaporation. Concentrated leachate is brought back to sealed deposits.
EBI Énergie won and signed a 25-year agreement with Hydro-Québec to produce 9.4 MW of renewable electricity until 2036.

Agricultural Gas

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Extraction and Gas Composition of Agricultural Biogas

Extraction process:

- Anaerobic Digestion of Organic Matter
- The resulting biogas is consisting is methane, carbon dioxide, a few nitrogen as well as hydrogen sulfide at high humidity

Substrates / Feedstock

- Different substrates can be fed into the digester
- Renewable resources (NaWaRo), such as maize, sugar cane, cassava, Sudan Grass, hay, etc.
- Agricultural waist, manure and garbage
- Determined means for handling the different substrates
- Methane content may vary depending on the feedstock

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

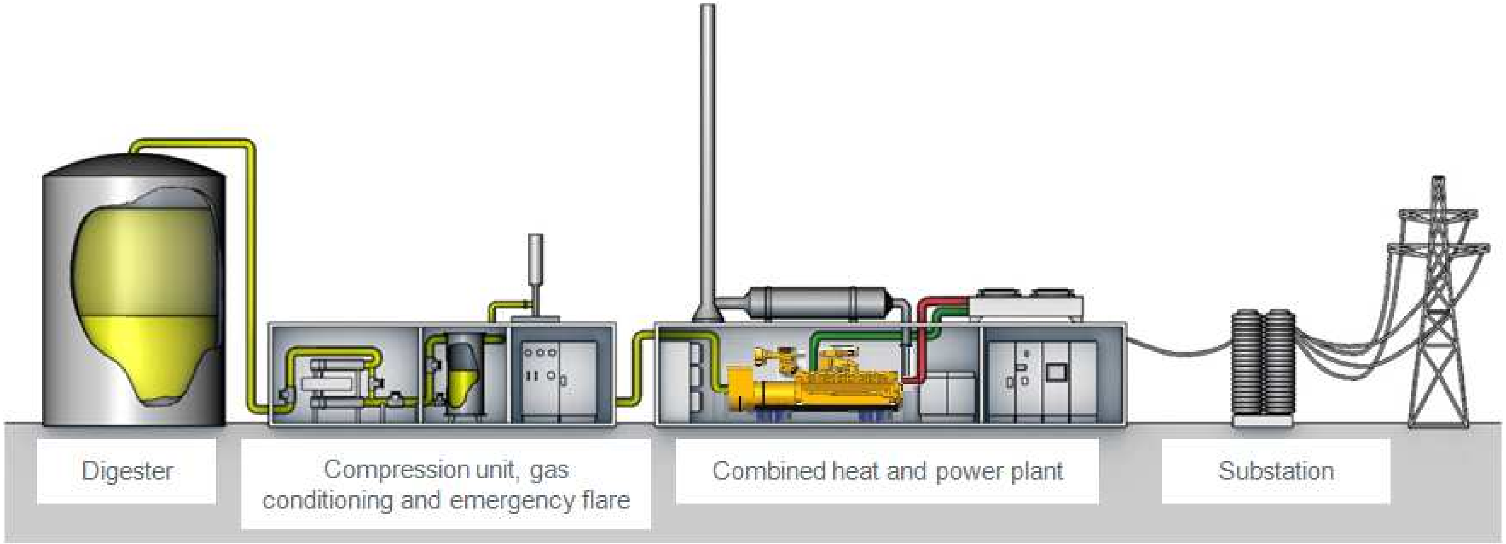
Extraction of Agricultural Biogas

- Biological conversion of organic matter without absence of oxygen
- e.g. $C_6H_{12}O_6$ (Sugar) → $3CO_2$ + **$3CH_4$**
- Accompanying stuff: hydrogen sulphide, moisture

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

How ag biogas can be used

Extraction ❯ Conditioning ❯ Power Generator (CHP) ❯ Feed-in point to utility



Typical agricultural biogas plants

- Feedstock manure and corn into a digester
  → Biogas: Methane, CO_2, H_2S
- Rejected engine heat can be utilized to heat the digester for a well-working biogical process, as well as for district heating of buildings in the neighborhood
- Electrical power is usually fed into the grid (Utility)

Challenges agricultural biogas – Available systems from CES

- Humid biogas - (Gas Dryer)
- High amount of hydrogen sulfide (H_2S) - (Desulphurization) - It is to obeserve the acceptable limit values according to the Technical Circular TR 0199-99-13017/05

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	less than 300 ppm	10 ppm
	(corresponds to 0.15 Vol %)	(corresponds to 0.03 Vol %)	(corresponds to 0.001 Vol %)

- For biological or chemical desulphurization - different systems and means can be provided by Biogas Plant Contractors

Gas Dryer

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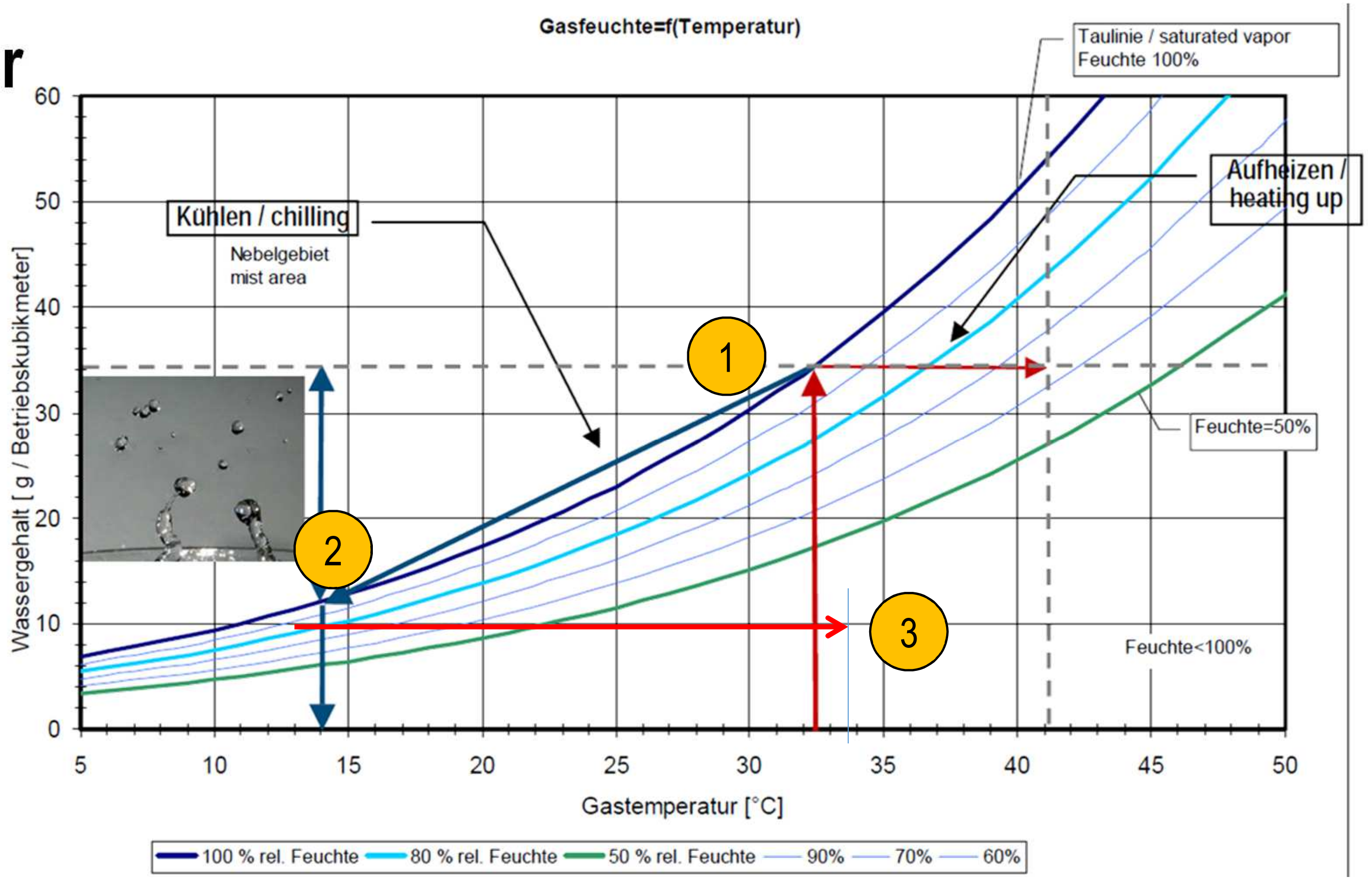
Humid fuel gas – gas dryer

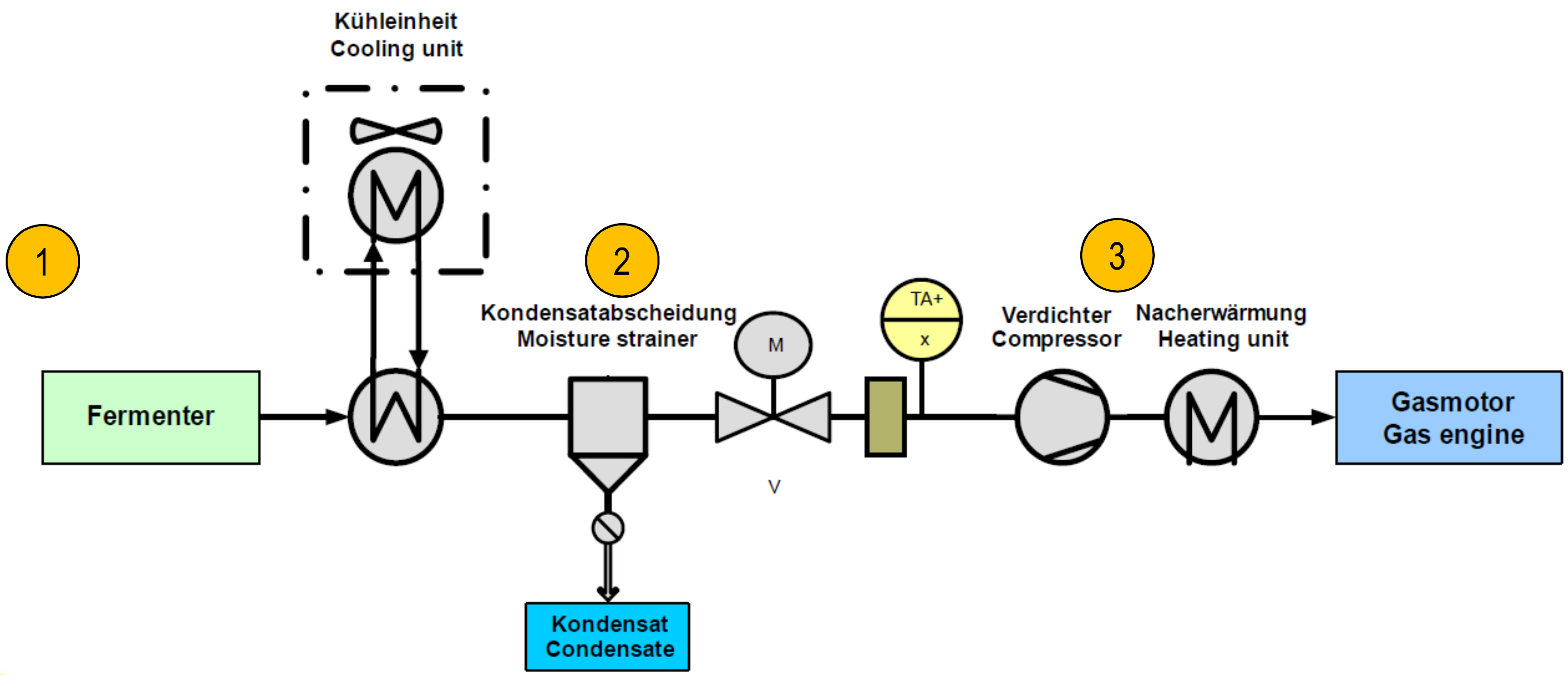
1 Gas from the fermenter

2 Gas chilled / droplet separator

3 Gas after-heated for utilization in the genset



Process of the gas drying



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

Adjecent to the tax office building of Goettingen the biogas plant Rosdorf, equipped with three gas engines CG132-12 rating of 600 kWe each. These are generating 25 million kWh of heat (Warm Water) annually, plus electricity for 5,000 homes by utilizing the biogas from the plant, fed by Biomass from the region.

The produced biogas substitutes 600 liters oil per day, which has an impact of saving 10 000 t of greenhouse gases per year

Coal Mine Methane
In some countries considered as Renewable Energy

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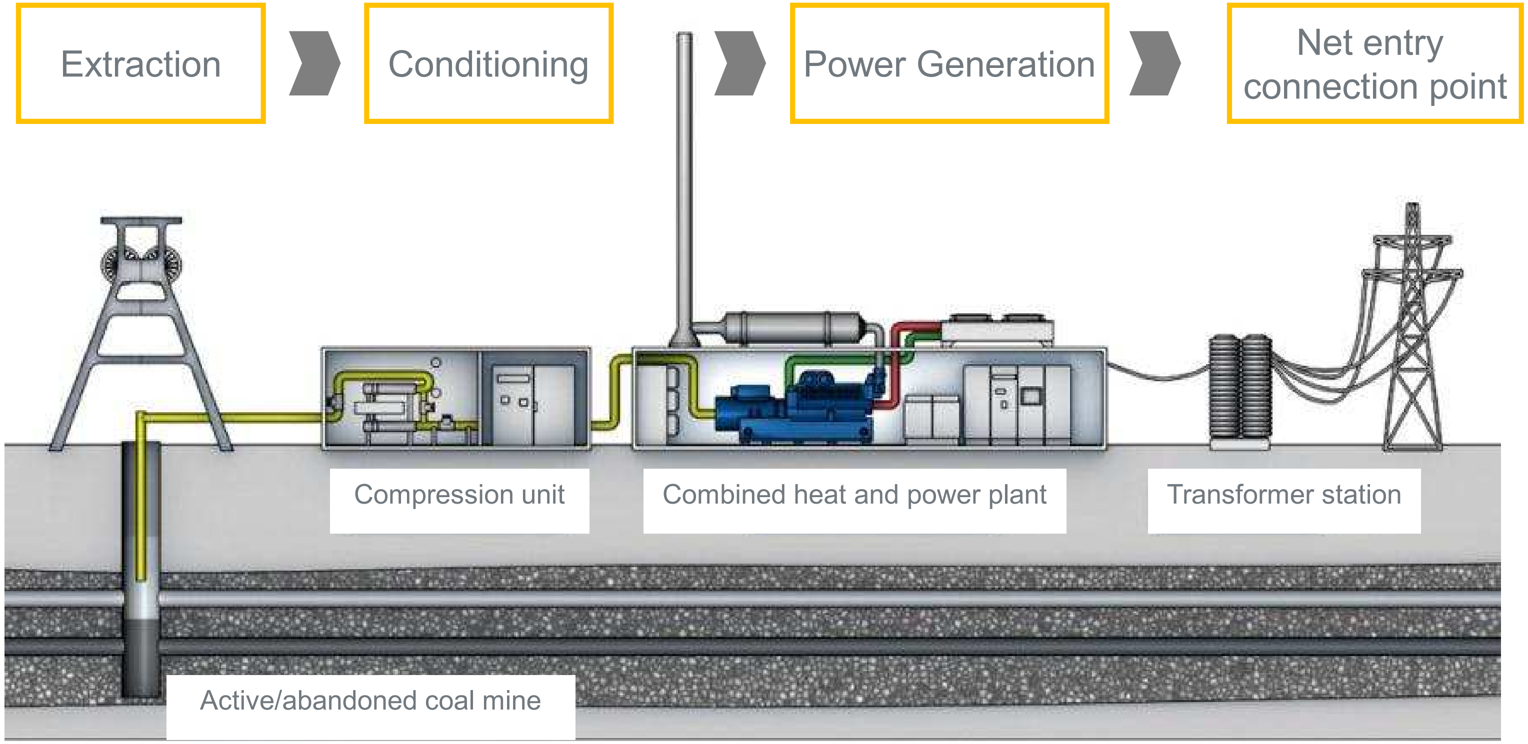
How can I utilize Coal Mine Gas?



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Types of Coal Mine Gas

Methane exhausted from unexplored coal beds

- Coalbed methane (CBM)
- Virtually equivalent to natural gas quality

Methane from active underground mining

- Coal Seam methane (CSM), sometimes called CMM (Coal Mine Methane)
- Coal Mine Gas extracted from active coal mines, sometimes with a rather low content of Methane (<40% CH_4), rest admixed Air

Methane exhausted from abandoned mines

- Abandoned mine methane(AMM)
- Hardly combustible due to high CO_2/N_2 portions ("Cold Combustion")
- Methane content diminishes over the time and can become lower than 30% from the extracted gas mixture

Composition

- Global/regional differences for the methane content, e.g China extremely low CH4-content (sometimes about 12%)
- The gas needs to be analyzed to determine its compounds and the best means to convert to electricity

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

Benefits of the use of Coal Mine Gas

Save the environment by capturing and using methane

- Methane is considered as 25 times more powerful than CO_2 as a greenhouse gas

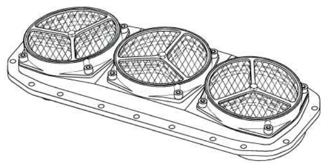
Financial benefits

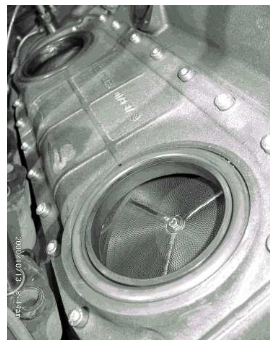
- Income from using Coal Mine gas to generate electricity and/or heat
- Generation of CO_2-certificates by avoiding methane emissions
- Utilization of Coal Mine Gas can be required by law
- In some countries special feed-in-tariffs for electricity can be negotiated for electricity generated by Coal Mine Gas

Improved mine safety by preventing pit explosions (risk at 4-16% CH_4)

Challenges

- Difficulty of humid Coal Mine Gas
- Dust loading of Coal Mine Gas
- Danger of explosion
- Fluctuating CH4-contents
- Low CH4-contents from AMM

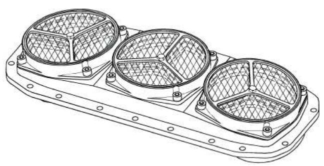


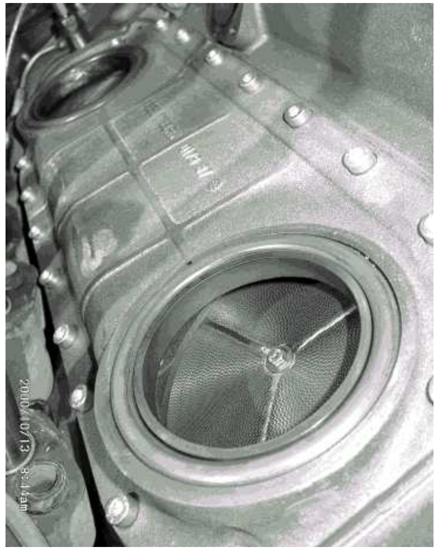


Challenges and solutions

Danger of explosion

- Installation of flame arrestors at the inlet side the gas control train and engine internal for preventing backfiring into the admission system and gas pipeline

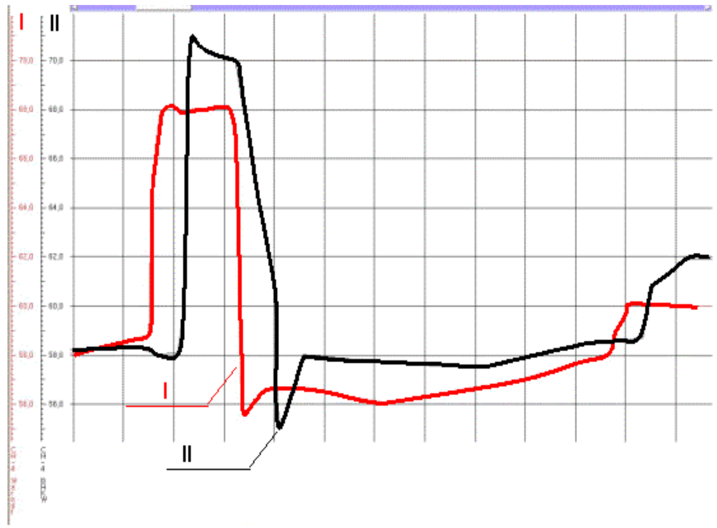




Challenges and solutions

Fluctuating CH4-contents

- A CH4 sensor needs to be installed at the inlet side of the gas pressure control unit in order to adjust the gas mixer for best air-to-gas ratio whilst operation and for engine start purposes
- Gas storage tanks can be utilized to keep gas quality consistent.



Challenges and solutions

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 starting probably an Air-Throttle at the air filter
- For methane contents <30% the differential pressure between gas and air needs to be increased by the use of the lower-heating-value-kit right before the gas mixer (carburetor)

Genset / Engine
60 x G3520C

Segment / Fuel Type
Coal Mine Methane

Customer / Operator
Jincheng Sihe Mine, China

Total Output
120 MWe

Installation / Commissioning
2008

Jincheng Sihe Mine, China

This is one of the largest CMM projects worldwide. Total output of 120 MWe with gas engines and a combined cycle turbine system using steam which is generated by exhaust gas. This application shows an overall utilization rate of 80%. The site is producing 840,000 MWh/a, power is sold to the utility plus 2.9 MMTCO2e CERs (CO2-Certificates) that have an economic value of $45.3M/a at $15 USD/Certificate.

Summary

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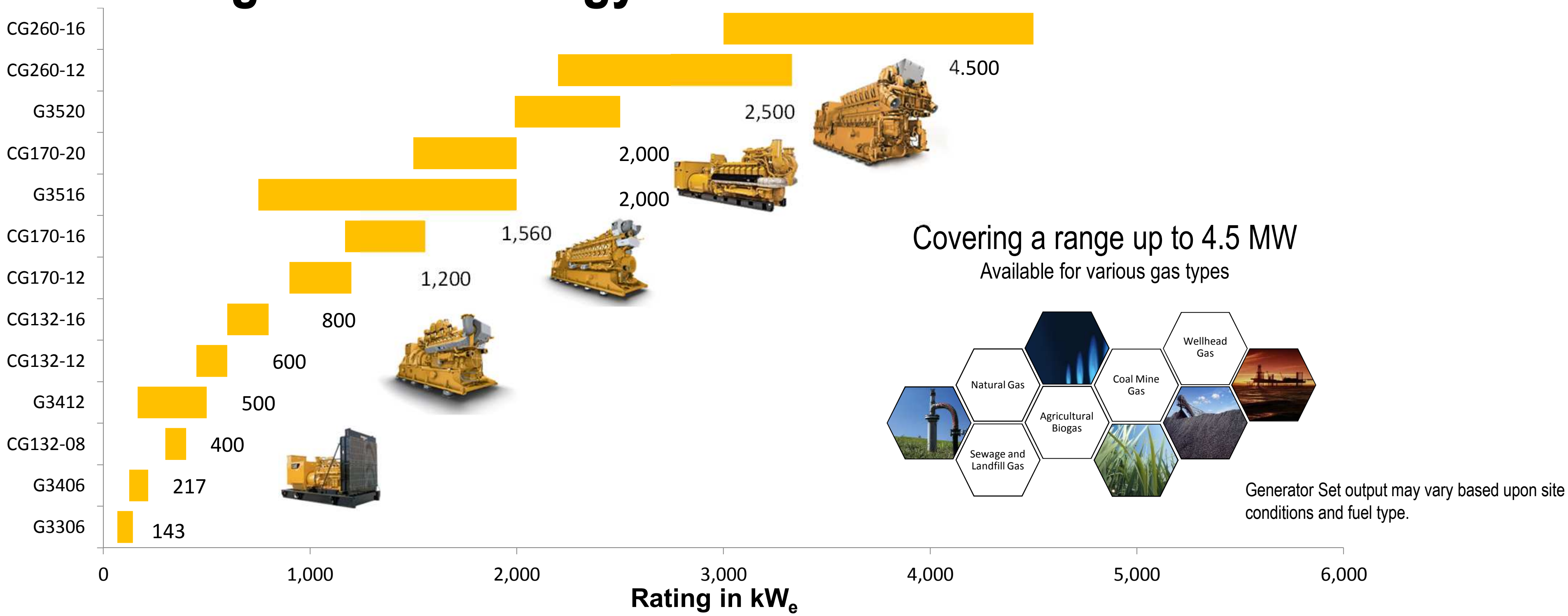
Wide Range of Low Energy Genset Products



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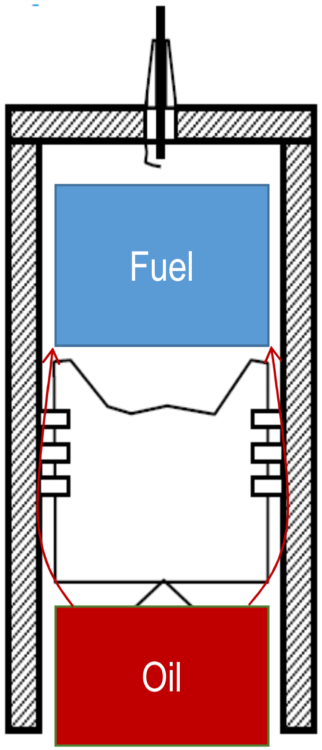
Fuel specification guidelines

- **Gas Heating Value**: 13.8 – 23.6 MJ/Nm3 relates to 3,8 – 6,5 kWh/m³ (350 – 600 Btu/scf) in case of less than 13,8 MJ/Nm³ rating can be determined upon a special factory request (TA)
- **Methane %**: Min methane content is 30%-45%, depending on other fuel constituents
- **Methane Number**: Min Methane Number of 120-130 (Detonation Margin)
- **Natural Gas**: Biogas and Landfill units are also capable for Natural Gas operation upon special factory request

Lube Oil Monitoring and Maintenance

- Monitor Oil Quality by taking probes regularly to determine oil changes right in time
- Oil contents a higher sulfate ash of 0.5 - 1.0 wt. % which compensates Sulfur a bit
- More additives to ensure neutralization of acids (fluor, chlor, sulphur)
- Too many unneccessary additives can even lead to deposits in the 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)	less than 80 %	less than 50 %	less than 50 %
* at lowest temperature of the entire gas pipe system			
Silicon compounds (total VOSiC) per 10 kWh	less than 20 mg	less than 1 mg	0 mg

→ Different Maintenance Schedules

Example of maintenance schedules 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

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