



**Enabling high
penetration
renewables.
No silver bullet**

CATERPILLAR®

**Energy Power
Systems**



What does a high renewable penetration mine look like?



Renewable Diesel – (Hydrotreated Vegetable Oil)

All CAT EP engines are Renewable Diesel ready

How it's made:

- Vegetable oil feedstocks are treated with high pressure hydrogen over a catalyst to remove oxygen and fully saturate the carbons with Hydrogen
- Distilled to remove unwanted fractions

Benefits:

- Drop in diesel replacement
- EPA GREET is 62% GHG reduction for soy-based HVO
- EU RED is 65% - 85% GHG reduction, dependent on where/how HVO was derived
- High cetane number (higher cetane = better combustion)
- Reduced exhaust particulates
- Performance and maintenance specifications are very similar to fossil diesel

**GHG Protocols (www.ghgprotocol.org) currently does not have an established method to determine lifecycle CO2 reductions from the use of biogenic fuels.*





H₂



Hydrogen-based Caterpillar Power Generation Solutions

Caterpillar EP Continues to Build on its Expertise in Hydrogen

20+ yrs of experience with hydrogen blends in reciprocating engines

Caterpillar developing hydrogen fueled reciprocating engines and turbines

Caterpillar deploying fuel cells as part of microgrid power solutions

**Opportunities for
hydrogen power
systems**



Historical Genset Experience With H₂ : Coke oven plant

27 MW Power Plant based on CG260-16 generator sets

Each unit: 3000 kW (2928 kW_e), 40.5% efficiency

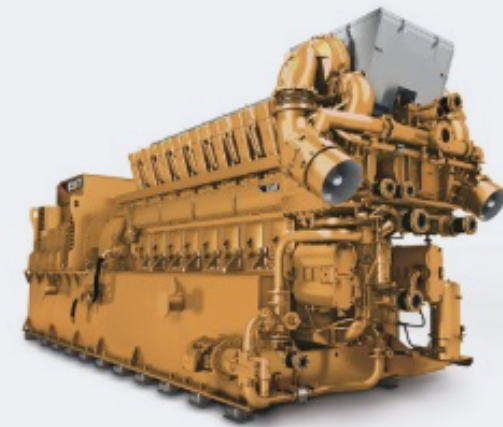
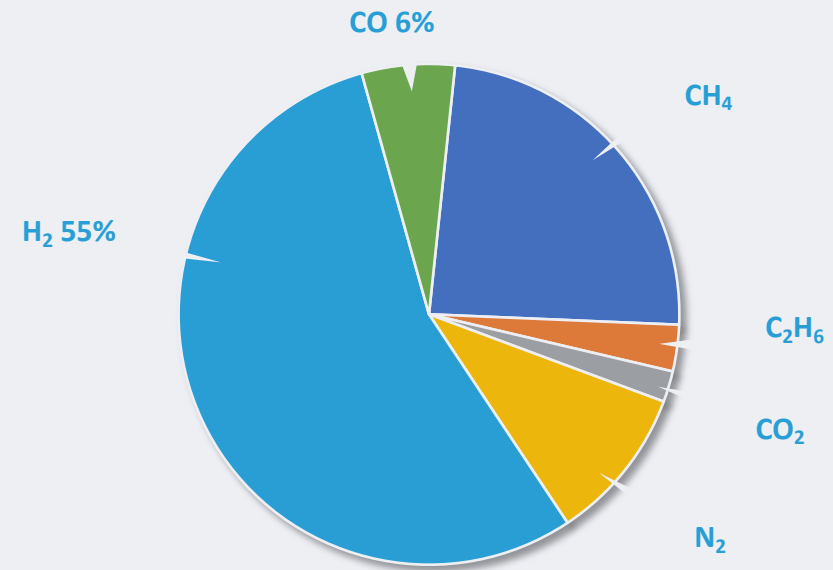
Fuel: Coke oven gas (Steel Manufacturing)

55% to 60% hydrogen

MN \approx 35

22 years of successful operation

same maintenance and durability when operating on high hydrogen content compared to natural gas engines



Natural Gas Product Range

0.5 to 100 MW power plants

Efficient Electric Production,
Combined Heat and Power (CHP)

Continuous Operation, Fast Ramp
Up, high Block Loads

Low Emissions

Wide Range of Gases:
Natural Gas, Propane, Biogas, Coal
Mine Methane, Hydrogen, etc.



Likely Paths for Hydrogen Utilisation

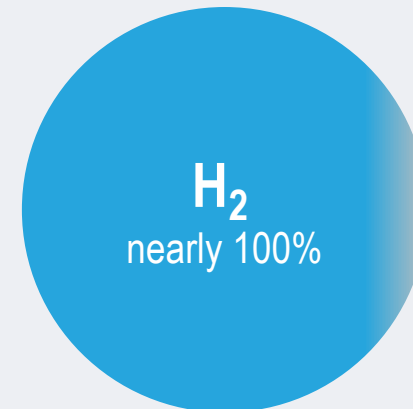
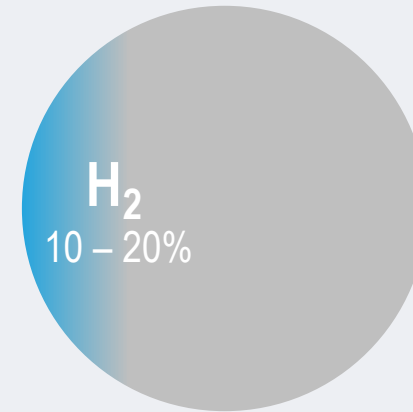
Two distinct and parallel applications:

Hydrogen blending: 10 – 20% H₂ (vol) mixed with natural gas

- Uses installed storage and distribution capacity of existing natural gas grid
- Cat/MWM gensets can utilize these hydrogen/natural gas blends with limited or no impact on ratings and performance

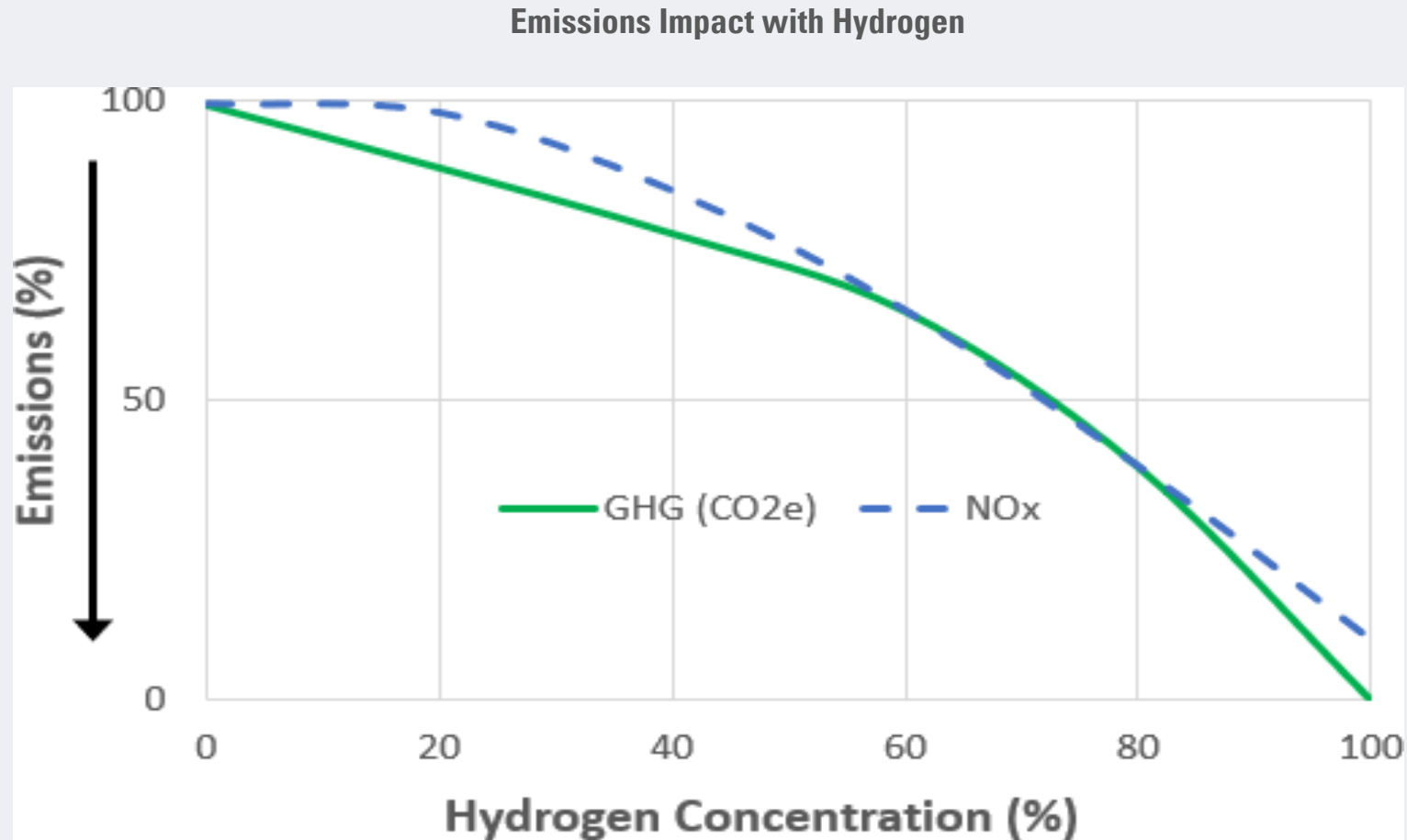
100% H₂ or nearly 100% at dedicated locations where H₂ is a product of a production process

- Requires specialised gensets and costly H₂ storage / distribution infrastructure
- H₂ availability is key. 1 MW gen = 57 M3 H₂ @ 700 bar a day!



Emissions Impact

Existing engines - % hydrogen as a fuel



GHG REDUCTION IS NOT A STRAIGHT LINE. LOW BLENDING % HAVE LITTLE IMPACT ON GHG ABATEMENT

Field Unit

Power Overview (@1.0pf)

	100% H ₂	Natural Gas / Up to 25% H ₂
Generator set power rating – ekW (kVA)	1250 (1562)	2000 (2500)
Fuel consumption at 100% load MJ/ekW-hr (Btu/ekW-hr)	10.05 (9526)	8.56 (8114)
Recoverable heat from JW circuit (JW+AC1+OC) kW (Btu/min)	940 (53458)	952 (54140)
Recoverable heat from exhaust – kW (Btu/min)	517 (29402)	1134 (64491)
Genset efficiency – %	41.0	43.5
Thermal efficiency – %	41.8	42.6
Voltage – V	400 - 11,000	400 - 11,000

**Materials and specifications are preliminary and subject to change without notice.*

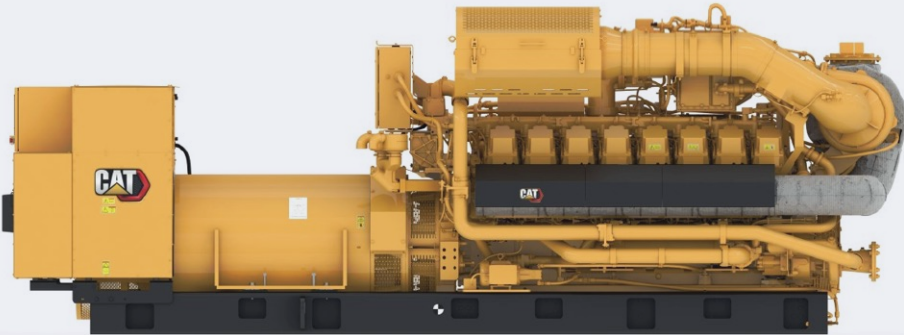


Image shown may not reflect actual configuration

Existing 25% H2 G3500H units can be retro fitted to
100% ability with kit in due course



Solar Turbines Hydrogen Capabilities

SoLoNOx™

Up to 20% H₂

10..25 ppm Nox (nat gas @15% O₂)

- Refineries in United States up to 20% H₂
- Chemical Plant Applications in China & Europe up to 14% H₂



Conventional Combustion

Up to 100% H₂

300..350 ppm Nox (Nat gas @15% O₂)

- Steel Industry Applications in China up to 65% H₂
- Propane Dehydrogenation application in Belgium up to 83% H₂
- Refinery Application in the United States up to 37% H₂



Take-aways

- All genset engines can run on Renewable Diesel (GHG reducing also called HVO)
- Green Hydrogen is one of several fuels considered to help reduce carbon footprint.
- Caterpillar currently offers reciprocating engines and turbines capable of running on hydrogen and hydrogen blends. Sustained investment planned to develop full H2 capability.
 - First 100% H2 ready G3516 gensets around 1.25 MW per unit available as demonstrators (field follow) by 1st half of 2023 (Tentative). Can work both on H2 and Nat Gas.
 - Standard combustion Solar Turbines are H2 ready 100%. End of the decade for SoLoNOx
- Still a lot of barriers for hydrogen to achieve critical mass - infrastructure, cost, regulations, safety, storage, packaging, governmental policy and incentives, etc.



Thank You

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