Fuel Flexibility Solutions in Distributed Power

PANAMCHAM, Panama

GE Distributed Power
September, 2016

Imagination at work
GE’s Mission:
To invent the next industrial era,
And build, move, power and cure the world

Imagining the things others don’t / Building the things others can’t / Delivering outcomes that make the world work better

~$149B Revenue in 2014
$17B Operating Earnings
The new GE Power
~$30B ‘14 revenue ~65,000 employees >120 countries

**Gas power systems**
Schenectady, NY, USA

- High efficiency, scale power
  - Power Plants (combined and simple cycle)
  - Gas turbines
  - Steam turbines
  - Generators and controls
  - Heat recovery steam generators

**Power services**
Baden, Switzerland

- Optimizing plant performance
  - Installation planning/execution
  - Maintenance, repairs and outage solutions
  - Multi-year service agreements
  - Hardware/software blended upgrades
  - Data-driven software solutions

**Distributed power**
Jenbach, Austria

- Power near and at the point of use
  - Reciprocating engines (0.2 to 10MW)
  - Jenbacher, Waukesha & Diesel engines, power equipment and services
  - High efficiency and fuel flexibility: Natural gas, CHP, oilfield power, diesel and special gas applications

**Water/process tech**
Trevose, PA, USA

- Energy efficient water solutions
  - Chemical and monitoring solutions
  - Engineered systems
  - Mobile water
  - Build-own-operate services

**Steam power systems**
Baden, Switzerland

- Advanced steam power expertise
  - Complete portfolio, turnkey power plants
  - Widest range of generators and Steam Turbines
  - Air Quality Control Systems (AQCS) including CCS
  - Turbine Island solutions for Nuclear

**GE Hitachi nuclear**
Wilmington, NC, USA

- Advanced reactor technologies
  - ESBWR, ABWR, PRISM
  - Outage and asset optimization services
  - Fuels and engineering services

# PoweringEveryone
Overview
GE’s Distributed Power business is a leading provider of engines, power equipment and services, focused on power generation and gas compression at or near the point of use. Distributed Power’s product portfolio includes highly efficient industrial reciprocating engines generating up to 10 MW of power each for numerous industries globally.

Service offerings
GE’s global service network provides life cycle support for more than 36,000 reciprocating engines worldwide – anywhere and anytime, backed by our authorized service providers in more than 170 countries.
GE’s Distributed Power provides customers of all types the ability to generate reliable, sustainable power whenever and wherever it is needed.
Distributed Power

Products

Power generation
• Electrical output: 220 – 10,380 kWe, el. efficiency up to 49.9%, overall efficiency up to >90%
• 20,000+ engines installed, 25,000 MW power globally
• Natural gas, CHP, excellence in special gas applications (biogas, LFG, CMG, BFG), oilfield power

Gas compression
• Output: 335 bhp – 5,000 bhp (220 kWe – 3,605 kWe)
• 16,000+ compression engines delivered, over 16 million bhp power globally (12,000 MW)
• Wellhead, gathering, storage/transmission

Diesel
• Output: 2,550-2,780 kWe
Covering a broad output range with Distributed Power (60 Hz/kWe)

**POWER GENERATION**

- **TYPE 2**
  - 249 kW – 335 kW
- **TYPE 3**
  - 633 kW – 1.059 MW
- **Type 4**
  - 850 kW – 1.426 MW
- **Type 6**
  - 1.795 MW – 4.498 MW
- **Type 9**
  - 9.35 MW

- **VGF**
  - 265 kW – 830 kW
- **VHP**
  - 600 kW – 1.6 MW
- **275GL+**
  - 2.415 MW – 3.215 MW

**MECHANICAL/O&G/MINING/MARINE**

- **VGF**
  - 265 kW– 830 kW
- **VHP**
  - 600 kW – 1.6 MW
- **275GL+**
  - 2.415 MW – 3.215 MW

**MOBILE/EMERGENCY POWER**

- **J320** generator set
  - 1 MW
- **mobileFlex** J320/VHP
  - Gas Engines 860 kW – 1MW

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Three main areas of use in power gen

Renewables and waste-to-energy utilization

- Reducing CO$_2$ emissions
- Alternatives to fossil fuels
- Biogas, landfill gas, coal mine gas, special gases (steel gas, wood gas, process gases)
- Jenbacher Types 2, 3, 4, 6

Decentralized Power generation and cogeneration (natural gas)

- Reliable energy supply for remote areas
- Supporting local power needs
- Avoiding transport and distribution losses
- Enhanced total efficiency
- Jenbacher Types 2, 3, 4, 6, 9
- 616 stationary diesel engines

Oilfield Power (associated petroleum gas)

- Reliability for rugged, remote applications
- Increased exploration, development in remote regions
- Emission regulations driving increased use of natural gas versus diesel-powered gensets
- Jenbacher Types 2, 3, 4, 6
- Waukesha Types VGF, VHP, 275GL+

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Fuel flexibility and tailor-made solutions

- Associated petroleum gas
- Landfill gas
- Coal mine gas
- Biogas
- Special gases
- Greenhouse applications
- District heating
- Cogeneration Trigeneration (Natural gas)
- Island mode
Natural Gas fueled CHP

- > 6,900 natural gas fueled units
- > 10,900 MWel worldwide
- Highly efficient generation of power, heat and cooling
- Reduces primary energy use
- Minimizes transmission losses
- Enhanced total efficiency – greater than 95%
- Reduces fossil fuel use and greenhouse gas emissions
CHP Scheme

The combined simultaneous production of electricity and heat from a single fuel source. In Engine case, CHP is the recovery of waste heat during power generation in order to make hot water or steam or cooling.

The Term “Cogeneration” is used interchangeably with CHP.

CHP Application may Include:
- Electricity
- Steam
- Hot water
- Process Heating
- Cooling and Refrigeration
- Drying
- Mechanical Drives
NG CHP – Cost of Electricity

Segments

1) District Heating
(Untilies, Municipal Utilities)

2) Industries
(Textile, Chemical, Food, Beverage,...)

3) Commercial Buildings
(Hospitals, Airports, Shopping Malls, Universities, Hotels)

Gas cost/efficiency and heat utilization drive CoE
Helping Coca Cola to reduce CO₂-emissions

Coca-Cola Hellenic Bottling plants throughout Europe use GE’s Jenbacher CHP engines, reducing operational costs and eliminating up to 40% of their annual emissions. For instance, in Coca Cola Hellenic’s Romania bottling facility two J620 engines are supplying a total of 6 MW.

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Biogas

> 4,290 Jenbacher biogas engines >3,000 MW worldwide

- Anaerobic digestion produces fuel gas
- Renewable – from organic and animal waste
- 7,000 cows can power 1 MW plant
Biogas Scheme

GE scope ~35% of total biogas plant capex: Jenbacher engine, heat exchangers, generator

Source: GE Jenbacher/KWE
Biogas yield of biomasses

Gas mixture composition:
- 50 – 70% methane (CH4)
- 30 – 50% carbon dioxide (CO2)

Dry matter concentration
- dry fermentation: 20 - 30%
- wet fermentation: 10 - 15%
  - Absence of oxygen
  - pH value from 6.5 to 7.5

Temperature
- mesophile process: 35 - 40°C
- thermophile process: 50 - 55°C

Retention time
- minimum 15 days
- range: 20 - 50 days
- common: 25 - 30 days
### Biogas yield of animal waste

**Energy potential**

1 Live Stock Unit (LSU) = 500 kg live weight respectively

1 LSU = 0.6 - 1.2 milking cow
approx. 1.3 m³ Biogas/LSU, day
LHV = approx. 6.0 kWh/Nm³
~7,000 cows = 1 MWel

1 LSU = 2 - 6 hogs
approx. 1.5 m³ Biogas/LSU, day
LHV = approx. 6.0 kWh/Nm³
~70,000 hogs = 1 MWel

1 LSU = 250 - 320 layers
approx. 2 m³ Biogas/LSU, day
LHV = approx. 6.5 kWh/Nm³
~1.4 million layers = 1 MWel

**Advantages of anaerobic digestion**

**For the Farmer**
- Improvement of manure properties: odor reduction, elimination of acid components, viscosity decrease, mineralization of organic nitrogen, reduction of pathogenic germs and weed seeds
- Additional income from heat and power production

**For the Environment**
- Reduction of methane and ammonia emissions from manure
- Reduction of nitrate wash-out into groundwater
- Recycling of fertilizer compounds from organic wastes
- Reduction of carbon dioxide emissions by substitution of fossil resources
Biogas – Cost of Electricity

Segments

1) Energy Crops
2) Agricultural Waste
3) Municipal Waste

Cost of kW

<table>
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<tr>
<th>Segments</th>
<th>Fuel</th>
<th>Service BoP</th>
<th>Service Genset</th>
<th>Investment BoP</th>
<th>Investment Genset</th>
<th>Thermal Savings CoE</th>
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</table>

Electric Oph (oh/y): 8000 8000 8000
Thermal Oph (oh/y): 4000 4000 4000
Gas tariff: .03 €/kWh Free free

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GE Jenbacher - Reliable operation on biogas

Biogas Gosdorfg/AT
Achieved 8,740 out of 8,760 oph/y in 2005
99.8% Availability with Biogas
Average >98% fleet reliability at Biogas (1,000+ units)
• Jenbacher gas engines achieves > 41% electrical efficiency, 8,000 OpH
• More than 1,900 Jenbacher gas engines around the world with an electrical power of more than 1,900 MW
• By capturing landfill gas instead of emitting it directly into the atmosphere and using it for power generation in place of fossil fuels, these engines can reduce greenhouse gas emissions of about 60 million metric tons each year.
Landfill Gas Scheme

These fuel gases are produced by the conversion of liquid or solid organic substances by micro-organisms. Like associated petroleum gas, they are characterized by a medium to high methane content and the constituents N2 and CO2. However, as this gas emanates from highly heterogeneous substances, special care must be taken with regard to trace substances and impurities.

How does it work

Municipal waste contains about 150 to 250 kg of organic carbon per ton. These substances are biologically degradable and are converted by microorganisms into landfill gas. Stable, anaerobic methane fermentation begins one to two years after the waste is deposited in the landfill.
Landfill Gas – Cost of electricity

Segments

1) Landfill gas (developed)

2) Landfill gas Undeveloped

Assumptions
Electricity from Landfill gas has an approximate cost as low as 33 €/MWe if the cost to install the piping and gas collection in an existing landfill site is avoided. If the power generation system require gas treatment, COE could increase only an additional 4%.

1 MWe requires approx. 520 Nm3/h of LFG. Equivalent to € 660,000 of investment to develop LFG site.

Cost of kW

- Fuel
- Service BoP
- Service Genset
- Investment BoP
- Investment Genset
- Thermal Savings
- CoE

Gas tariff: free
Supporting one of California’s largest landfill gas-to-energy plants

An 11.5 MW landfill gas plant with six J616 of GE’s Jenbacher engines located at the Ox Mountain Landfill provides renewable electricity to the San Francisco Bay region. The output of the plant is enough to provide electrical power for 7,500 to 10,000 average U.S. homes.
Coal mine gas

- > 250 Jenbacher coal mine gas engines > 600 MWe worldwide
- Reduces greenhouse gas emissions
- 1 MW plant saves more than 30,000 tons CO$_2$ per year
- Degasification improves mine safety
Coal mine Scheme

Similar to natural gas in terms of combustion but
- gas contaminations
- gas humidity
- gas pressure fluctuations
- Quick CH₄-fluctuations

Fuel cost and net efficiency drive COE
Coal mine gas – Cost of Electricity

Segments

1) CMM from active mines
   Coal Mine Methane
   Local Mines, International Utilities, Authorities, Carbon Developers

2) AMM from abandoned mines
   Abandoned Mine Methane
   Gas Right Owners, Local Utilities, EPCs

3) CBM from virgin coal seams
   Coalbed Methane
   International CBM Developers, EPCs

Greenhouse gas reduction & mine safety drive business
Helping to reduce the environmental impact of Australia’s coal mines

A 45.6 MW alternative energy plant is located at Anglo Coal’s Moranbah North mine saving 1.3 million tons of CO$_2$ equivalent per year – or the average of taking 330,000 cars off the road.
Special Gas

- Industrial waste gases
  - Power produced from steel and chemical industry waste gases
  - Industries become more energy efficient
- Synthetic gases from gasification
  - Highly efficient power generation with biomass and waste gasification
Wood gas application

Wood gas:
- H2: 35 - 45%
- CH4: 8 - 12%
- CO: 20 - 30%
- CO2: 15 - 25%
- N2: 3 - 5%
- LHV = 3 - 3.5 kWh/m³N
Wood gas – Cost of Electricity

Segments

1) Wood Gas developed in Europe (CHP)
   • High sophisticated approach
   • Significant incentives needed
   • District heating

2) Wood Gas in Undeveloped/Developing countries
   • Power generation for rural areas
   • Low tech approach
   • Manual operation

Cost of kW

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<th>Wood gas dev</th>
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Electrical Oph (oh/y): 7200
Thermal Oph (oh/y): 4000
Fuel cost (€/kWh): .035
Free

Capex drive high CoE
Strong incentive scheme required
Highly efficient power generation with special gas

The efficient combustion of wood gas requires highly sophisticated gas engines. One J620 engine provide power and heat at the wood gas plant in the town of Güssing, Austria.
Steel gas – Cost of Electricity

Segments

1) Blast Furnace Gas
Steel industry (integrated steel plant)

2) Coke gas
Coke industry or steel industry (integrated steel plant)

3) LDG
Converter Gas
Steel industry

Furnace Off Gas
Non ferrous metals industry (FeCr; FeMn; FeTi;.....)

Capex/opex for gas cleaning could be high

Cost of kW

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<th>€ Cent / kWh</th>
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<tr>
<td>BFG</td>
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<td>cokegas</td>
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<td>LDG</td>
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</table>

- Fuel
- Service BoP
- Service Genset
- Investment BoP
- Investment Genset
- Thermal Savings
- CoE

Gas tariff: free

Electrical Oph (oh/y): 8000
Thermal Oph (oh/y): 4000
Sophisticated, customer oriented solutions for the steel industry

GE provides highly developed Jenbacher gas engine technology for efficient power generation with coke gas, blast furnace gas and converter gas. The Arcelor Mittal steel factory in Avilés, Spain operates 12 J620 Jenbacher gas engines, using LD converter gas.
Sewage gas

> 600 Jenbacher sewage gas engines > 450 MW worldwide

• Sewage fermentation produces fuel gas
• Waste water from city of half a million powers 1 MW plant
• Covers up to 100% of energy needed for sewage plant
Sewage Gas - Scheme

- Sewage gas
- Gas compressor
- Gasometer
- Digestor
- Sludge drying
- Sewage sludge
- Heat exchanger
- Heat consumer
- Exhaust gas
- Electrical energy
- Sewage sludge, agricultural utilization possible
Sewage gas – Cost of Electricity

Applications:

1) Municipal WWTP:
   Municipalities, Utilities, specialized EPCs
   500,000 inhabitants approx. 1MWe

Anaerobic vs. aerobic fermentation decisive

Cost of kW

- Fuel
- Service BoP
- Service Genset
- Investment BoP
- Investment Genset
- Thermal Savings
- CoE

Electrical Oph (oh/y): 8000
Thermal Oph (oh/y): 4000
Gas tariff: Free
In Strass, Austria, a major overhaul of the Jenbacher J208 was performed at the local sewage plant after 60,000 operating hours. In 2009, GE’s J312 gas engine was added to the plant. Together, the engines provide heat and a total electrical output of 940 kW, generating 120% of the facility’s energy demand. The excess power is fed into the local grid.
Greenhouse applications

About 1,200 Jenbacher CO² fertilization plants with an electrical output of more than 2,400 MW worldwide

- Powers grow lights
- Provides heat for greenhouses
- Purified exhaust used as fertilizer
Greenhouse Fertilization

Fuel gas flows into a Jenbacher gas engine, where it is converted to electrical energy and exhaust gas. The exhaust gas is directed to a Catalytic converter, followed by a Heat exchanger, where it heats a Buffer. The heated Buffer then supplies Heat to a Heat consumer (Greenhouse). Additionally, CO₂ is introduced into the system to increase the concentration of CO₂ in the Greenhouse, improving plant growth. The heat is also used for Lighting and Electrical energy is generated as a byproduct of the process.
Greenhouse – Cost of Electricity

Segments

1) Greenhouse with CO$_2$ fertilization

Growers or investors

Other financial benefits:

- **Increase of crop (production, quality)**
- Less illness and damage, Increased CO$_2$ level
- **Timing of harvest (setting)**
- Price deviation throughout the year
- **Minimize the amount of pesticides**
  Prevent bugs from coming in, and bees from flying out
- **Lower energy cost**

Flexible & highly efficient power, high CO$_2$/heat ratio
100% load in island with light control
Driving innovation: the world’s first 24-cylinder gas engine

The world’s first Jenbacher 4 MW 24-cylinder gas engine of GE is powering one of the largest commercial tomato greenhouses in the Netherlands, offering an economic supply of onsite electrical and thermal power while also employing the engines’ cleaned exhaust gas as a fertilizer.
Flare gas

> 330 Jenbacher gas engines > 450 MWel worldwide

- 150 billion m³ gas flared per year
- Equals annual natural gas demand of France and Germany
- Substitutes diesel oil for power generation and avoids transportation costs
- 1 MW plant saves 2 million liters of diesel per year
Flare gas Scheme

Gas flare → Flare gas → Desulphurization → Heat exchanger → Heat consumer → Electrical energy
Segments

1) Flare gas
Petroleum production.

Penalties drive implementation
GE’s 30 MW power plant supports energy demand of oil field production

In Southwestern Argentina, 20 of GE’s Jenbacher gas engines are fueled by untreated associated gas from the oil and gas fields. The 30 MW power plant provides a reliable electricity supply to overcome the country’s energy shortages.
Multiple values for our customers

Fuel flexibility
• Natural gas
• Renewable gases
• Waste gases and special gases
• Associated petroleum gas
• Diesel

Top efficiency and service
• Electrical efficiency up to 49.9%
• Overall efficiency: >90%
• High power density
• Extended service intervals
• Low life cycle costs

Environmental benefits
• Low emissions (NOx, CO, SOx, etc.)
• Ability to reduce CO\textsubscript{2} footprint:
  - Use of renewable gases
  - High overall efficiency

Durability and reliability
• Established, field-tested designs
• Optimized, robust engine components
• Stationary engine concept
• Maximum operational safety and availability
• Proven control and monitoring concept
• Continuous focus on product development
Multi-year agreements

Improve your performance at lower cost

- Collaboration with you to achieve your business goals
- A service agreement tailored to complement your capabilities: maintenance coverage, performance guarantee, operation support
- GE expertise and operations excellence at your service
Meeting customer needs through digital-industrial solutions

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</table>

A SINGLE PANE of glass and source of truth to improve customer assets, stations, and fleet

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Our customer’s success determines our future.

We are dedicated to delivering innovative, custom-tailored solutions designed to meet our customers’ specific power Generation and mechanical drive needs.