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Power Generation Symposium | Europe

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Fuel Flexibility: Increasing the sustainability of Internal Combustion Engines

PowerGen Symposium 2022

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29th June 2022

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- Since 8 years with RRPS
- Background: Mechanical Engineering and Business (Technical University Graz)
- Nearly 30 year Power Gen professional (Jenbacher and General Electric)
- When not at work: Mountains, Travel, cooking/eating, …

Michael Wagner

Director Product & Solutions Management - Stationary

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Alternative – Renewable Liquid Fuels for Diesel Engines

Development of fuels are triggered by GHG reduction requirements, variety of alternative fuels and feedstock will increase by time to aim sustainability

Time: 1892 — 2021 — 2023 — 2030

GHG reduction requirements:
- 1992 United Nations Framework Convention on Climate Change
- 1997 Kyoto Protocol
- 2015 Paris Climate Protection Agreement
- 2020 Nationally determined contributions

Sustainability: low → high

Fuel type	Fossil Diesel Fuel	Biodiesel 1st Gen (FAME)	Synthetic diesel fuel (CtL/GtL/BtL/HVO)	Power to Liquid (PtL)
Feedstock	Crude Oil	Vegetable Oil & Methanol	Organic waste Natural gas Coal	Water + CO2
Specification	JP5 / JP8 / F63 ISO8217 / GB19147 / GB252/ DIN 51603	EN 14214 ASTM D 6751	EN 15940	EN 15940 (Today's focus)
	Mixtures: EN 590 (B7) / BS 2869 (B7) / ASTM D975 (B5) EN 16709 (B20, B30)		RRS Series Release for EN15940 fuels: S4000Gx3 & S4000Gx4 S1600Gx0 & S1600Gx1	

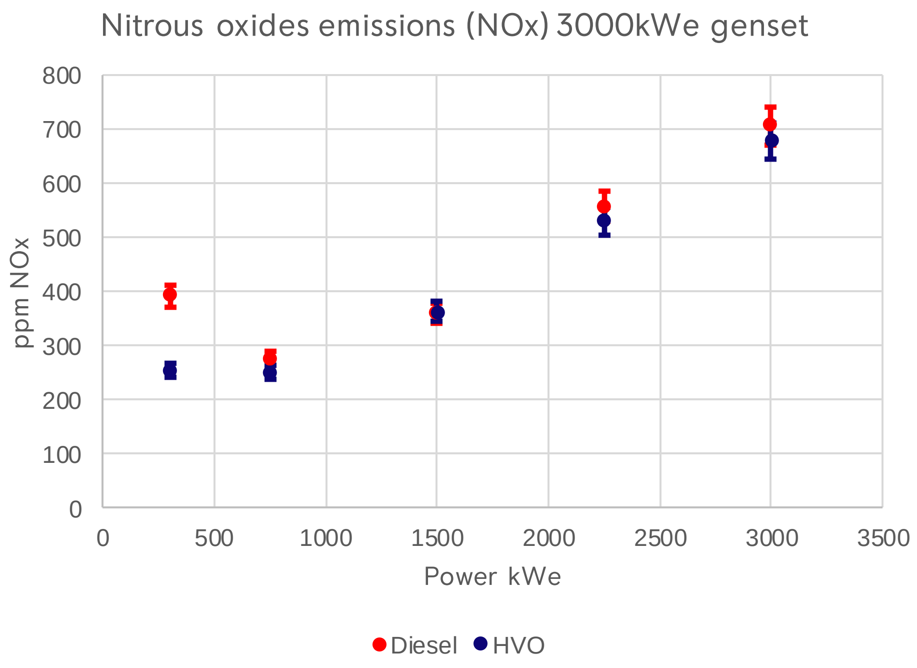
FAME = fatty acid methyl ester, CtL = Coal-to-Liquid, GtL = Gas-to-Liquid, BtL = Biomass-to-Liquid, HVO = Hydrogenated Vegetable Oils, PtL = Power-to-Liquid

6 key parameters identified to derive current and near-future sustainable fuel strategy, HVO & PtL are high ranked

	Fuel-type	CtL	GtL (w/o Biogas)	FAME (1st Gen Biodiesel)	BtL	HVO	PtL
Properties general	Sustainability of Feedstock ●	Coal & Natural Gas		Biomass, Animal waste, Algae & Lignin			Water & CO2
	CO2 reduction Well-to-Wheel[1] ●	1%	1%	<78%[2]	<90%[2]	<90%[2]	>90%
	NOx & PM reduction ●	Yes		Yes (blending <30%)	Yes		
	Drop-in fuel	Yes					
Properties RRS	Long-term storage life	Yes[3]		Less	Yes[3]		
	Combability w/ elastomers & engine oils	Yes[3]		Less	Yes[3]		
	Asset performance[4] ●	Same or better		Less	Same or better		
	Service & maintenance intervals[4] ●	Same or better		Less	Same or better		
Market	Commercial availability ●	N/A	Yes	Yes	N/A	Yes	N/A
	Pricing	Dependent on local legislation and political incentivation					
	Key parameters ●	2/6	4/6	3/6	5/6	6/6	6/6

1) Compared to EN590 Fossil Diesel Fuel B0 = 95.1MJ/CO2, 2) Depend on feedstock, 3) No FAME Content, 4) Compared to EN590 Fossil Diesel Fuel

Reduction of harmful pollutants



NOx emissions comparison between diesel and HVO

- Significant improvement of the emissions in low power range operations
  → less NOx emissions in part load testing
- small emission improvement in middle and high power ranges
- In average 8% lower NOx emissions
- Lower urea consumption expected

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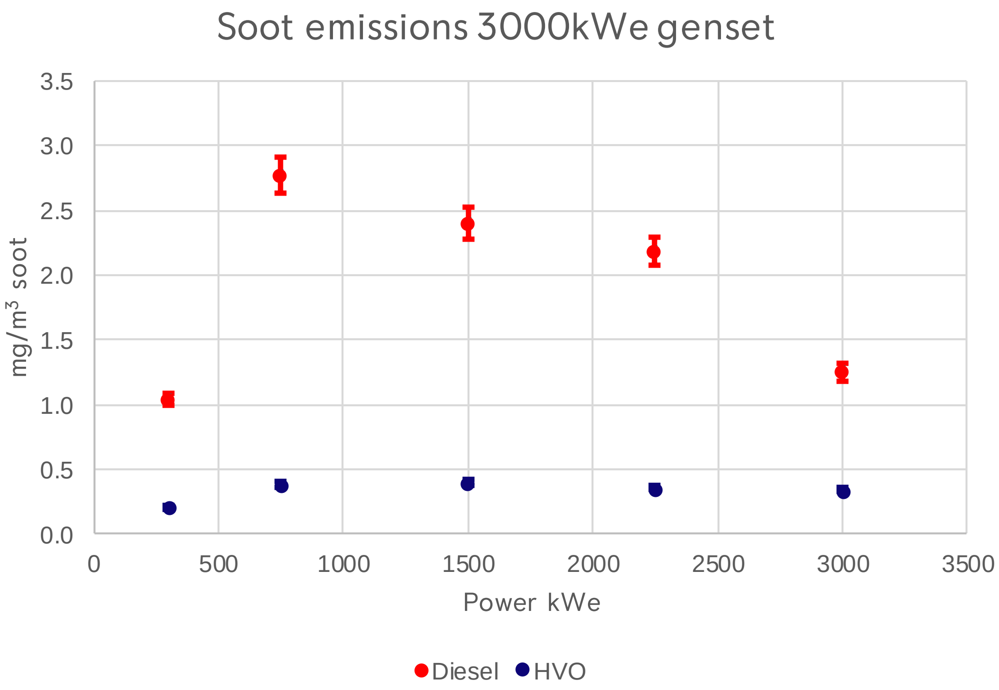
Reduction of harmful pollutants

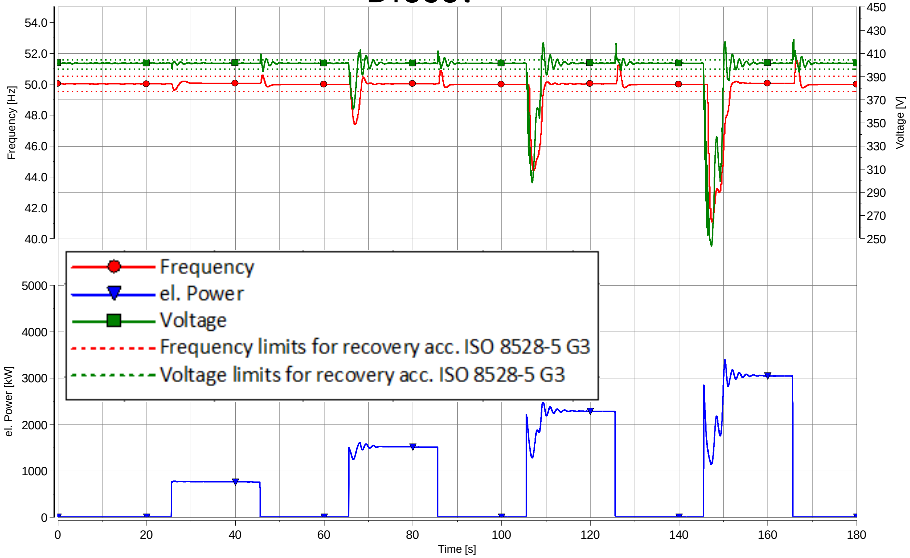


Comparison of soot emissions between diesel and HVO

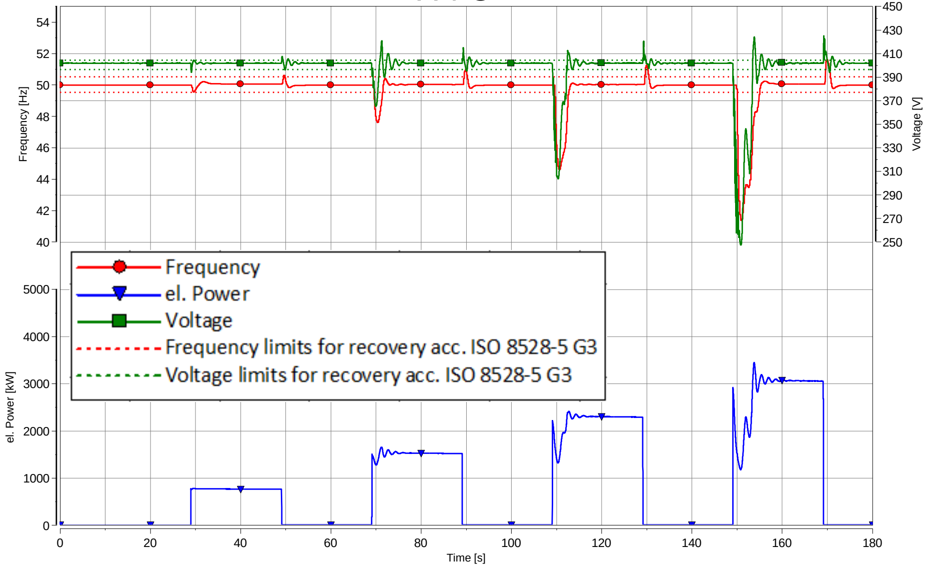
- Significant reduction of soot emissions for the whole power range
- The range of soot reduction is 50-80%
- Black smoke is reduced

Same performance

Diesel



HVO



- Measuring of the block loads (25%, 50%, 75%, 100%) engine: 20V 4000 G94F
- Comparison of the load steps between diesel and HVO no performance deviations regarding voltage, frequency and power
- Settling time is the same, transient behavior between the fuels is comparable
- Injection system has reserves, → amout of injected fuel is very fast variable → same dynamic loading performance

Long storage capabilities, positive chemical properties

Good storage properties (only if 0% FAME-content), similar to B0 heating oil, resistent against diesel pest

Biological degradable, less hazardous substance properties compared to E590 diesel

Better ability of ignition → better, more homogenic combustion due to higher cetane number

Hydrophobic fuel → simplification of water separation

		Dieselfuel	HVO
Norm		EN590	EN15940
H-sentences (physical.)	pictogram		
H226 fluid and steam flammable		yes	No
H-senteces (health hazards)	pictogram		
H304 can be deadly if swallowed or entered into respiratory tract.		yes	yes
H315 causes skin irritations.		yes	No
H332 health hazardous by breathing in.		yes	No
H373 organs (blood, liver, thymus) can be damaged due to longer long exposure.		yes	No
H351 presumably causes cancer.		yes	No
H-sentences (environment)	pictogram		
H411 toxic for water organisms.		yes	No

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Significant reduction of greenhouse gas emissions (HVO)

- CO_2 from the atmosphere will be bound in the raw materials
- The raw materials are used to produce HVO
- HVO is used in the combustion while the engine is operating
- Due to the combustion CO_2 is emitted back into the atmosphere
- Greenhouse gases are bounded again in the raw materials

→ closed carbon cycle

Summary

Reduction of harmful pollutants: up to -80% soot (mg/m^3) & up to -8% nitrous oxides (ppm NO_x)

Same performance: same maximum power, load acceptance and consumption

Simple drop-in fuel: no engine hard- or software adaptions necessary. Blends are possible.

No effect on service & maintenance intervals: Standard warranty conditions apply.

Long storage capability: High reliability under cold conditions and high oxidation stability (no FAME)

Positive chemical properties: higher cetane-number and better water separation (hydrophobic)

Approved for *mtu* GenDrive engines: S4000 & S1600, 50Hz & 60Hz all emission optimizations & power ratings

Significant reduction of greenhouse gas emissions (CO2) with HVO: Improved ecological footprint & corporate image

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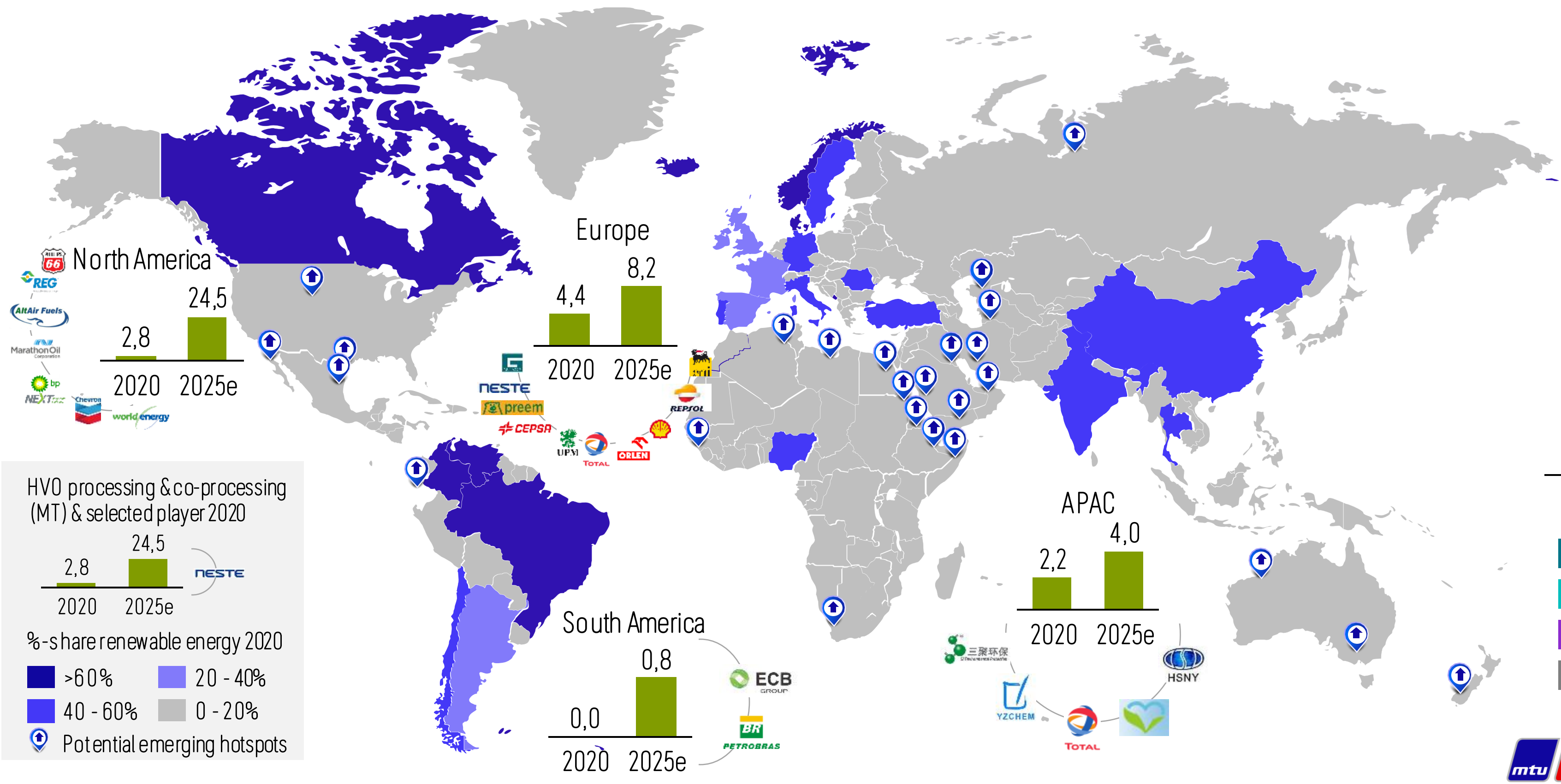
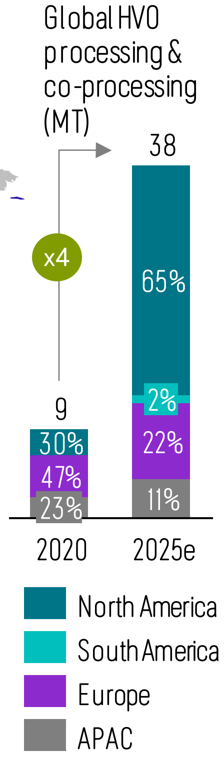
Global HVO processing and co-processing volumes will quadruple by 2025 vs 2020, production locations of renewable energies will serve as PtL hotspots beyond 2025





Sources: RRS Market Intelligence VSM (BloombergNEF, dataset Global Renewable Fuel Projects Tracker Oct. 2021, IEA Hydrogen Database); RRS Strategy & Business Development (Greenea Horizon 2030 Jan. 2021, S&P Global Platts Analytics, Fraunhofer IEE, IEA ORG)

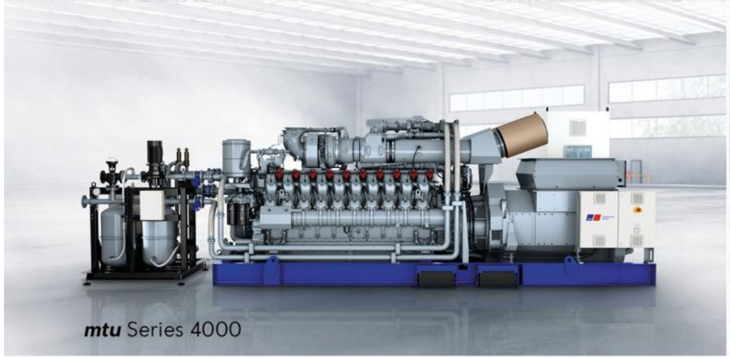
Alternative – Renewable Fuel for Gas Engines

The transition from natural gas to Hydrogen

WAY TO NET ZERO
Renew-able fuel

New *mtu* hydrogen solutions

WAY TO NET ZERO
H2 ready



mtu Series 4000

mtu Series 500

H2 Blending **10%**

H2 Blending **25%**

100% H2

+ Conversion Kits for installed ***mtu*** Gas Engines

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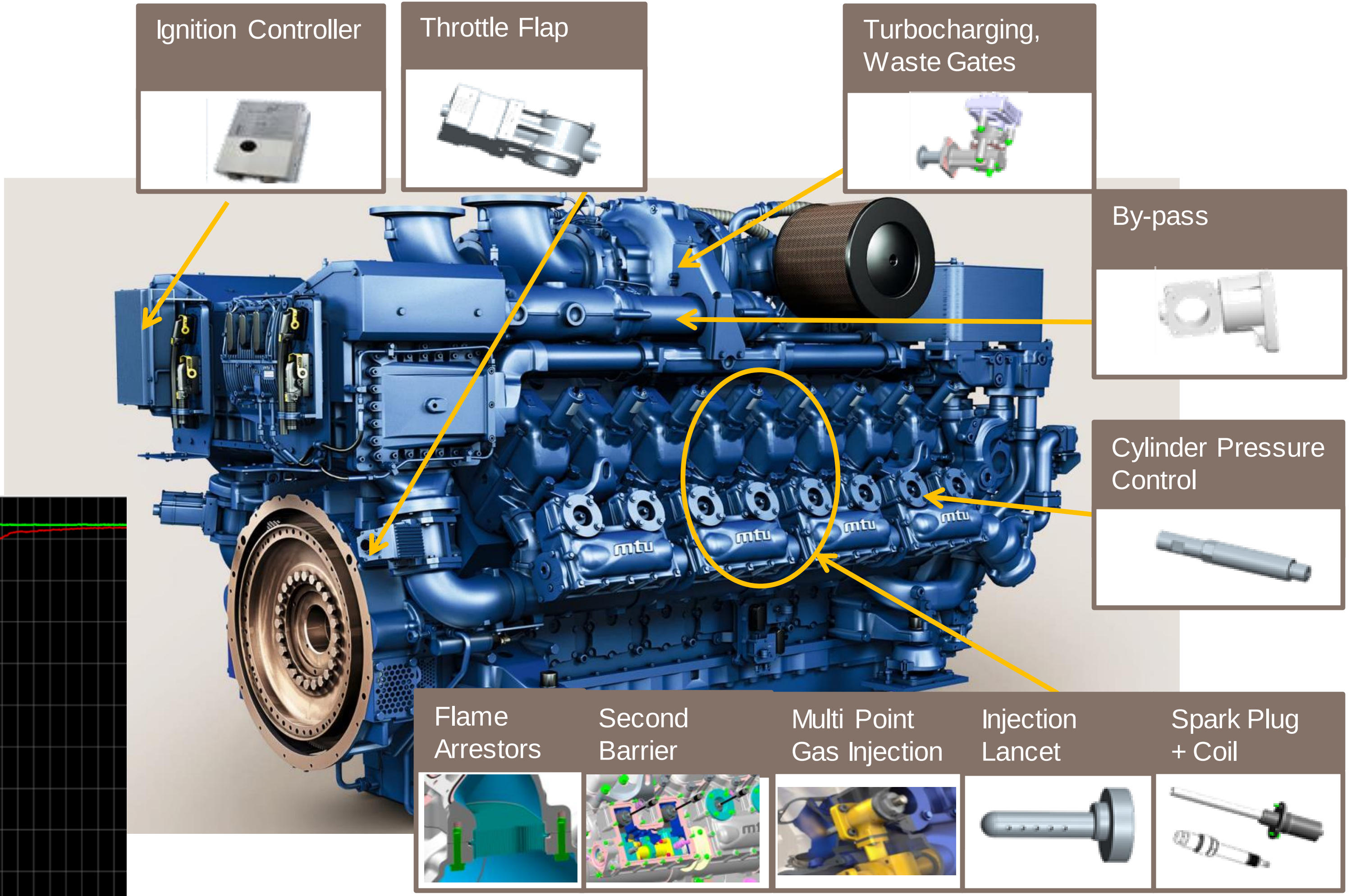
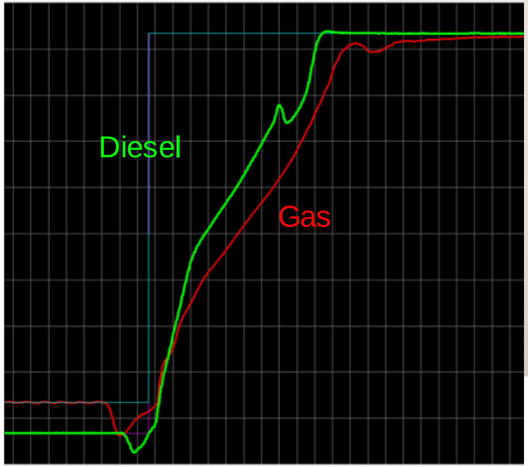
Technical Concept,

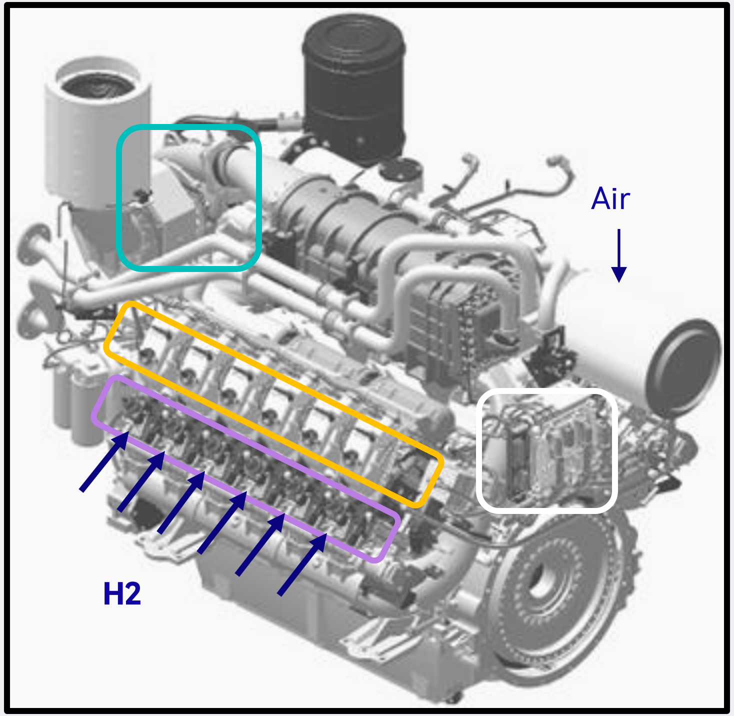
key components and performance





100% H2 Engine Port Injection

Hydrogen Conversion Kit



Turbocharging
High air to gas ratio for Low NOx

Piston Design
Lower compression ratio

Multi Point Injection
State of the art of injection in Mobile Gas engine

Engine Control
Multiport Injection
(incl. **Cylinder pressure monitoring**)

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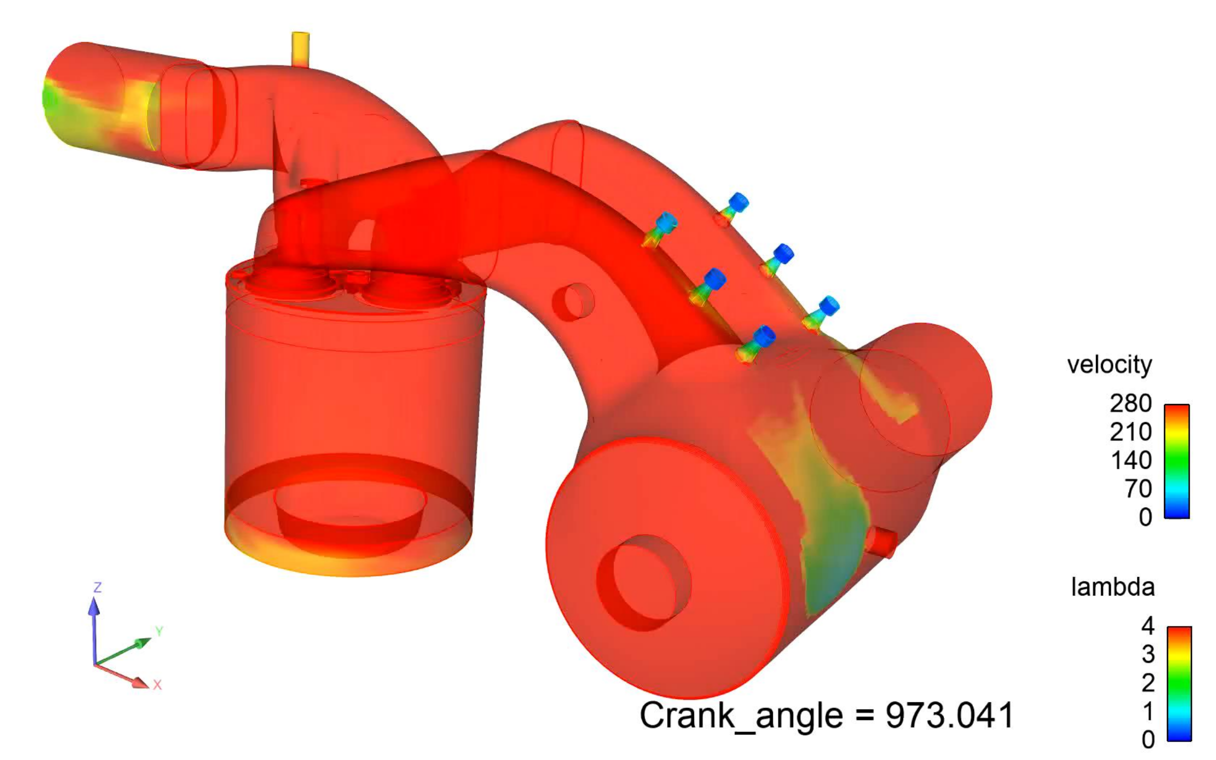
Hydrogen Engine 3D-CFD Combustion Simulation



The Simulation shows a very homogeneous air-fuel mixture and combustion

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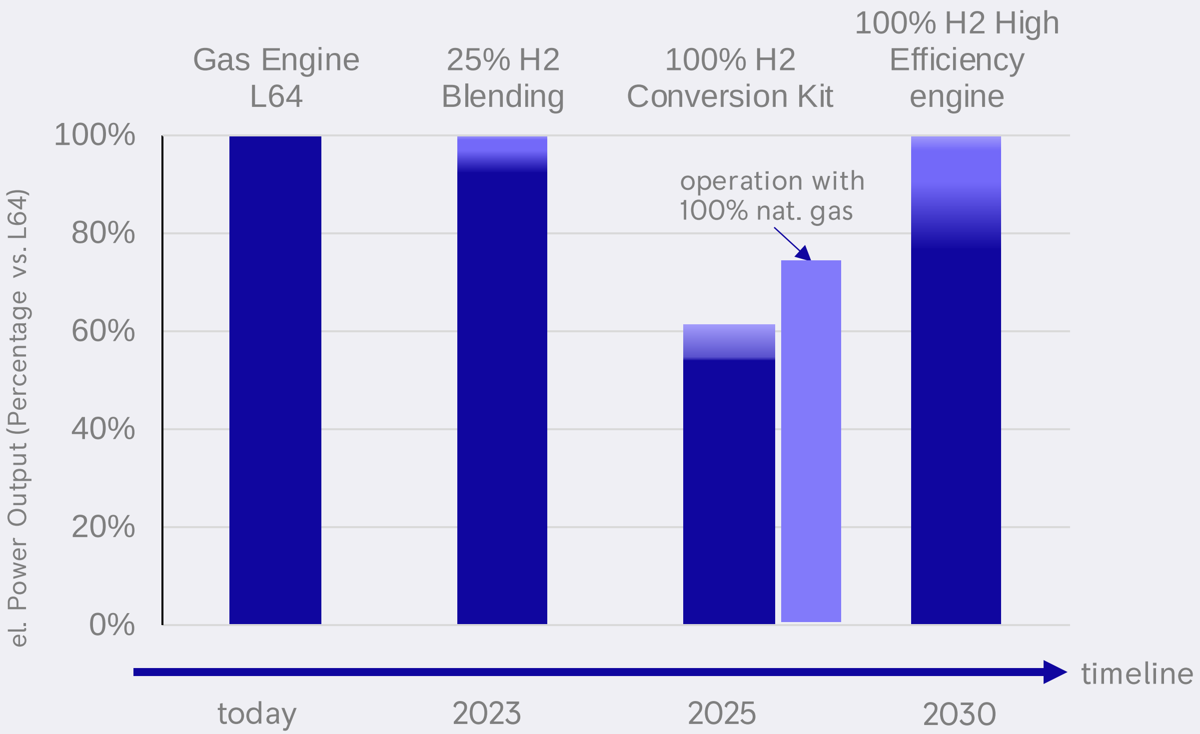
Target is to maximize the specific output and enable Bi-fuel operation



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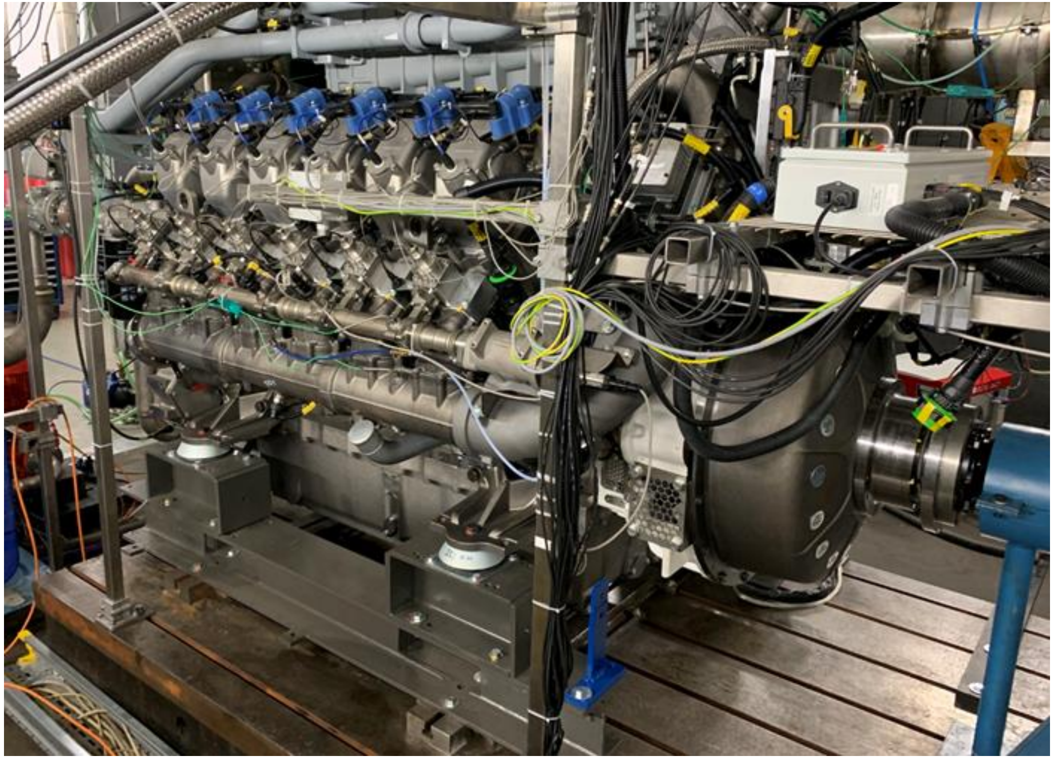
H2 engine development ... important milestones achieved

June '22: Delivery and installation of 170 kWe Hydrogen CHP system (6R 500/2G) at "Microgrid Validation Center" in FN ... week 29/'22 Commissioning

H2 engine development … important milestones achieved



June '22:
First fire 12V4000 Hydrogen at Testbed

Renewable Liquid Fuels

We have tested and approved the use of HVO and GtL fuels for defined ***mtu*** diesel engines.

H_2 blended to Natural Gas

The blending of certain levels of hydrogen into the natural gas pipeline is seen as a valuable option during the transition to Carbon Free Gas.

100% H_2 Gas Engine

Upgrading of mtu Gas Engines will be technically and economically possible.

H_2 Fuel Cell

Demonstration of new concepts for modular FC system integration will set the foundation for large scale power generation from PEM fuel cell technology.

Rolls-Royce Solutions ...

Our Sustainability Product Roadmap

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Thank you for your attention!

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