H2 as a future fuel for CHP

H2 (Water) stof tot nadenken, 2021
A leading technology provider of gas engines, power equipment, a digital platform, Headquartered in Jenbach, Austria, with additional primary and related services for power generation and gas compression at or near the point of use.

Renowned for our proven Jenbacher* and Waukesha* product brands.

Gas engines from 200 to 10,400 kW

Operations in Welland, Ontario, Canada, and Waukesha, Wisconsin, USA.
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: ~4,900
- 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 3
- 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

### Jenbacher Type 2
- 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%
- Fast start version: 2-minute startup capability
- Delivered engines: ~10,100
- Launch date: 1988

### 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

*Indicates a trademark
Transitioning to 100% Renewable fuels

Today

45%  ←  EU  →  55%

- Natural Gas CHP
- Biogas

Today’s mix of fossil natural gas and renewable gases

Tomorrow

- Biomethane or Synthetic Methane CHP
- Biomethane & CO₂ usage or Hydrogen CHP
- Hydrogen CHP
- Biogas

Carbon neutral fuels & green hydrogen
Integrated energy system

Decentralized CHP

Fuel

Primary energy savings ~33%
CO₂ savings ~33%

Source: Illustration von CogenEurope, © COGEN Europe
Jenbacher gas engines with hydrogen operation
MW scale
Jenbacher’s experience with Hydrogen & Hydrogen mixtures

Coke gas (Profusa)
COD 1994
- H₂: ~50-70 Vol%  
- CH₄: ~20-25 Vol%  
- LHV: ~5 kWh/m³

Process gas (Krems)
COD 1996
- H₂: ~15-17 Vol%  
- CH₄: ~1.5 Vol%  
- LHV: ~0.5 kWh/m³

Syngas (Mutsu)
COD 2003
- H₂: ~30-40 Vol%  
- CO: ~25-30 Vol%  
- LHV: ~2.5 kWh/m³

Pure Hydrogen
2021+
- H₂: ... 100 Vol%  
- Nat. Gas or Inerts  
- LHV: ~3 kWh/m³

Commercial operation

More than 250MW installed with syngas / process gases
90 projects in 28 countries and experience with all engine types

Future
Jenbacher gas engine solutions for H₂

A

H₂ in natural gas pipeline

A-1: Low H₂ blending
Optimized for NG <5%v H₂

A-2: Medium H₂ blending
broadband product 5-20 (30)%v H₂

B

H₂ local admixing

B-1: Special gas engine
operational optimized up to ~60%v H₂

B-2: NG / H₂ engine
dual gas engine 100%v NG / H₂

C

Pure H₂

C: H₂ engine
hydrogen engine (H₂)
100%v H₂

Conventional NG+H₂ fuel mixture boosted system

H₂ fuel injection system

no modifications required

existing versions available

existing versions available

pilots available (pre-serial engines)

pilots available (pre-serial engines)
H₂ mixed in pipeline natural gas (typically up to 20% vol)

Important fuel properties to consider
- Heating Value
- Methane Number
- Laminar Flame Speed

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Constraints</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>Fluctuation</td>
<td>≤ 4 %/min</td>
</tr>
<tr>
<td>MN</td>
<td>RoC</td>
<td>≤ 10 MN/min</td>
</tr>
<tr>
<td>H₂ content in NG</td>
<td>RoC</td>
<td>≤ 4 Vol%/min</td>
</tr>
<tr>
<td>100% H₂</td>
<td>H₂ purity</td>
<td>not relevant</td>
</tr>
</tbody>
</table>

Transmission level
- Distribution level

**Mixtures**

<table>
<thead>
<tr>
<th>Component</th>
<th>NG example</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>97.6</td>
<td>0</td>
</tr>
<tr>
<td>C₂H₆</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>C₃H₈</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>H₂</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>LHV</td>
<td>36 730</td>
<td>10 800</td>
</tr>
<tr>
<td>WI</td>
<td>48 704</td>
<td>41 000</td>
</tr>
<tr>
<td>MN</td>
<td>92</td>
<td>0</td>
</tr>
</tbody>
</table>

Laminar flame speed cm/s 38 >300
Hydrogen added to pipeline Natural Gas

H2 Admixing-Effect on Wobbe Index

H2 Admixing-Effect on Methane Number

>5%(v) \( \text{H}_2 \) in pipeline gas … we recommend a signal to gas engines about \( \text{H}_2 \) content
>5%(v) $\text{H}_2$ in pipeline gas … we recommend a signal to gas engines about $\text{H}_2$ content
**H₂ local admixing to natural gas**

**Important fuel properties to consider**

- **Heating Value**
- **Methane Number**
- **Laminar Flame Speed**

✓ H₂ content to control system available

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Vol-%</th>
<th>Hydrogen</th>
<th>LHV (kJ/Nm³)</th>
<th>WI (kJ/Nm³)</th>
<th>MN (kJ/Nm³)</th>
<th>Laminar flame speed (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4</td>
<td>0</td>
<td>0</td>
<td>10 800</td>
<td>41 000</td>
<td>0</td>
<td>&gt;300</td>
</tr>
<tr>
<td>C2H6</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3H8</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2</td>
<td>100</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NG example**

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<th>MN (kJ/Nm³)</th>
<th>Laminar flame speed (cm/s)</th>
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<td>C2H6</td>
<td>2</td>
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<td></td>
</tr>
</tbody>
</table>

**Mixing at the plant**
H₂ local admixing demo projects

30%v H₂
Bozen - Italy
2017, Horizon 2020 Demo
J612, main fuel NG

30%v H₂
Biogas Stream - Austria
2008 Demo
J312, main fuel NG

42%v H₂
Hychico – Argentina
Operating since 2008
J420, main fuel NG

60%v H₂
H2ORIZON - Stuttgart
Commissioning 2020
J312, main fuel NG

up to 100% H₂
HanseWerk Natur - Hamburg
Commissioning 11/2020
J416, main fuel NG

60%v H₂
Ando Hasama - Japan
Commissioning 01/2020
J312, main fuel NG
Hychico, Diadema Wind Park and Hydrogen Plant, Chubut Province, Argentina

About the region:
Currently large oil & gas fields
2,000 GW wind power potential, compared to 600 GW global installations today
Ideal place for exporting green H₂ and e-fuels in the future

Green H₂ demo:
- 6.3 MW wind park with 54.9% CF (2017), avg. >50%
- 0.8 MW of electrolyser (2 units), 120 Nm³/hr H₂
- H₂ with high purity (99.998%), O₂ for local market
- Underground H₂ storage research

J420 converts H₂ back to power
- Output: 1,415 kWₑ
- Main Fuel: NG MN >90
- Operation with controlled H₂ blending
  - 0-27 v% H₂: 1,415 kW
  - 28-42 v% H₂: 1,415 to 1,180 kW

~70,000 oh since 2008

www.hychico.com
First 100% Hydrogen pilot engine with ~1MW HanseWerk Natur (E.on), GER

**Engine type and version**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>J416 C202 (Natural gas)</th>
<th>J416 C202 (Hydrogen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Natural gas</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Nom. output Pel*</td>
<td>999 kWel</td>
<td>&gt;600 kWel</td>
</tr>
<tr>
<td>Elec./total eff. @ nom. output</td>
<td>~42%/~93.5%</td>
<td>40%/~93%</td>
</tr>
<tr>
<td>Expected H₂ content w/o derating*</td>
<td>-</td>
<td>~20 Vol%</td>
</tr>
<tr>
<td>Max H₂ content (w/ derating)*</td>
<td>-</td>
<td>100 Vol%</td>
</tr>
</tbody>
</table>

* Controlled H₂ blending, base gas quality MN~80

Engine designed and optimized for operation with natural gas fuel,

Engine capable to run on 100% hydrogen and any mixture of natural gas and hydrogen (Dual-Fuel engine)

- 100% NG as commercial fuel achieving max. total efficiency
- Up to 100% H₂ operation possible (H₂ as demonstration fuel)

**Milestones**

✓ Factory test successful in Aug., 2020
✓ Site demonstration in Nov. 2020
✓ PR about site demonstration by INNIO and E.ON in Q4, 2020

With hydrogen becoming a commercial fuel, INNIO Jenbacher will invest in optimizing gas engine performance
Important fuel properties to consider

- Heating Value
- Methane Number
- Laminar Flame Speed

First 100% H2 demo in 2001
H2 engine offerings
### H2 engine – Type 4 – 50Hz (pre-serial engine)

<table>
<thead>
<tr>
<th>H2: &lt;100mg NOx @5%O2</th>
<th>J412-H2</th>
<th>J416-H2</th>
<th>J420-H2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Output (kW)</strong></td>
<td>531</td>
<td>710</td>
<td>889</td>
</tr>
<tr>
<td><strong>Thermal Output (kW)</strong></td>
<td>630</td>
<td>838</td>
<td>1,049</td>
</tr>
<tr>
<td><strong>Electrical Efficiency (%)</strong></td>
<td>39.4</td>
<td>39.5</td>
<td>39.5</td>
</tr>
<tr>
<td><strong>Total Efficiency (%)</strong></td>
<td>86.1</td>
<td>86.1</td>
<td>86.2</td>
</tr>
<tr>
<td><strong>H2 consumption (kg/h)</strong></td>
<td>40</td>
<td>54</td>
<td>67</td>
</tr>
<tr>
<td><strong>H2 consumption (Nm³/h)</strong></td>
<td>450</td>
<td>599</td>
<td>749</td>
</tr>
</tbody>
</table>

Best effort performance is about 10% higher in output

### Technology
- Port injection (gas pressure 8+bar)
- Cylinder selective combustion control
- Wastegate for turbo charger

Alternatively, a “Dual Fuel Product” – 100% NG / 100% H2 – is available
H2 engine – fuel supply system
Main difference between a NG engine and a H2 engine

Intercooler on both pictures is not shown
Future role of Jenbacher gas engines in a renewable world
H2 ready means the Jenbacher gas engines can operate with up to 20%(v) of hydrogen and can be converted to 100% H2 operation. A H2 ready designed power plant helps to reduce future H2 retrofit costs.