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Combined Heat and Power

Caterpillar Energy Solutions

Tobias Wedemeier & Michael Dressler

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Agenda

- What is Combined Heat and Power “CHP”?
- Operating Range for CHP
- Calculation of Profitability
- Product Range
- References

What is Combined Heat and Power “CHP”?

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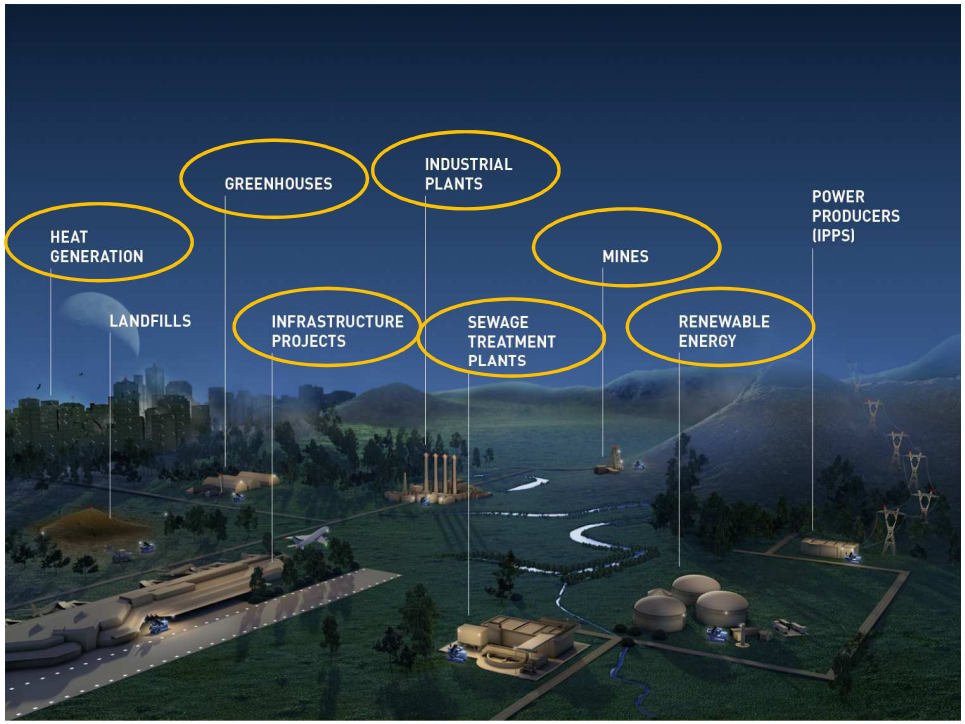
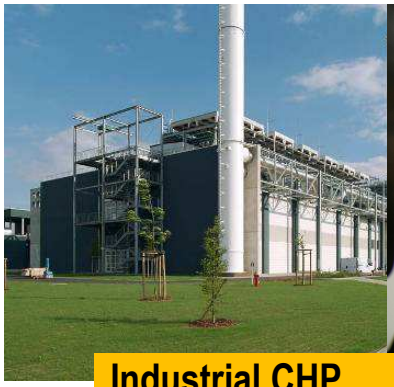
Market segments – Where is Combined Heat and Power used?



Key drivers

- Energy isn't just wasted in the places that we finally use it – most of the waste in our electricity system happens before it even reaches our homes and businesses.
- Our power stations offer a great opportunity to not only provide electricity but also hot water and heating power.

Market segments – Where is Combined Heat and Power used?



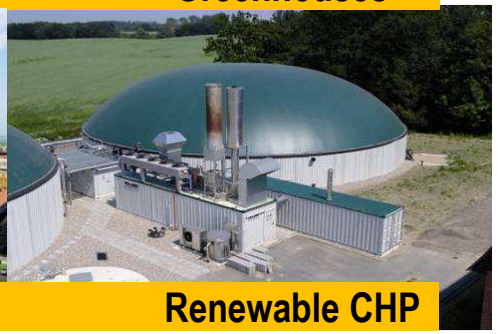
Industrial CHP

District Heating

Greenhouses

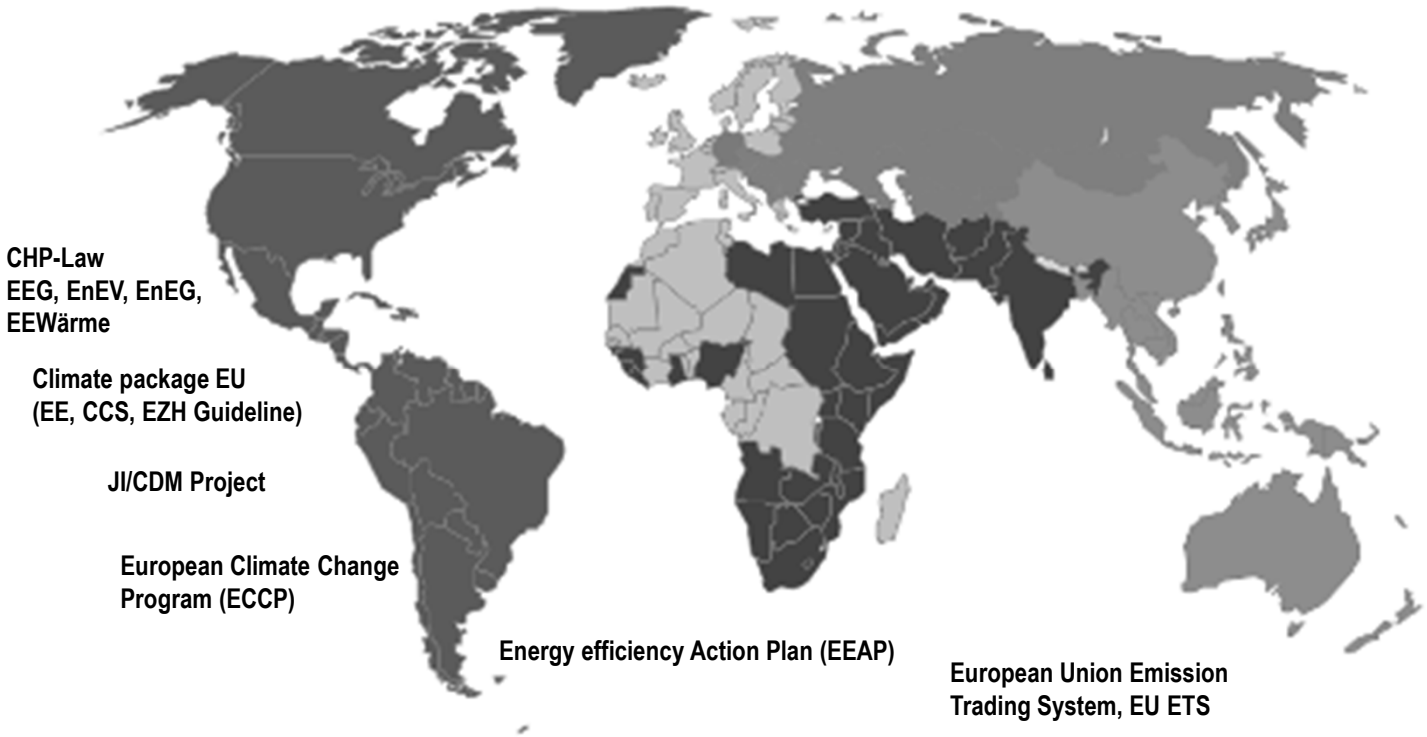
Trigeneration

Coal Mine Methane



Renewable CHP

Market drivers of CHP Technology



CHP is growing globally – driven by

- Growth in distributed generation
- Increasing energy efficiency
- Reducing energy operating costs
- Reducing greenhouse gas emissions
- Increasing use of government incentives to promote cogeneration
- Enhancing the energy infrastructure
- Improving energy security and resiliency

Elaborated Solutions
make Cat® products to an excellent Partner for your Projects

Advantages for the operator

- Overall efficiencies of over 95 percent possible
- Cost reducing through higher efficiency of the complete energy supply
- Uninterruptible electricity supply
- Adapted energy production to the respective requirements (Electricity- or Heat driven)

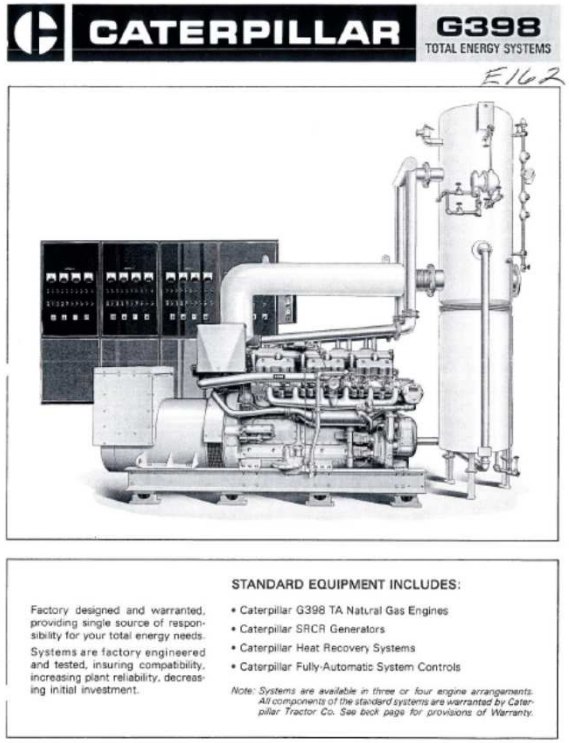
Generation of Heat & Power at the same time

- Decentralized energy supply - generation of energy for the own requirement
- Independence from power interruptions and fluctuations
- Usage of Exhaust heat as heat, coldness, steam or for the generation of additional electricity
- Different technologies available on the market for CHP

Decades of Experience in Combined Heat & Power

Since 1960, Caterpillar and its dealers have provided CHP solutions to our customers.

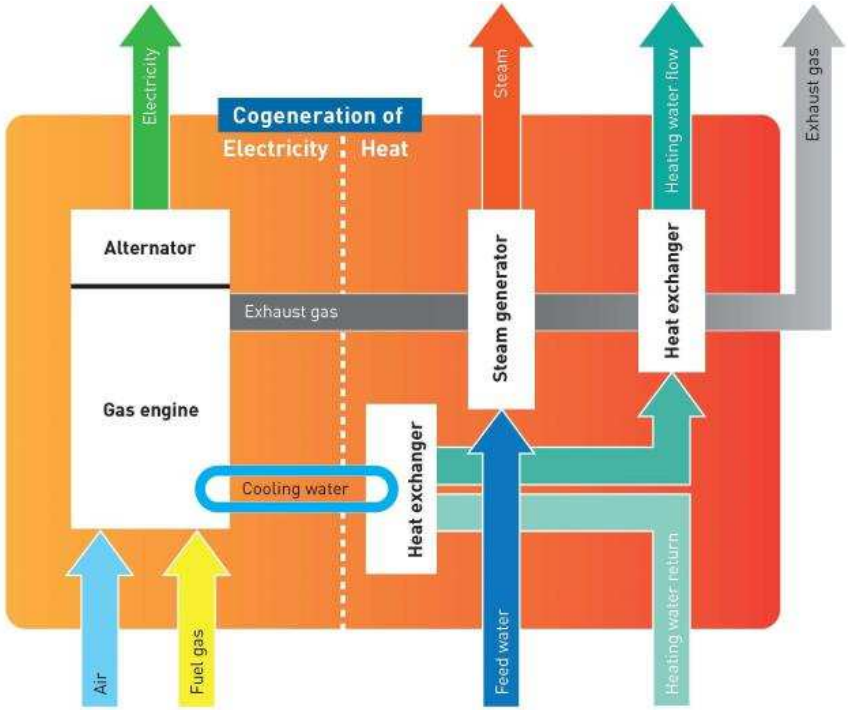
- CHP packages
- Power Modules
- Gas Engine Driven Chillers
- Auxiliary equipment
- Switchgear & Controls
- Product Support



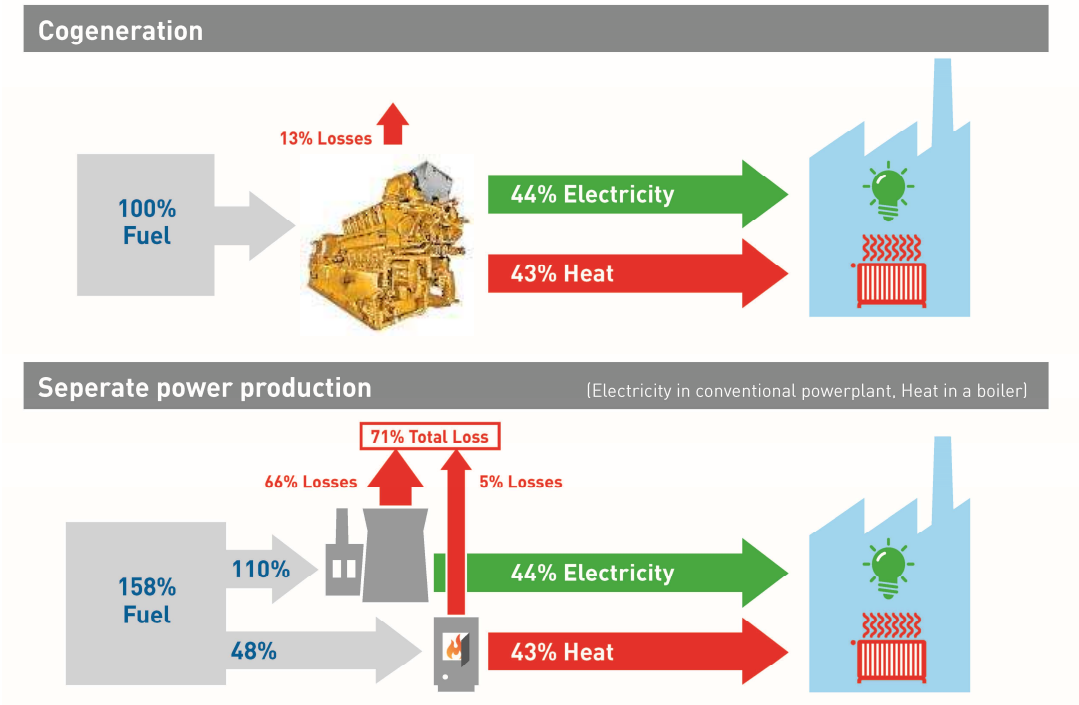
How does Combined Heat and Power “CHP” works?

Definition CHP – The simultaneous and sequential use of power and heat from the same fuel source

- CHP = “**Cogeneration**”
- CHP = “**Trigeneration**” when waste heat supplies both heating and cooling
- CHP = “**Quad generation**” when waste heat supplies both heating, cooling & CO2



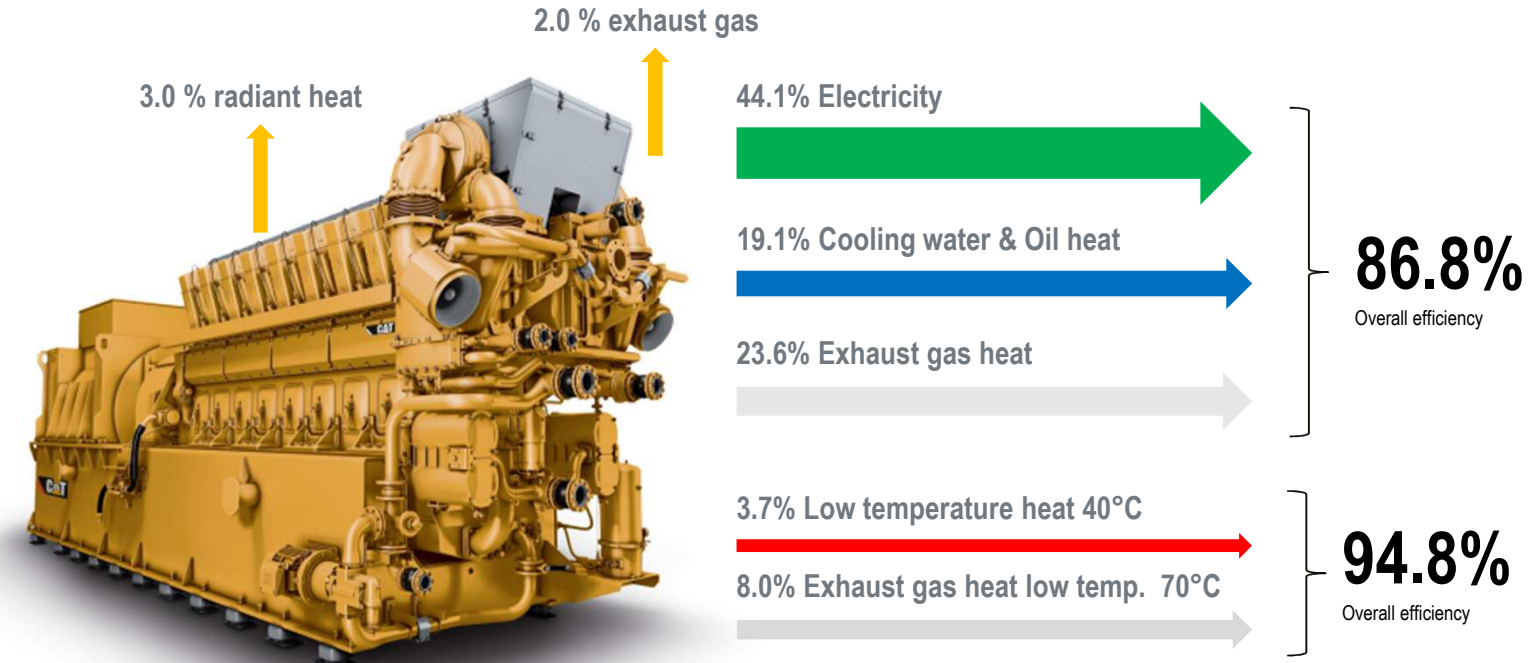
Independence with higher Efficiency



Variable usage of engine and exhaust heat for improved efficiency of the overall system

Combined Heat and Power on the example of a standard CHP unit CG260 series

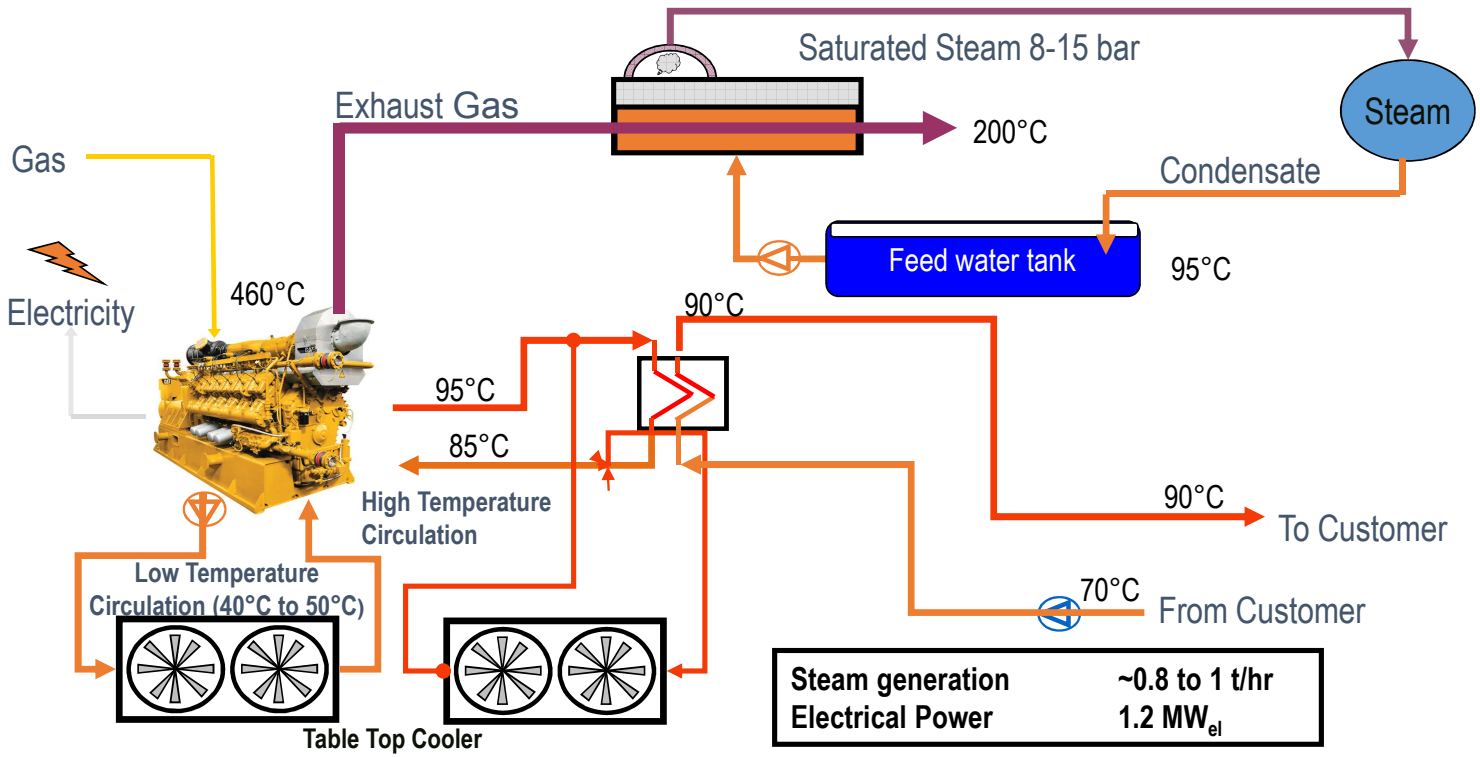
- As Low Temperature-CHP unit you reach an Overall Efficiency of up to 94.8%



Variable Usage of Heat quantities for different Requirements

- Thermal Heat (old and new building – local and district heating)
- Hot water (private usage and public institutions)
- Optimal integration into industrial processes to use the process heat (warm-hot water. steam)
- Refrigeration cooling and air conditioning
- Using proven steam processes. the electrical efficiency of the plant can be increased

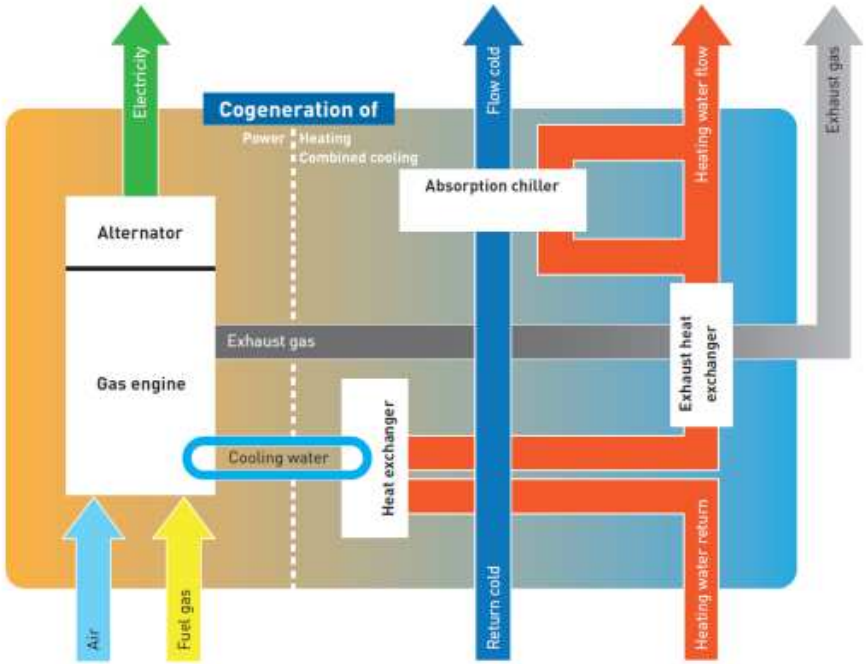
Flow Chart of a Steam Process



Combined Cooling – Heat and Power “CCHP”

CCHP – combined generation of cooling heating and power

- Expansion of Combined Heat and Power
- Heat-driven refrigeration systems use the heat of the CHP plant
- The cooling process is based on the principle of evaporation
- Different technologies available on the market for CCHP (gas engines. fuel cells. steam turbine)



Operating Range for CHP

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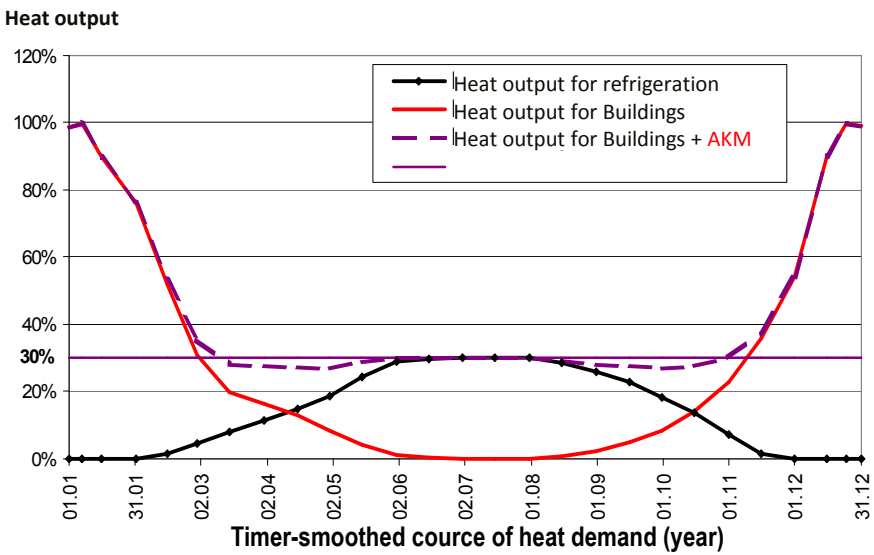
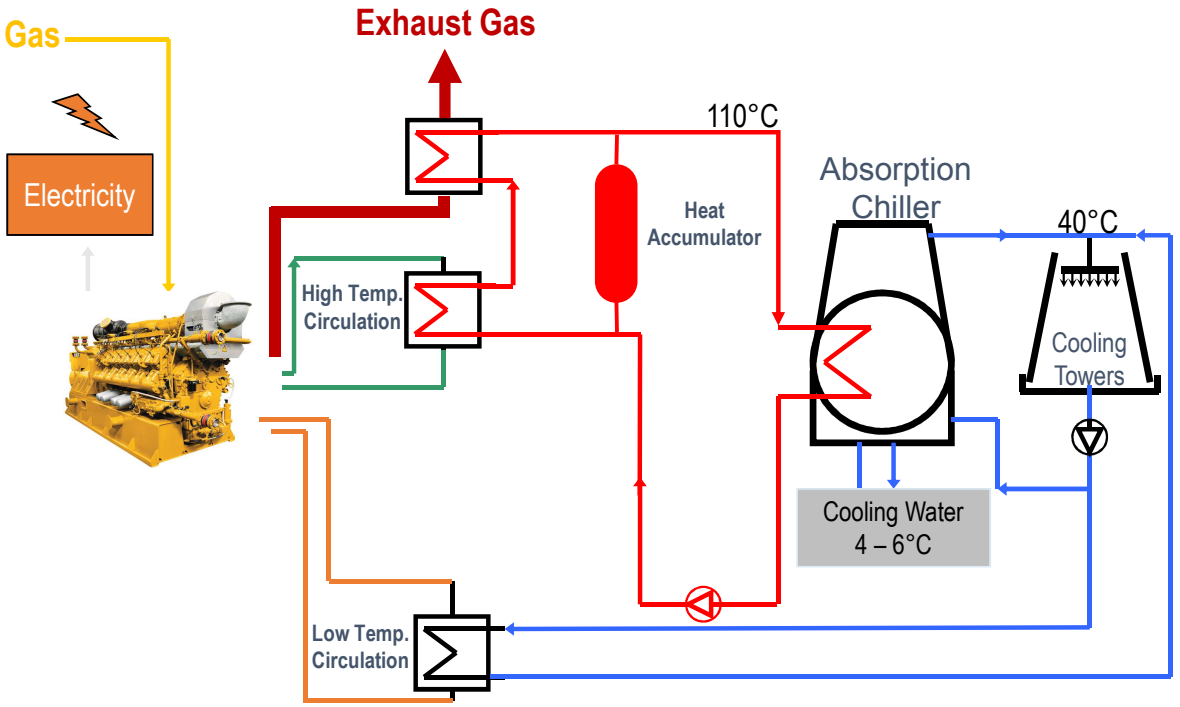
Benefits by the use of a CCHP plant

- The refrigeration can be done in the summer in addition to the heat generation in the winter or in warmer countries in the year-round operation
- The refrigeration increases in times of low demand for heat the usage rate. thus lowers the operating costs
- Compressor chillers can be replaced by efficient. thermally driven chillers
- With high and steady cooling demand cooling networks provide favorable conditions for usage innovative refrigeration technology economically



Flow chart of an Absorption Chiller – Indirect fired



CHP – Easy Integration. Reliable Supply and Efficiency

Electricity

- Different generator voltages from 400V to 11kV
- Standby operation. zero supply regulation or coverage of own requirements
- Parallel grid operation and / or Island operation
- Solutions for an energy requirement of 400 kW_{el} to 40 MW_{el}

Steam

- Usage of the exhaust energy to generate steam
- Steam generation for industrial processes
- Simultaneous heat extraction from the cooling water for heating purposes

Coldness

- Generated coldness usable for room cooling and process refrigeration. including ultra cryogenic applications
- Conversion of the produced heat in cooling energy
- Higher plant life by summer and winter operation

Heat

- Thermal heat. process heat and domestic water heating
- Integration into the existing heating systems
- Electricity or heat-driven operation mode

Challenges and Solutions

Integration

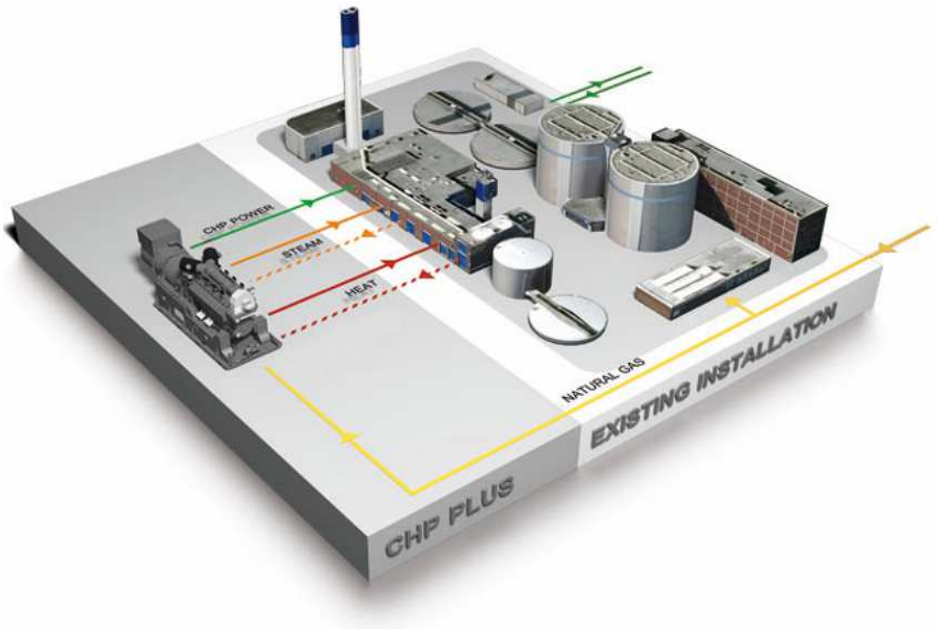
- Flexible Integration in existing supply systems
- Improvement in existing infrastructure through targeted supplements and optimization
- Container solutions provide quick availability without additional construction effort

Efficiency

- Maximum utilization of the overall efficiency of the complete system in focus

Supply safety

- Supply safety through local electricity- and heat generation
- Redundancies by existing heat generators. refrigeration systems or grid connection
- Uninterruptible electricity supply with power failure
- Better electricity quality than in the public network



Calculation of Profitability

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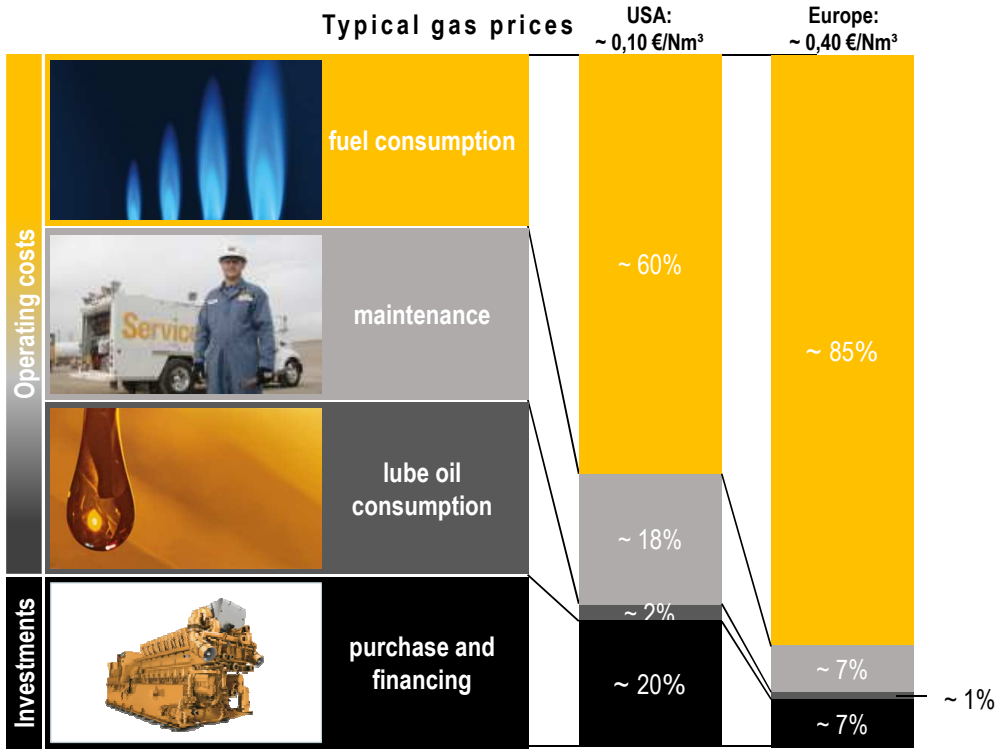
Importance of Highest Total Efficiency



Key drivers

- Profitability highly depends on efficiency because the largest cost share – whether low or high gas price – is fuel consumption.
- A difference of 2 to 4% efficiency is equal to the full investment cost for the genset making a LCCA (Life cycle cost analysis) over 8 years

CHP Profitability Calculation

Example of an CG 170-16

CG170-16		
1560 kW_{el} Natural Gas-CHP		
Elektrical Power	kW	1560
Thermal Power	kW	1577
Fuel Effort	kW	3600

Investment costs	€ 750.000

Imputed Interest	%	10
Calculation Period	Years	10

Application example		
6.000 operating hours per year		
Price for Natural Gas	€/kWh	0.043
Purchase price for electricity	€/kWh	0.0895
Price for district heating	€/kWh	0.04

Possible Proceeds and Savings		
Avoidance Electricity Procurement	€/a	748.224
Avoidance Heat Procurement	€/a	378.432
CHP-Remuneration	€/a	252.697
Proceeds / Savings		€ 1.379.353

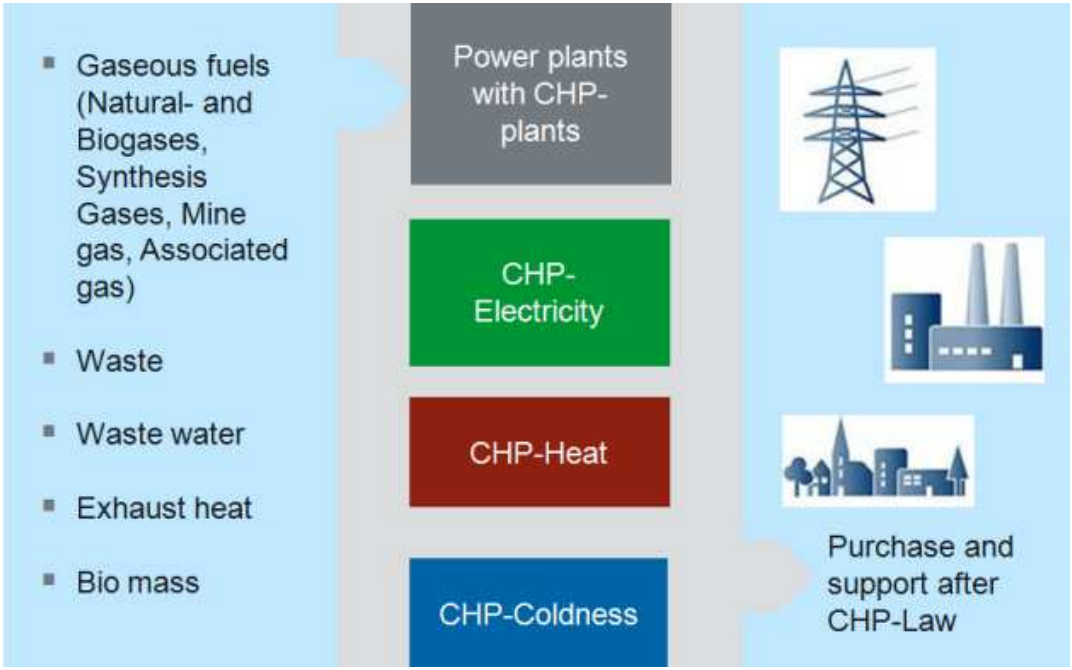
Efficiency		
Capital value	€	1.862.080
Intern Interest	%	62.0

Payback period	< 2 Years

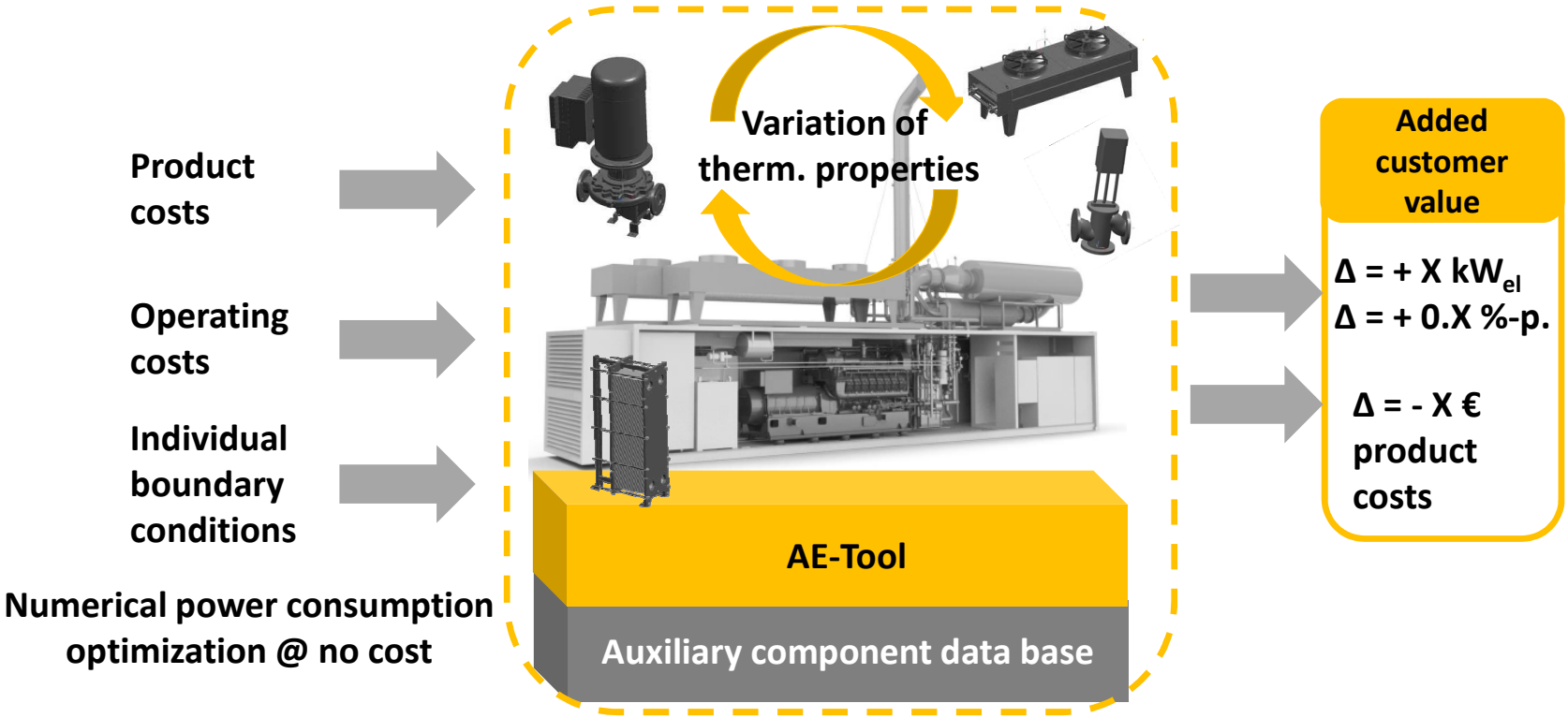
Your Profit after < 2 Years

Summary CHP Efficiency

- Payback periods of < 2 Years presentable
- Self-sufficiency has a better efficiency than Electricity feed
- Efficiency given in electricity operated and heat operated systems
- Minimum use of 100% of the heat even at electricity operations necessary
- For Maximum CHP support the system should be operated at least 30.000 full load hours in the first 6 years



Numerical Plant optimization — How does it work?



Auxiliary power consumption improvements — Overview

CHP	Genset el. efficiency	Old net el. efficiency	New net el. efficiency	Net elec. eff. gain	kW_{el} savings
CG132-08	42.3 %	41.1 %	**41.5 %**	+ 0.35 %	**+ 3.2**
CG132-12	42.0 %	40.9 %	**41.3 %**	+ 0.3 %	**+ 4.9**
CG132-16	42.5 %	41.3 %	**41.7 %**	+ 0.45 %	**+ 8.5**
CG170-12	43.6 %	42.6 %	**43.1 %**	+ 0.5 %	**+ 14.4**
CG170-16	43.3 %	42.2 %	**42.7 %**	+ 0.45 %	**+ 16.9**
CG170-20	43.7 %	42.5 %	**43.1 %**	+ 0.45 %	**+ 25.1**
CG260-16	44.1 %	43.0 %	**43.5 %**	+ 0.5 %	**+ 45.3**
CG260B-16	44.6 %	43.4 %	**43.9 %**	+ 0.5 %	**+ 56.6**

Product Range

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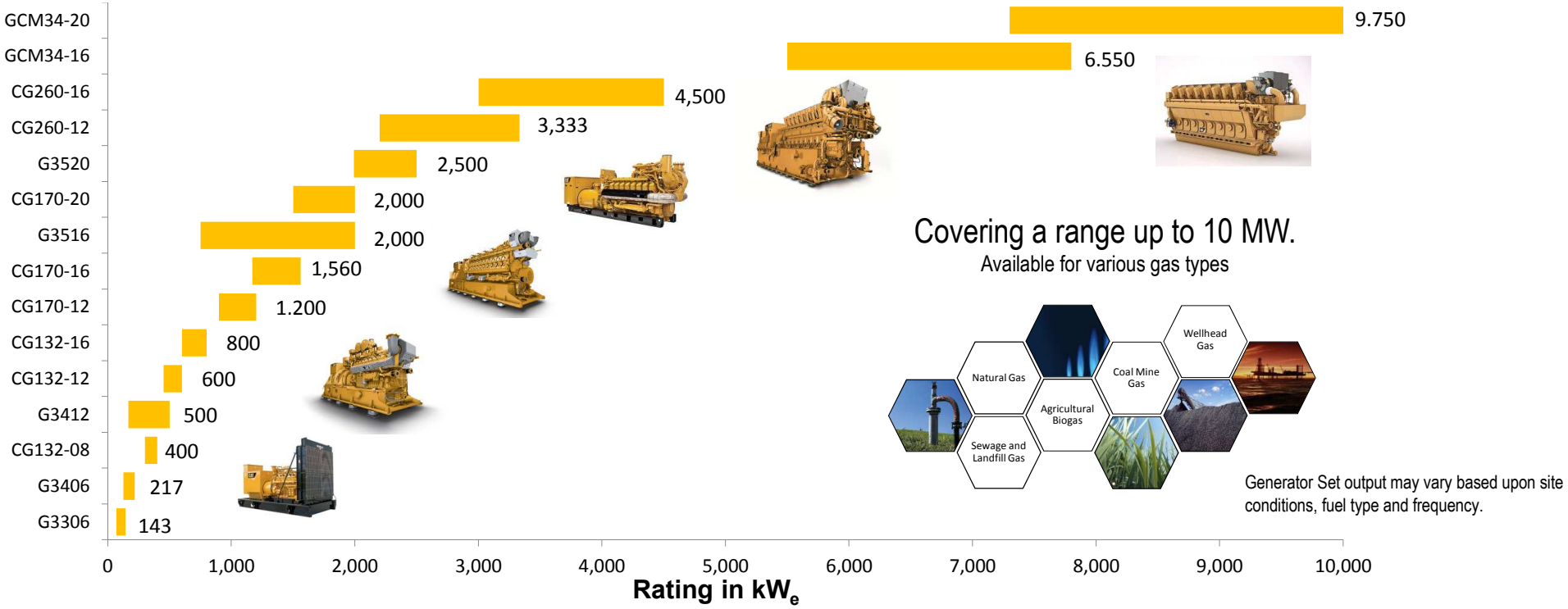
One Unified Product Portfolio of the Cat® Gas Engines



Covering a range up to 10 MW.

Available for various gas types

Generator Set output may vary based upon site conditions, fuel type and frequency.

CG132B — No better way to Power

CG132B	V8, V12, V16
Power range	400 – 800 kWe
Electrical efficiency	43.0% - 43.5%
Thermal efficiency	40.0% - 44.7%
First service interval	4,000 Oh
Major overhaul	Up to 80,000 Oh
Useable gases	NG, CMM, Biogas, Syngas

- Increased robustness ensures higher reliability and availability
- Reduced maintenance costs through extended intervals and lifetime
- Lower lube oil consumption helps operators save operational costs
- Decreased gas consumption due to higher efficiency and enhanced fuel flexibility

Available end of 2017
Flanged genset with service aligned lube oil management

CG170 – Different Versions for Customer Needs

CG170	V12, V16, V20
Power range	1,000 – 2,000 kWe
Electrical efficiency	40.0% - 44.4%
Thermal efficiency	43.2% - 47.0%
First service interval	4,000 Oh
Major overhaul	64,000 Oh
Useable gases	NG, CMM, Biogas

Installed capacity of more than 6,220 MW_{el} with over 4,266 gensets worldwide

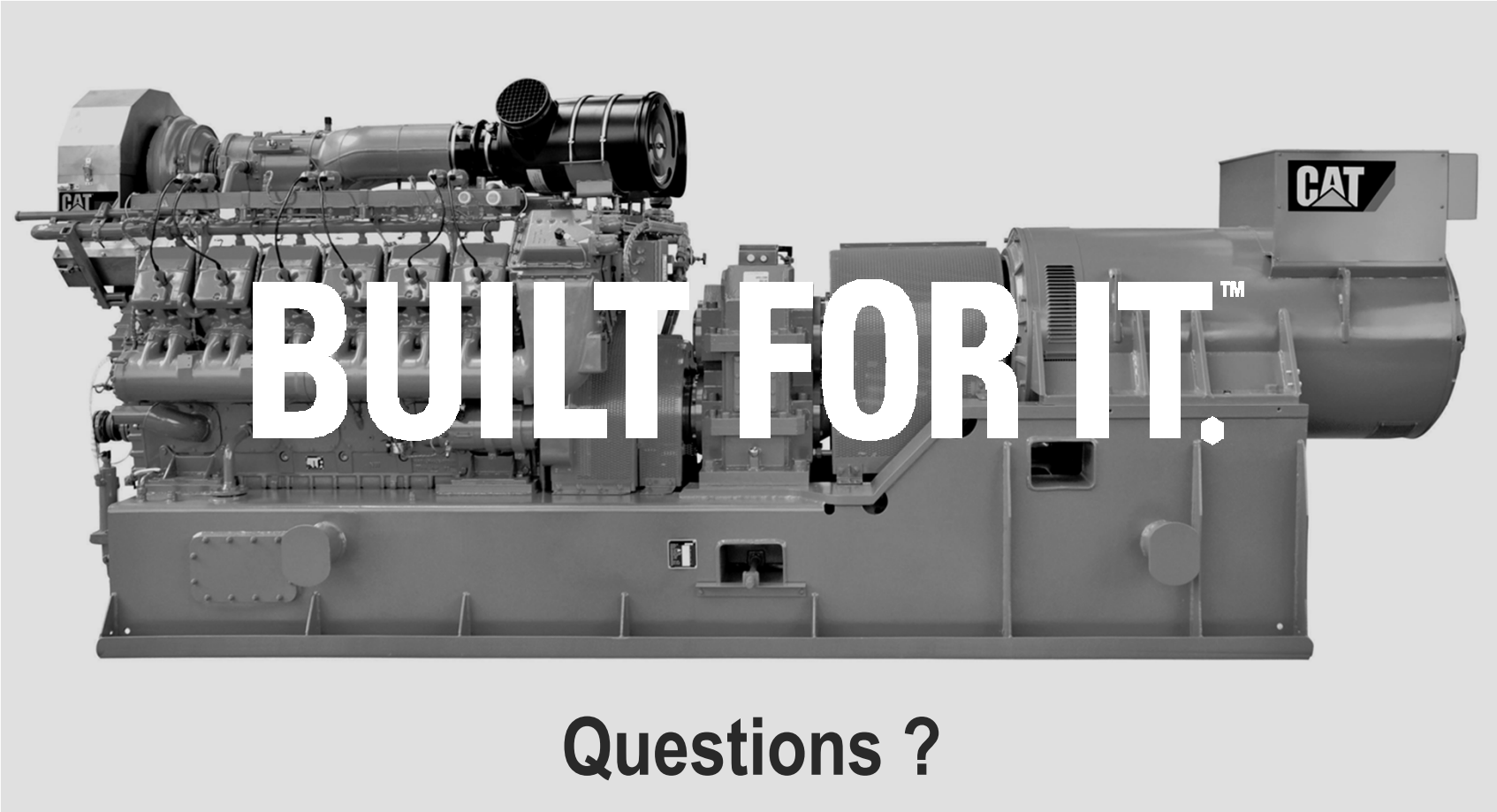
- Higher return on investment due to improved efficiency utilizing the miller combustion cycle
- High altitude and temperature capability on the otto cycle version of the CG170
- Gear box utilization at 60Hz provides improved cost of ownership and higher availability
- Flexible application with fluctuating gas composition and quality

CG260 – Proven Reliability

CG260	V12, V16
Power range	3,000 – 4,500 kWe
Electrical efficiency	40.0% - 44.4%
Thermal efficiency	43.2% - 47.0%
First service interval	4,000 Oh
Major overhaul	80.000 Oh
Useable gases	NG, CMM, Biogas, Syngas

Installed capacity of more than 3,076 MW_{el} with over 753 gensets worldwide

- High reliability and low maintenance costs due to open combustion chamber technology
- Low operating costs due to 30% lower lube oil consumption in comparison to si products
- Increased exhaust heat recovery options and full power at extreme ambient cor
- Optimized engine and plant control enables the use of different gas types and fluctuating gas qualities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