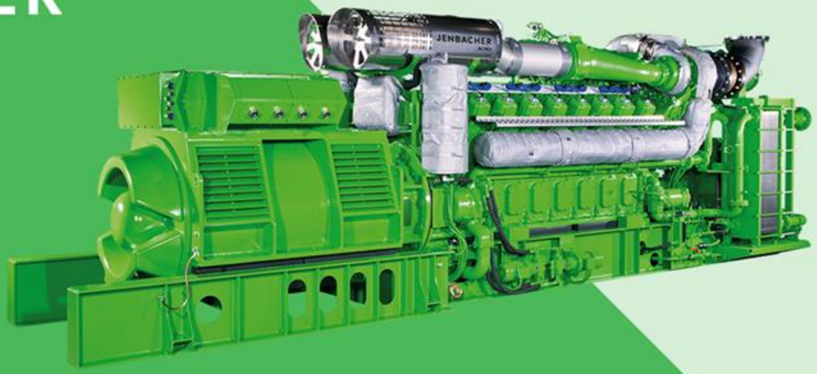
Decarbonization of Europe’s Power Generation

Ready for Hydrogen Engine Power Plants for 25% Hydrogen in Natural Gas



Bernadet Hochfilzer

22.09.2021

Agenda
Hydrogen in natural gas

Introduction

- Jenbacher* gas engines from INNIO*
- Jenbacher type 6 gas engines
- Jenbacher type 612 gas engine at LEC

H_2 admixing to the natural gas grid

Performance measurement: H_2 admixing to natural gas at LEC

- Measurement setup
- What changes?
- Which challenges we are facing?
- What happens with the engine operation window?
- What can we do?

INNIO‘s hydrogen admixing demo projects

Summary

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INNIO

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Introduction

Jenbacher* gas engines from INNIO*...

... provide electrical and thermal energy in a flexible, efficient and reliable manner – onsite and with a short lead time

... serve 50 and 60 Hz grids, operate in grid-parallel and island mode, have a fast load acceptance

… cover an electrical power range from 250 kW to 10.4 MW

… offer electrical efficiencies > 49 % and CHP efficiencies > 92 %

… cover a wide range of fuel gases incl. hydrogen and challenging special gas applications

… have low pollutant emissions and low oil consumption

… offer advanced monitoring and diagnostics possibilities

Type 2

250 - 330 kW

Type 3

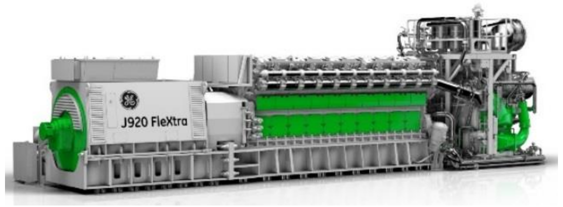
500 kW – 1 MW

Type 4

800 kW – 1.6 MW

Type 6

2.0 – 4.5 MW



J920 FleXtra

10.4 MW

Comprehensive gas-fired portfolio … 250 kW to 10.4 MW

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Introduction
Jenbacher* type 6 gas engines

Engine version	J624 K	J620, 616 and 612 J
Engine process	4-stroke spark ignition engine with lean A/F mixture	
Mixture preparation	Gas-mixer upstream of turbocharger, passive pre-chamber gas valve	
Turbocharging	2-stage	1-stage
Gas exchange	Single cylinder heads with 4 valves per cylinder	
	Advances early miller timing	Moderate early miller timing
Combustion concept	Gas scavenged prechamber, compact main chamber	
Ignition	High energy ignition system, spark plug	
Power control	CBP and TV	

Lean burn gas engine type 6 (2.0 – 4.5 MW)

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Introduction

Jenbacher* type 612 gas engine at LEC

Engine version	J612 – J02
Stroke / bore [mm]	220 / 190
Displacement [dm³]	6.24 per cylinder
BMEP [bar]	22
Rated speed [1/min]	1500 (50Hz)
Power output [kW_{mec}]	2058
Electrical efficiency [%]	45.8 @ MN $\geq$ 80 **
Total efficiency [%]	90.8
Start time [s]	< 300

**50 Hz operation with NO_X = 500 mg/Nm^3 @ 5 % O_2 according to ISO 3046

LEC testbench J612-J02

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H_2 admixing to the natural gas grid

Toward renewable fuels

H_2 in natural gas pipeline

Low H_2 blending | Medium H_2 blending

Optimized for NG
<5%v H_2

Broadband product
0-25%v H_2

- Increasing the use of renewable energy like hydrogen requires new approaches to energy storage and energy transport
- Blending hydrogen into the existing natural gas pipeline network appears to be a strategy for storing and delivering renewable energy to markets
- This approach is being seriously considered both in the US and in Europe
- Currently up to 5% H_2 in German gas network allowed [1]

[1] Deutscher Bundestag, Grenzwerte für Wasserstoff (H_2) in der Erdgasinfrastruktur, Wissenschaftliche Dienste Fachbereich WD8, 7.6.2019

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Performance measurement: H_2 admixing to natural gas at LEC

Measurement setup

Questions to be answered

Identify limiting factors

- Efficiency / heat balance
- Engine operating window
- Maximum blending rate

Outline required modifications

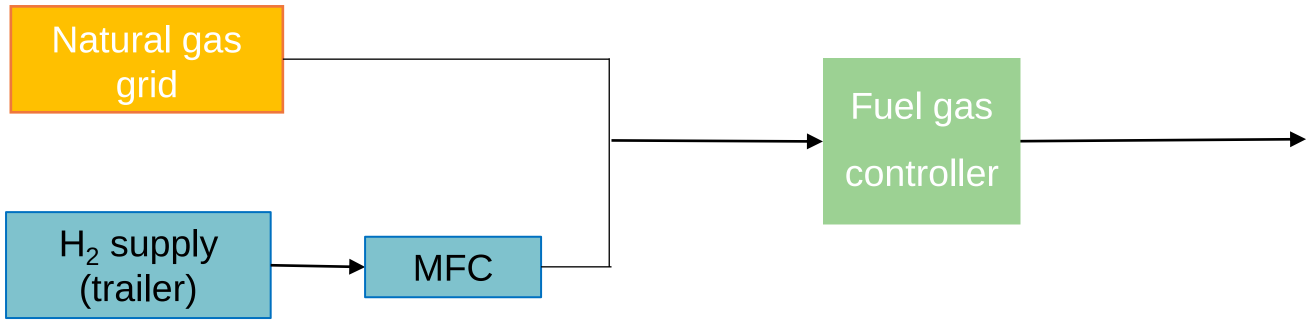
- Mitigation strategy

Testplan

Admixing H_2 to NG

- Load sweeps
- IT-NOx map
- Investigations on different emission control software versions
- H_2 maximum blending rate
- Variation of IT as a function of H_2

Gastrain



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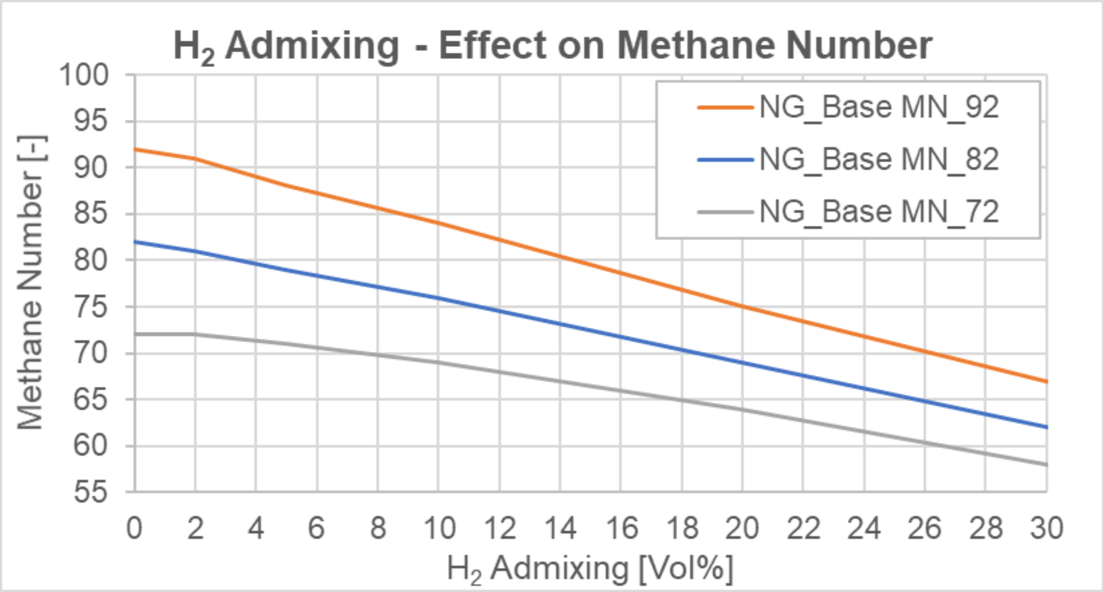
Performance measurement: H_2 admixing to natural gas at LEC

What changes?

Methane number



Example**:**

Low MN level of 70 and 25 % H_2 add-mixing ⇒ Delta MN ≈ -10

Low MN level of 80 and 25 % H_2 add-mixing ⇒ Delta MN ≈ -15

Heating value & Laminar flame speed

	Unit	NG MN90	NG MN90 + 25%Vol. H_2
Fuel lower heating value	kWh / Nm³	10.1	8.31
Fuel density	kg / Nm³	0.716	0.561
Fuel volume flow rate	Nm³ / h	286	347
Laminar flame speed	cm/s	15.2	16.7

Performance measurement: H_2 admixing to natural gas at LEC

Which challenges we are facing?

Limiting factors & risks

- Reduced methane number → impact on knock border
- Increased laminar flame speed → impact on combustion
- Ignition energy is less for H_2 → increased risk for backfire and deflagration
- Impact on mechanical components
- Grid code compliance / transient performance

Safety - relevant

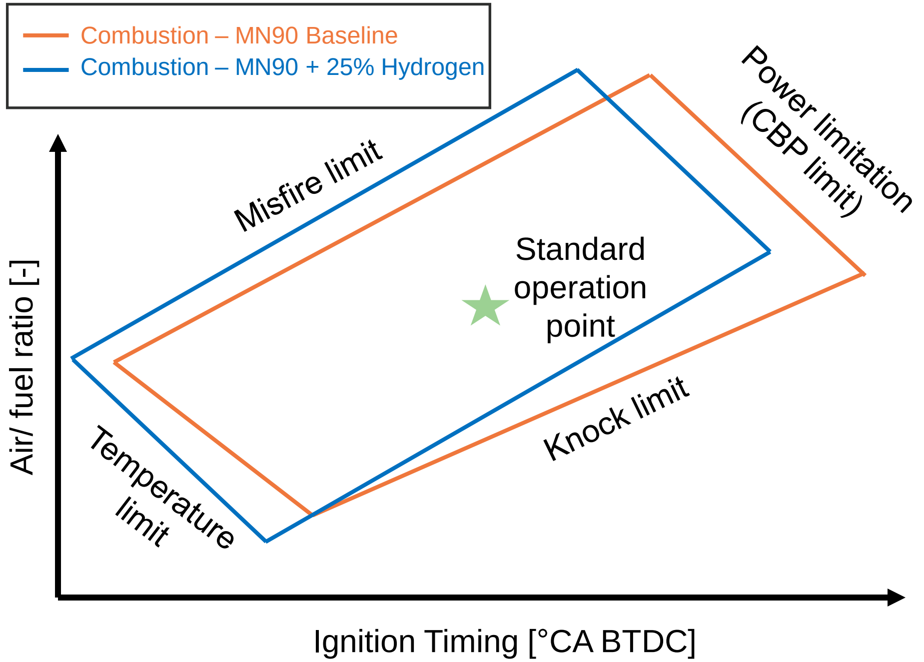
- Gas engine safety concept → additional control algorithms or sensors required
- Engine room ventilation concept
- Fire, gas, H_2 alarm system → H_2 leakage detection
- Engine room access control
- Operational instructions
- Material evaluation certificates

Performance measurement: H_2 admixing to natural gas at LEC

What happens with the engine operating window?

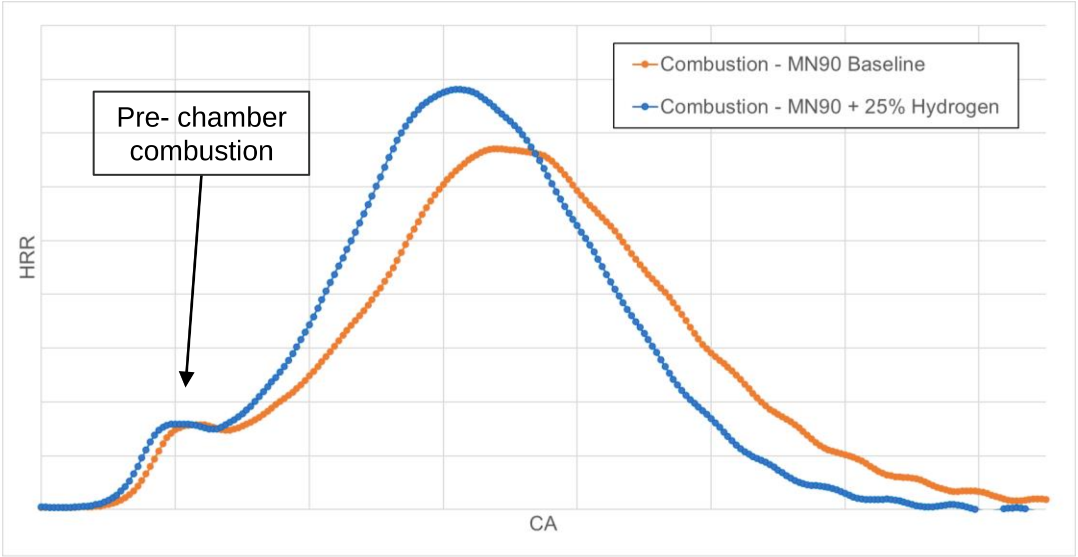
Engine operating window is restricted by four main limits:

- Knock border
- Misfire limit H_2
- Exhaust temperature or turbine inlet temperature
- Compressor bypass reserve (CBP) limit



Impact on operating window by adding 25%Vol. H_2 to NG:

- Increase of laminar flame speed and widening of lean flame initiation limit enabling operation at leaner fuel ratio
- Faster and earlier combustion leading to increased peak firing pressure and lower energy for the turbine
- Reduced methane number leading to lower knocking border
- Later ignition timing possible before T3 limit is reached
- Lower exhaust enthalpy leading to lower CBP position, limit reached before misfire limit



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Performance measurement: H_2 admixing to natural gas at LEC

What can we do?

J612 investigations @ LEC in Graz

- H_2 admixing to NG was tested up to 25%Vol. at various operating conditions including different emission control variants, engine load, ignition timing, charge temperature, NOx settings and the methane number of the natural gas.
- Additionally, tests with H_2 blending rate (transient) and operation at the maximum H_2 content were carried out. Finally, a mitigation strategy was applied to counteract the effects of hydrogen admixing.

Results

- The NOx emissions and the compressor bypass reserve can be kept constant by adapting the ignition timing as a function of the H_2 content.
- The strategy successfully mitigates any major changes in NOx, PFP, CBP-reserve, knock margin and turbocharger surge margin. A turbocharger adaptation is not required. A data sheet adaptation for this specific tested engine version is not required.

	Unit	*0% H_2 500 NOx	Delta – No adjustment, 25% H_2	Delta – only emission adjustment, 25% H_2	Delta – Emission and combustion constant, 25% H_2
Ignition timing	%	100	0	0	↓
NOx	%	100	↑	0	0
HC	%	100	↓	↓	↓
PFP	%	100	↑	↑	↓
Controls-Reserve	%	100	↓	↓	0
Surge Margin	%	100	↓	↓	0

*baseline data is valid for one specific engine version

Technical Concept

- H_2 signal
- Engine controls development
- NOx sensor

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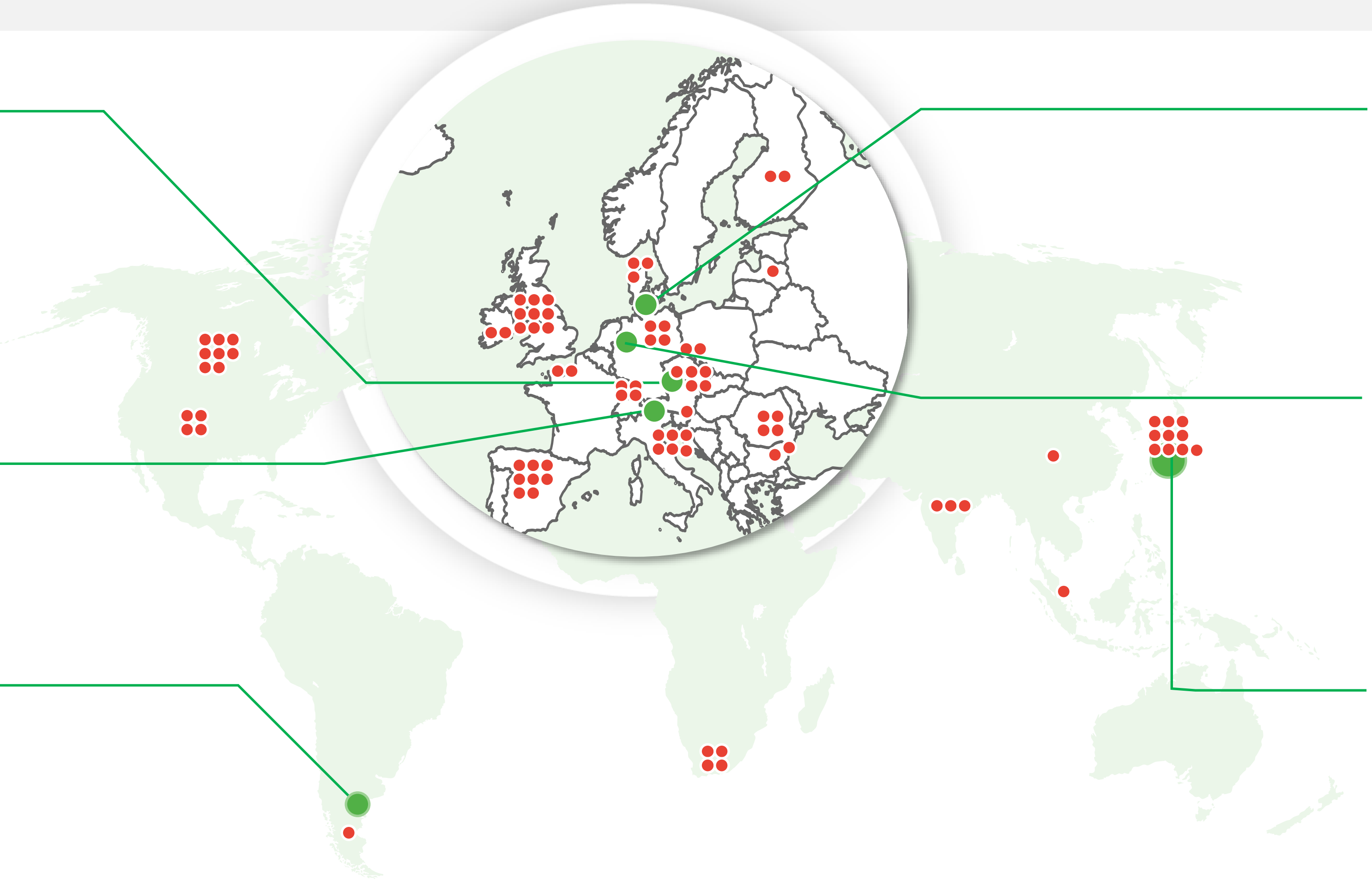
INNIO's* hydrogen admixing demo projects

It's happening now



30%v H_2

Biogas Stream- Austria
2008 demo
J312, main fuel NG

30%v H_2

Bozen - Italy
Horizon 2020 demo
J612, main fuel NG

42%v H_2

Hychico – Argentina
Operating since 2008
J420, main fuel NG

up to 100% H_2

HanseWerk Natur - Hamburg
Commissioning Q4/2020
J416, main fuel NG

60%v H_2

H2ORIZON - Stuttgart
Commissioning Q2/2020
J312, main fuel NG

60%v H_2

Ando Hasama - Japan
Commissioning 01/2020
J312, main fuel NG

More than **200 MW** of INNIO's installed fleet are **running on syn gases** with up to 70% H_2

* Indicates a trademark
● Syn gas plants (June 2019)

Performance measurement: H_2 admixing to natural gas at LEC
Summary

- Blending H_2 into the existing NG pipeline network is being seriously considered in both US and in Europe
- About half of the current Jenbacher product portfolio is affected, plus older versions in the field (installed NG base)
- Our investigations at LEC led to a robust technical concept enabling up to 25% H_2 in NG

Thank you for your attention!
Questions?

Introduction

Application variety

IPP & utilities

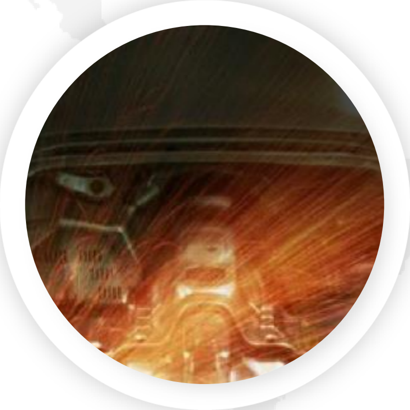
Commercial customers

Greenhouse

Biogas

Landfill gas*

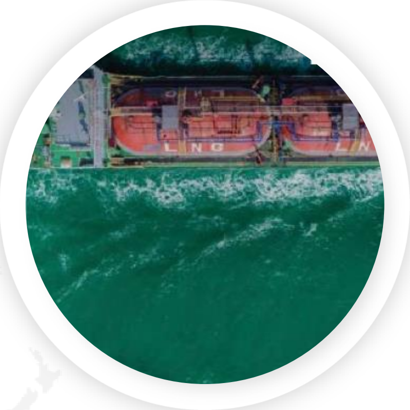
Fast-start applications e.g. data center industry



Industrial CHP/processing – e.g. automotive industry

Oilfield power generation

Gas compression



LNG

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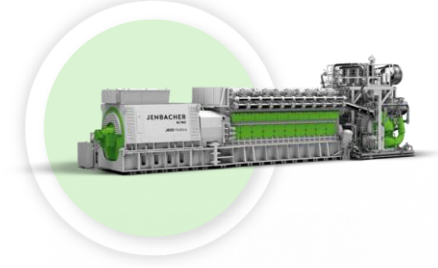
*Image: Deponie Wernsdorf, 2015; Landfill operator: Berliner Cleaning Service; Image Author: Firma Helicolor Luftbild Ost GmbH

Power generation – Delivering fuel flexibility, long service life, outstanding durability & reliability

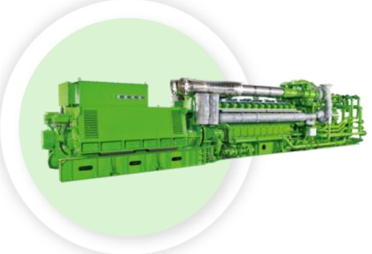
Jenbacher* gas engine platforms

Jenbacher J920 FleXtra



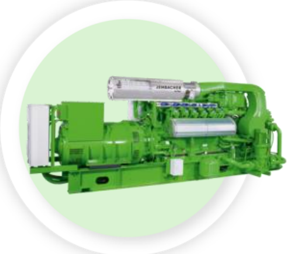
- V20 cylinder; 1,000/900 rpm (50/60 Hz)
- **Electrical output:** 10.4 MWe (50 Hz), 9.3 MWe (60 Hz)
- **Electrical/total efficiency:** 49.1/>90% (50 Hz), 49.9/>90% (60 Hz)
- **Fast start:** 2-minute startup capability
- **Delivered engines:** ~40
- **Launch date:** 2013

Jenbacher Type 6



- V12, V16, V20 cylinder; 1,500 rpm (50/60 Hz)
- V24 2-stage turbocharged
- **Electrical output:** 1.8 – 4.5 MWe (50 Hz)
- **Electrical efficiency:** up to 47%
- **Fast start version:** 45-sec (J620)
- **Delivered engines:** ~5,500
- **Launch date:** 1989 (J624 in 2007)

Jenbacher Type 4



- V12, V16 and V20 cylinder: 1,500/1,800 rpm (50/60 Hz)
- **Electrical output:** 0.8 – 1.5 MWe (50 Hz)
- **Electrical efficiency:** up to 44%
- **Delivered engines:** ~4,900
- **Launch date**: 2002

Jenbacher Type 3

- V12, V16 ,V20 cylinder; 1,500/1,800 rpm (50/60 Hz)
- **Electrical output:** 0.5 - 1 MWe (50 Hz)
- **Electrical efficiency:** up to 41.7%
- **Delivered engines:** ~10,100
- **Launch date:** 1988

Jenbacher Type 2

- L8 cylinder; 1,500/1,800 rpm (50/60 Hz)
- **Electrical output:** 250 - 330 kWe (50 Hz)
- **Electrical efficiency:** 39.5%
- **Delivered engines:** ~1,200
- **Launch date:** 1976

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Functional block diagram

Function of compressor bypass

- TB… turbocharger bypass valve
- DK… throttle valve