11th International Gas Turbine Conference (IGTC)
10– 11 October, 2023
Brussels, Belgium

Field Demonstrations of Hydrotreated Vegetable Oil as Biofuel for Gas Turbine Decarbonisation

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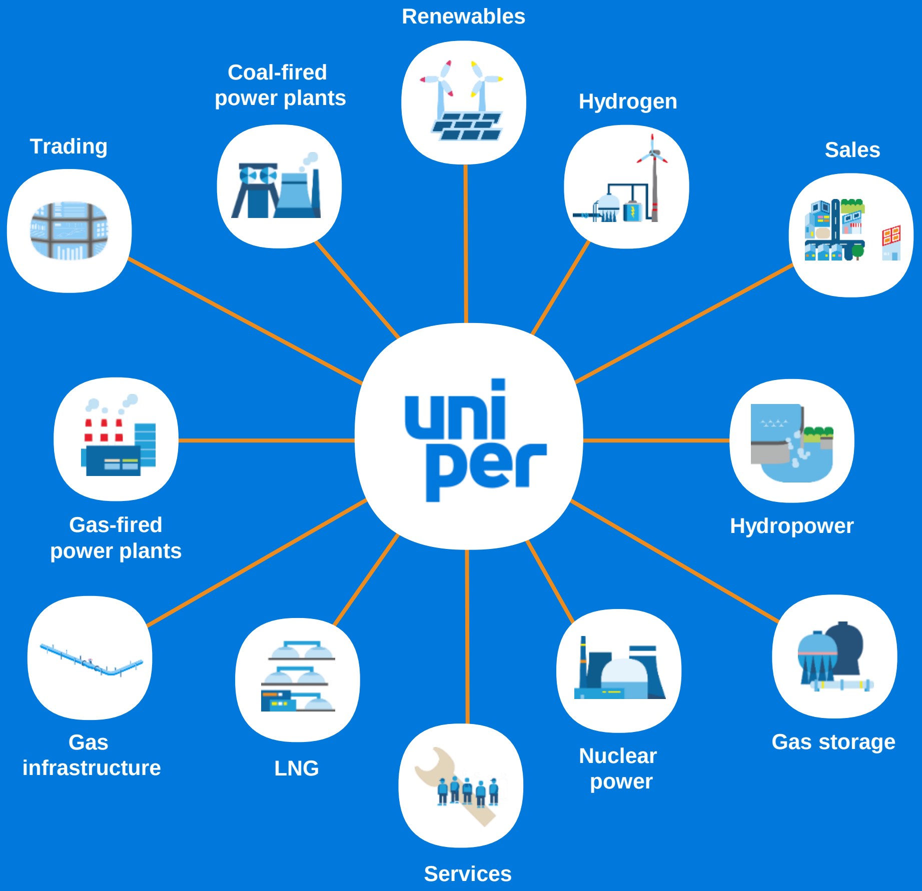
At a glance

- **7,000 employees** ensure security of supply in Europe
- Active in more than **40 countries**
- **~ 22.5 GW** generation capacity
- Entire business to be carbon-neutral by **2040**
- Gas portfolio consisting of roughly **200 TWh**
- **€3.7** Adj. EBIT (HY 2023)



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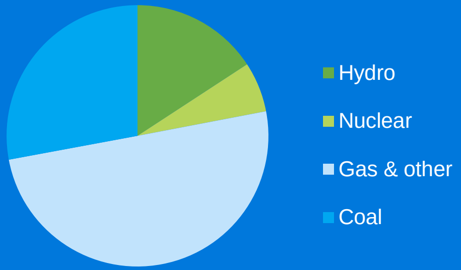
Green & Flexible Power: Closing the critical gap in the energy transition

Today	The way ahead	2030 – Highlights

Today

22.5 GW
of generating capacity (2022)

20% green



The way ahead

Grow green power

- Phase out coal by 2029[1].
- Grow wind and solar assets and renewable PPAs.
- Optimize value of hydro and nuclear.
- Pursue selective growth in hydro.

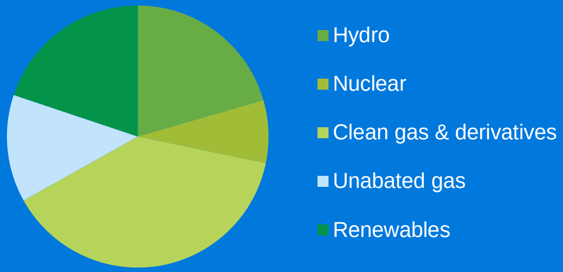
Grow flexible power

- Decarbonize existing gas plants.
- Invest in new flexible generation with net-zero capability.
- Grow in battery energy storage systems.

2030 – Highlights

15-20 GW
generation capacity installed

>80% green



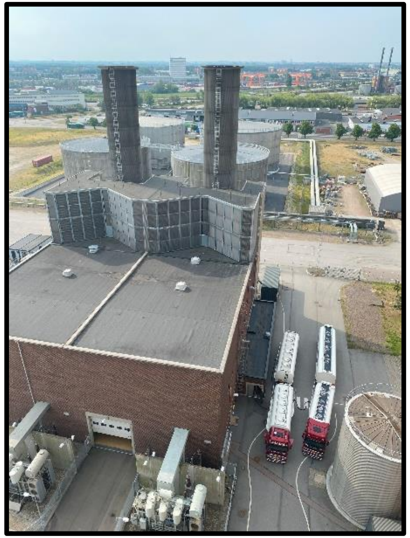
1 Disposal of Datteln 4 acc. to conditions from EU COM remedies assumed

A look at the world's first GT run on HVO (Malmö)…

https://youtu.be/v0FlPSvPqCM?si=ku4IFVgBS2ncMYCq

Hydrotreated Vegetable Oil (HVO) Field Demonstrations

V93.0 GT
(Sweden)



July 2021

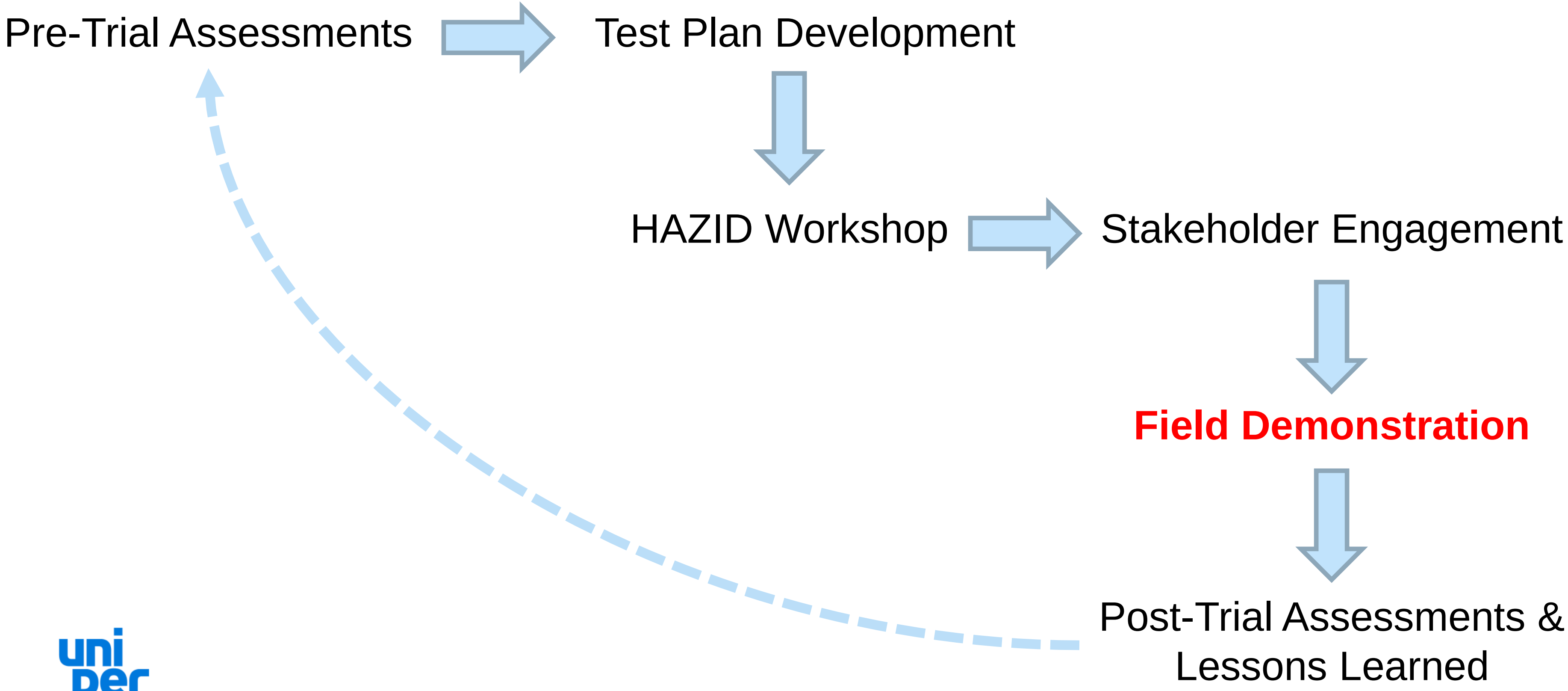
V93.1 GT
(Germany)

March 2022

Olympus Gas Generator (GG)
(UK)

August 2022

Hydrotreated Vegetable Oil (HVO) Field Demonstrations



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What is Hydrotreated Vegetable Oil (HVO)?

- Used as a drop-in replacement for fossil diesel in the transport sector.
- HVO is **not** fatty acid methyl ester (FAME) biodiesel.
- Major European producers: Neste, Eni, Total Energies
- Feedstock: waste oils, animal fats, non-food grade vegetable oils
- Free from aromatics, sulphur, and alkenes (potentially cleaner burn)
- Produced to EN15940 standard
- 80-90% lifecycle CO_2 reduction

Neste Sumoi, https://youtu.be/P4ACk53nyyw (2017)

HVO Properties (GT trial sample analysis, March 2022)

Property	Units	HEL (Light Heating Oil)	HVO
Density (15°C)	kg/m^3	835.6	780.6
LHV (mass)	MJ/kg	42.9	43.9
LHV (volume)	MJ/litre	35.8	34.2
Hydrogen	%mass	13.6	15.4
Sulphur	mg/kg	118	< 5
Ash	mg/kg	< 0.001	< 0.001
Aromatics	%vol	---	0.7
Trace Metals	mg/kg	< 0.5	< 0.5
Carbon intensity	gCO_2/MJ	95.1	4.4

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Öresundsverket (ÖVT) – Malmö, Sweden

- ÖVT was commissioned in the 1970s.
- KWU/Siemens **V93.0 GT**, open cycle, liquid-fuel only, 63 MW_e peak output
- Current fuel: Gas oil ("Eo1")
- Current GT combustion system: 2x down-fired silo combustors, 4x diffusion burners per silo with spill-return pressure atomisers, water injection for NO_x control
- Two-day trial in June 2021
- Certified HVO lifecycle carbon intensity = 8.3 gCO_2/MJ
- **World's first use of HVO in a gas turbine**
- Results presented at 2023 ASME Turbo Expo[1] and accepted for publication in ASME Journal of Engineering for Gas Turbines and Power.

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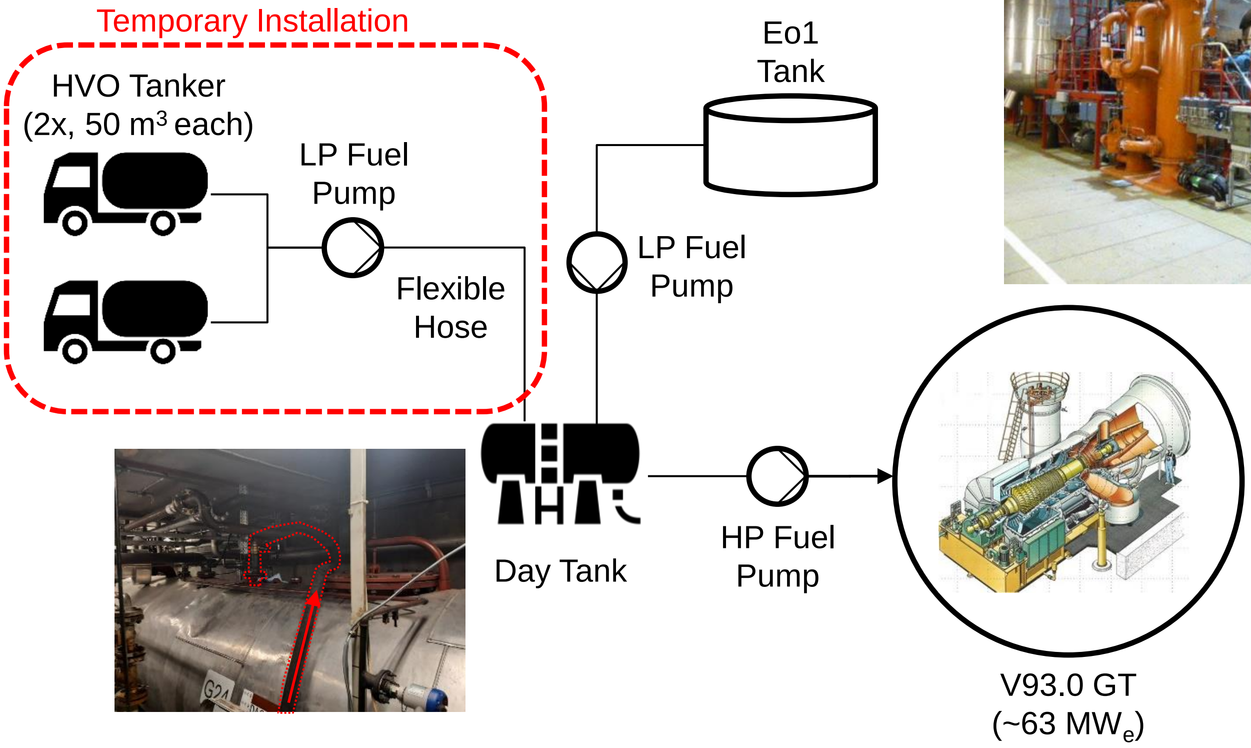
1 Runyon, J., et al., "Performance, Emissions, and Decarbonization of an Industrial Gas Turbine Operated with Hydrotreated Vegetable Oil," GT2023-101972, ASME Turbo Expo, Boston, 26-30 June, 2023.

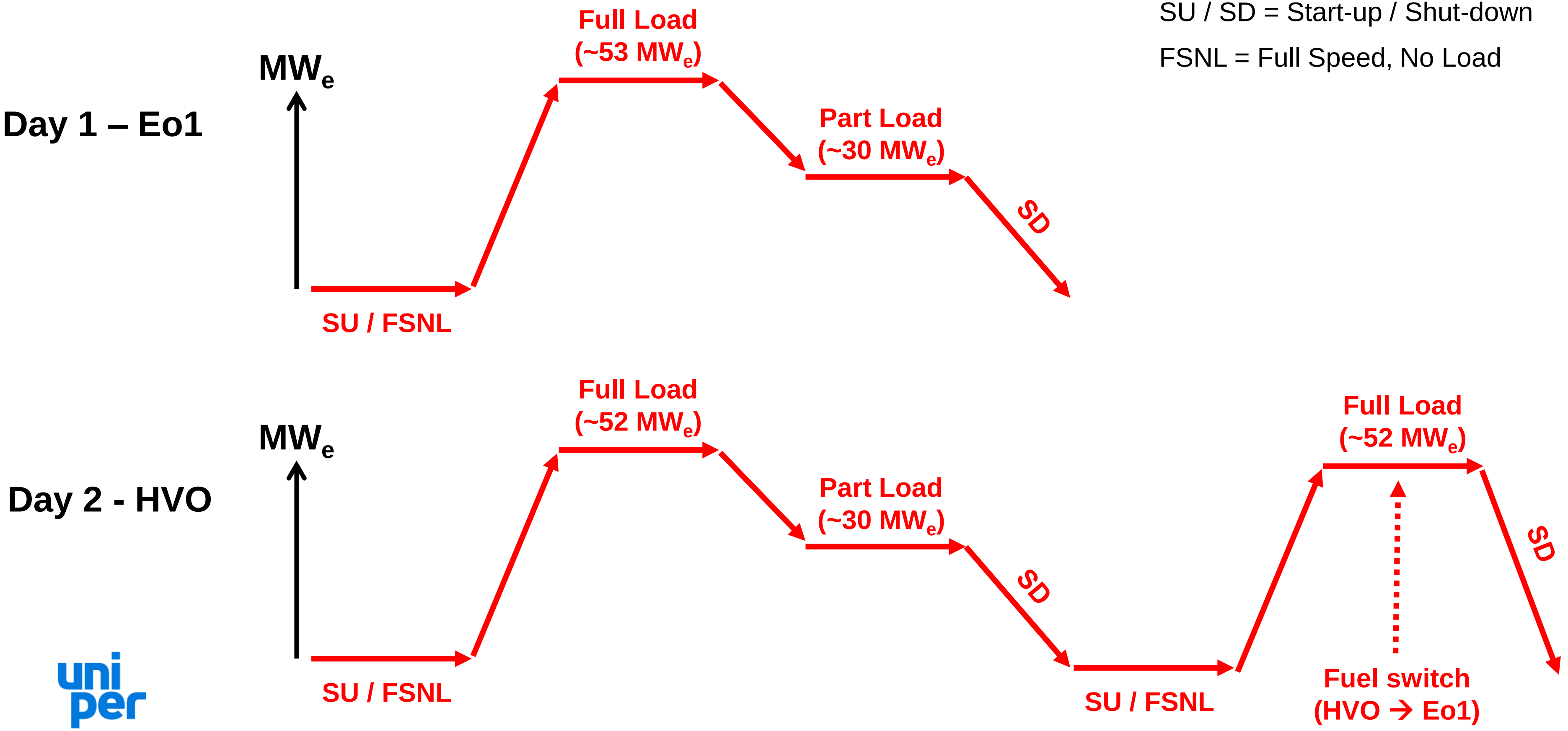
ÖVT HVO Trial Setup



ÖVT HVO Trial Test Plan (July 2021)

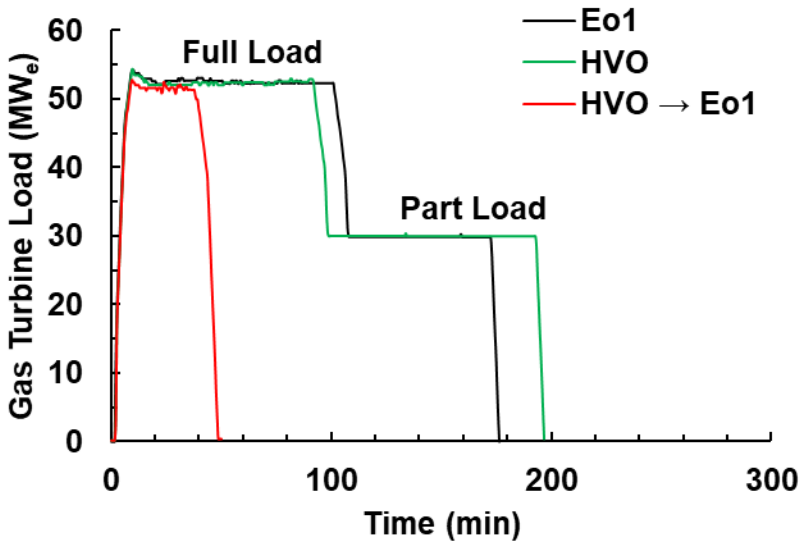
SU / SD = Start-up / Shut-down

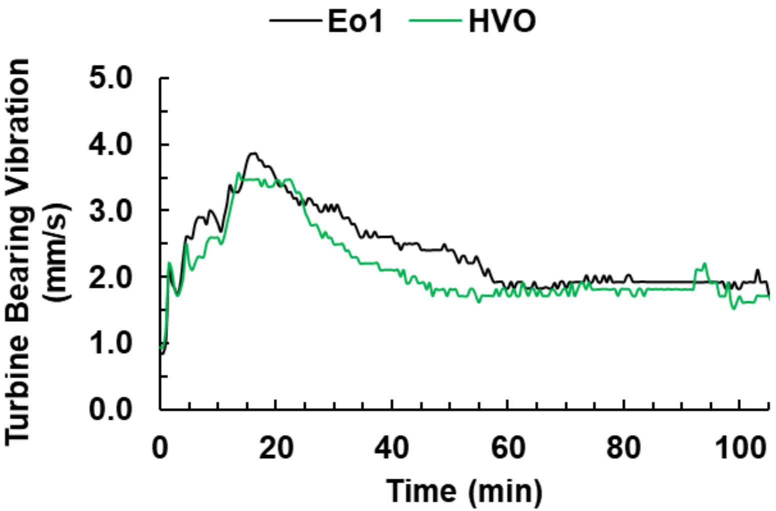
FSNL = Full Speed, No Load



Results – Performance

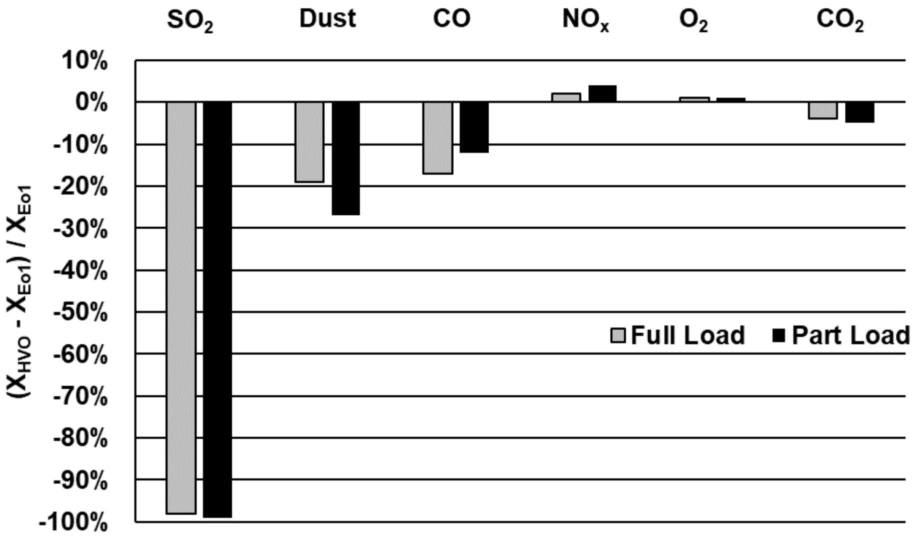
- No adverse impacts from HVO operation. **Results obtained without tuning or optimisation.**
- Successful full load fuel transition from HVO → Eo1.
- Transient conditions (± MW_e/min) show comparable control response.
- Slight increase in fuel return control valve position to accommodate increased HVO volumetric flow.
- Nearly identical turbine bearing vibration profiles following start-up.





Results – Emissions

- SO_2 virtually eliminated with HVO → Low-sulphur content
- Dust reduced by ~20-25% → Low ash and aromatic content
- CO reduced by ~10-15% → Higher H:C ratio
- NO_x increased by 2-4% (uncertainty ±7%) → No change to water injection rate
- Stack O_2 virtually unchanged → Higher stoichiometric AFR + lower LHV
- Stack CO_2 reduced by 4-5% → Higher H:C ratio

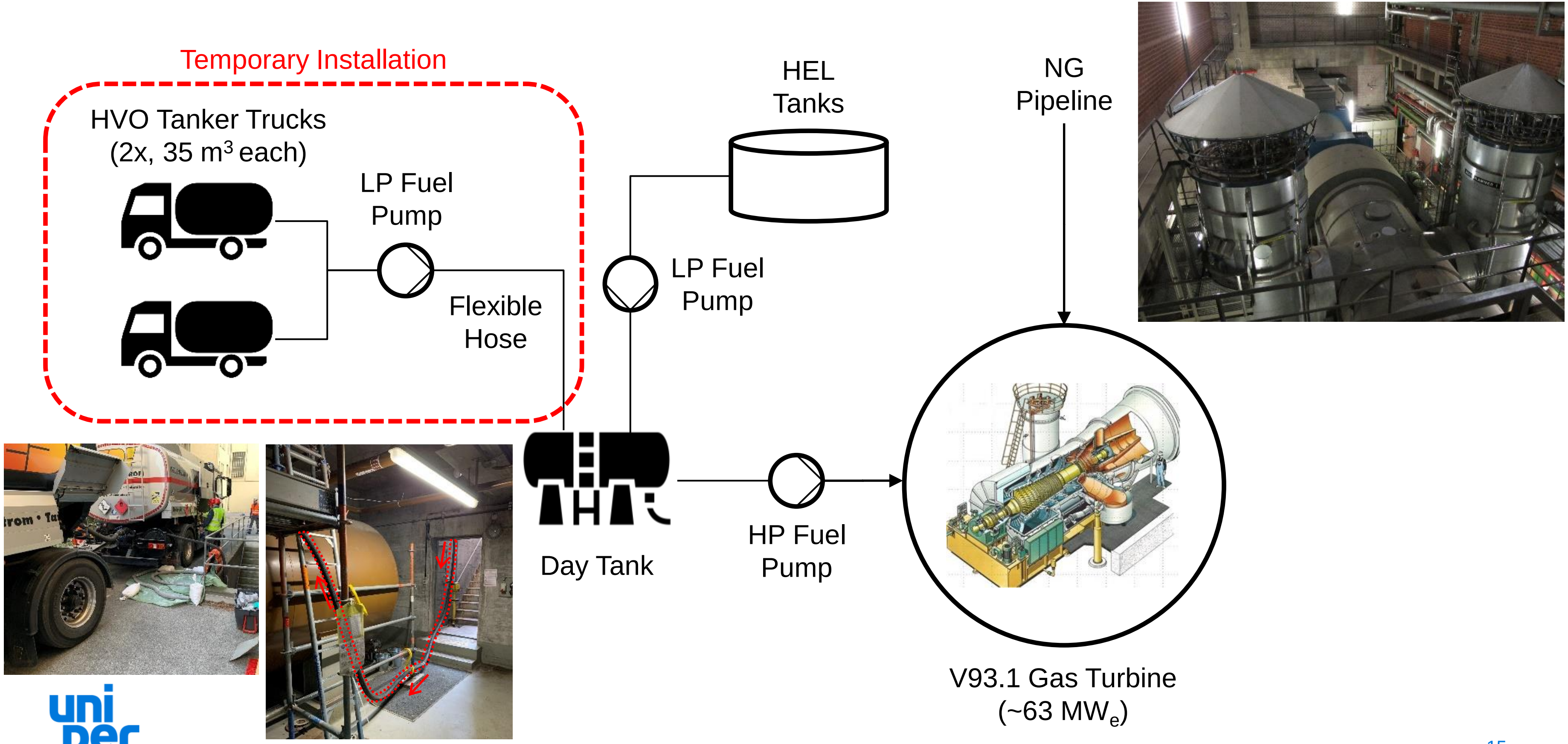


- All permitted emissions below existing gas oil limits.
- Slight increase in exhaust moisture content (higher H:C ratio)

Franken Power Plant – Nuremberg, Germany

- Franken Power Plant was commissioned in the 1970s.
- KWU/Siemens **V93.1 GT**, dual-fuel, 63 MW_e peak output
- Current fuels: Natural gas and extra light heating oil (“HEL”)
- Current GT combustion system: 2x down-fired silo combustors, 6x hybrid dual-fuel burners per silo, dry premixed natural gas or wet diffusion liquid heating oil operation
- Two-day HVO trial conducted in March 2022 using the V93.1 in OCGT configuration.
- Certified HVO lifecycle carbon intensity = 4.4 gCO_2/MJ
- **First use of HVO in a gas turbine in Germany.**

Franken HVO Trial Setup



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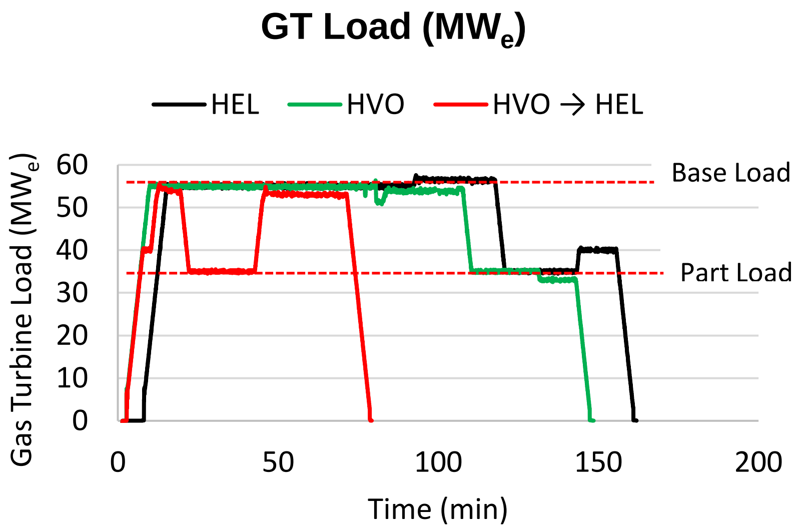
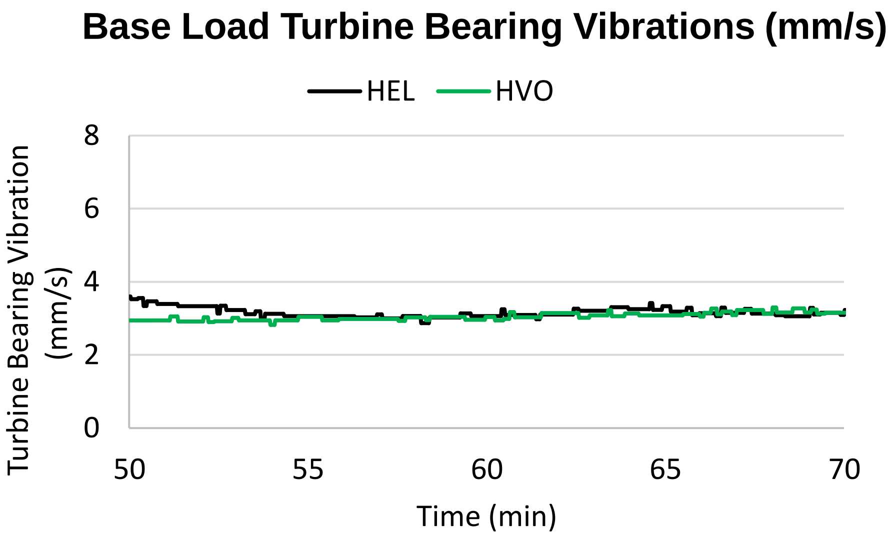
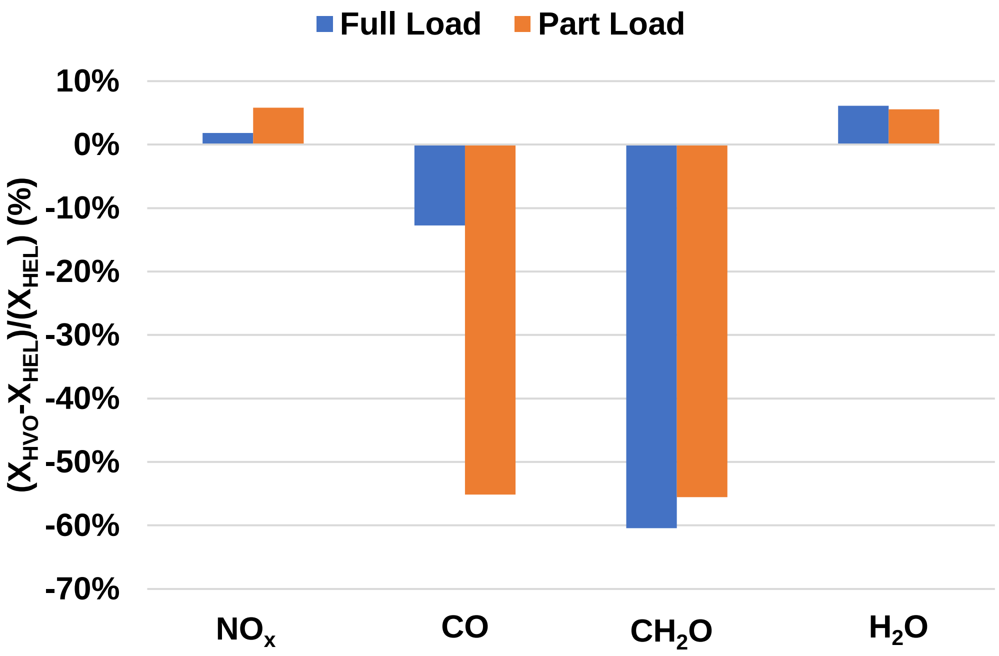
Franken HVO Gas Turbine Performance Results

- Acceptable start-up, ramp-up, base load, and part load performance during HVO operation.
- No changes made to existing GT control system.
- On-load fuel switch from HVO → HEL.





Franken HVO Gas Turbine Emissions



- Reductions in dust, CO, and CH_2O at base load and part load.
  - Dust reduction attributed to lack of aromatics and low ash content.
  - CO and CH_2O reduction attributed to higher H:C ratio of fuel.
- NO_x emissions are effectively equivalent within the measurement uncertainty.

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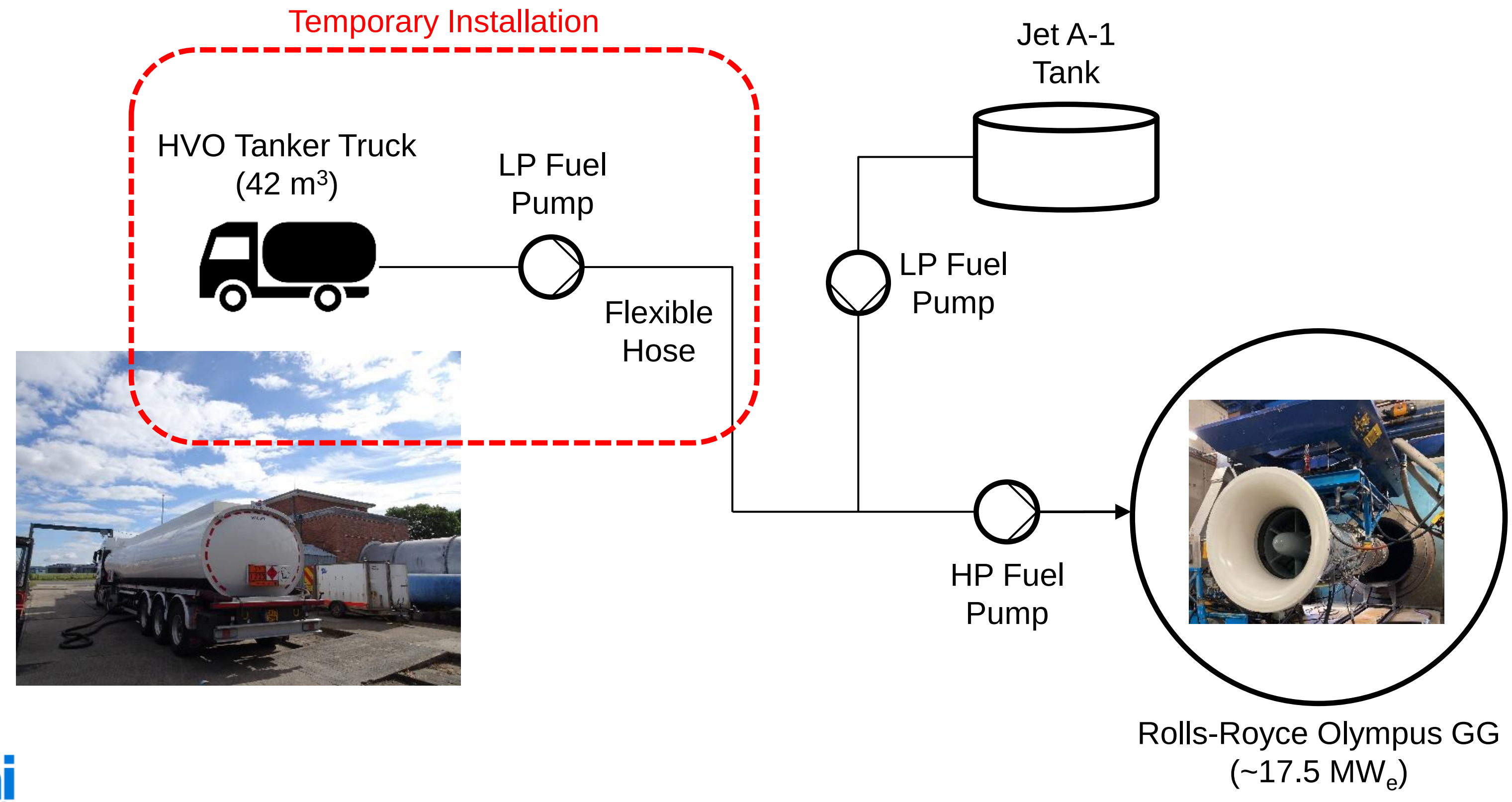
Taylor’s Lane Power Station – London, United Kingdom

- Taylor’s Lane OCGTs were commissioned in the 1970s.
- **Rolls-Royce Olympus GG**, liquid fuel, 17.5 MW_e peak output from power turbine
- Current fuel: Diesel
- Current GT combustion system: Can-annular, 8x cans with one pressure atomiser per can, diffusion, no water injection
- Three-day HVO trial conducted with Alba Power in August 2022 at an off-site, dedicated test cell.
- Jet A-1 used as baseline fuel in test facility.
- **First use of HVO in this application in the UK.**

Olympus HVO Trial Setup – Gloucester Jet Test Centre



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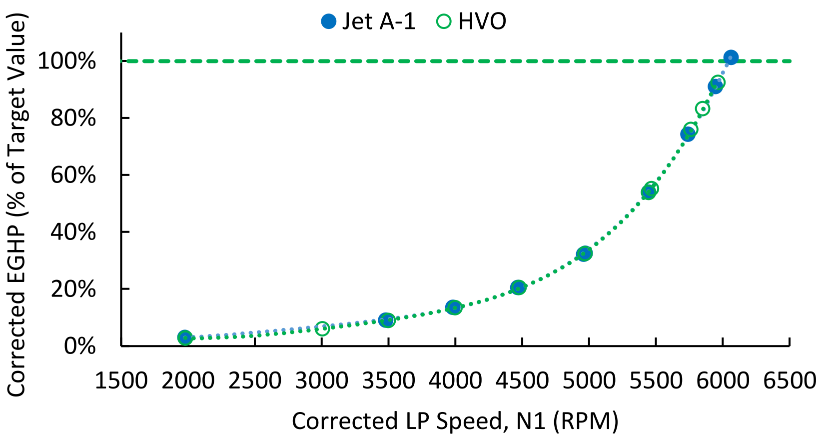
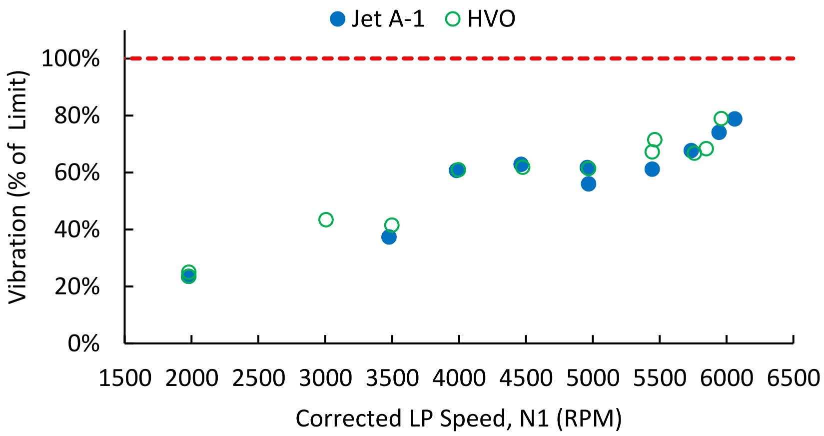
Results – Gas Generator Performance

- All results obtained without changes to test facility control settings between Jet A-1 and HVO test.
- No adverse impacts at ignition, idle, and ramp up to base/peak load equivalent speeds during HVO operation.
- Exhaust gas horsepower (EGHP) response identical between Jet A-1 and HVO – i.e., similar GG output.
- Acceptable vibration performance (proxy for combustion dynamics). Good exhaust gas temperature spread.

EGHP (% of OEM post-overhaul target)

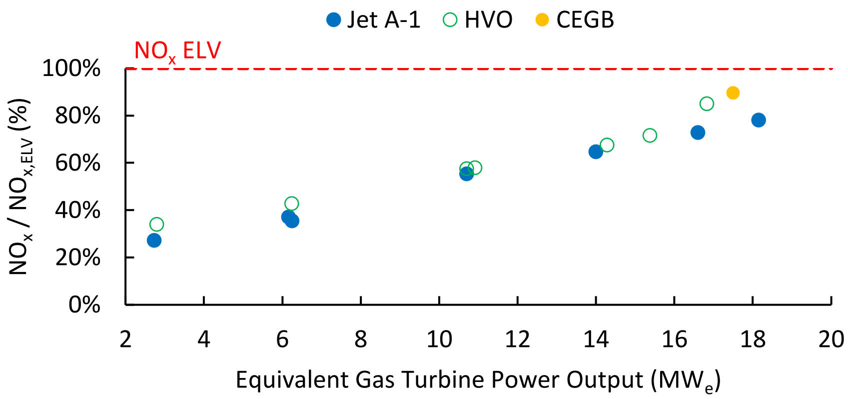


Vibration (% of OEM limit)



Olympus HVO Results – Exhaust Gas Emissions

- All permitted emissions expected to be within existing limits with HVO, within measurement uncertainty.
- High measurement uncertainty for HVO trial results due to non-standard sampling location and methodology.
- HVO results *relative to Jet A-1* (expect same relative changes with diesel):
  - Slight NO_x increase despite lower flame temperature → Lower ignition delay = longer post-flame residence time
  - CO reduction → Higher H:C ratio
  - CO_2 reduction → Higher H:C ratio
  - H_2O increase → Higher H:C ratio
  - O_2 virtually unchanged → Similar stoichiometric air-fuel ratio
  - Expect dust to reduce → Lower ash content and aromatics
  - Expect SO_2 to be virtually eliminated → Lower sulphur content



- Horiba PG250 multi-gas analyser
- Dry measurements corrected to 15% O_2
- Not a certified measurement, indicative only
- Similarity to historical diesel peak load NO_x measurement by Central Electricity Generating Board (CEGB).

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HVO Demonstration Conclusions

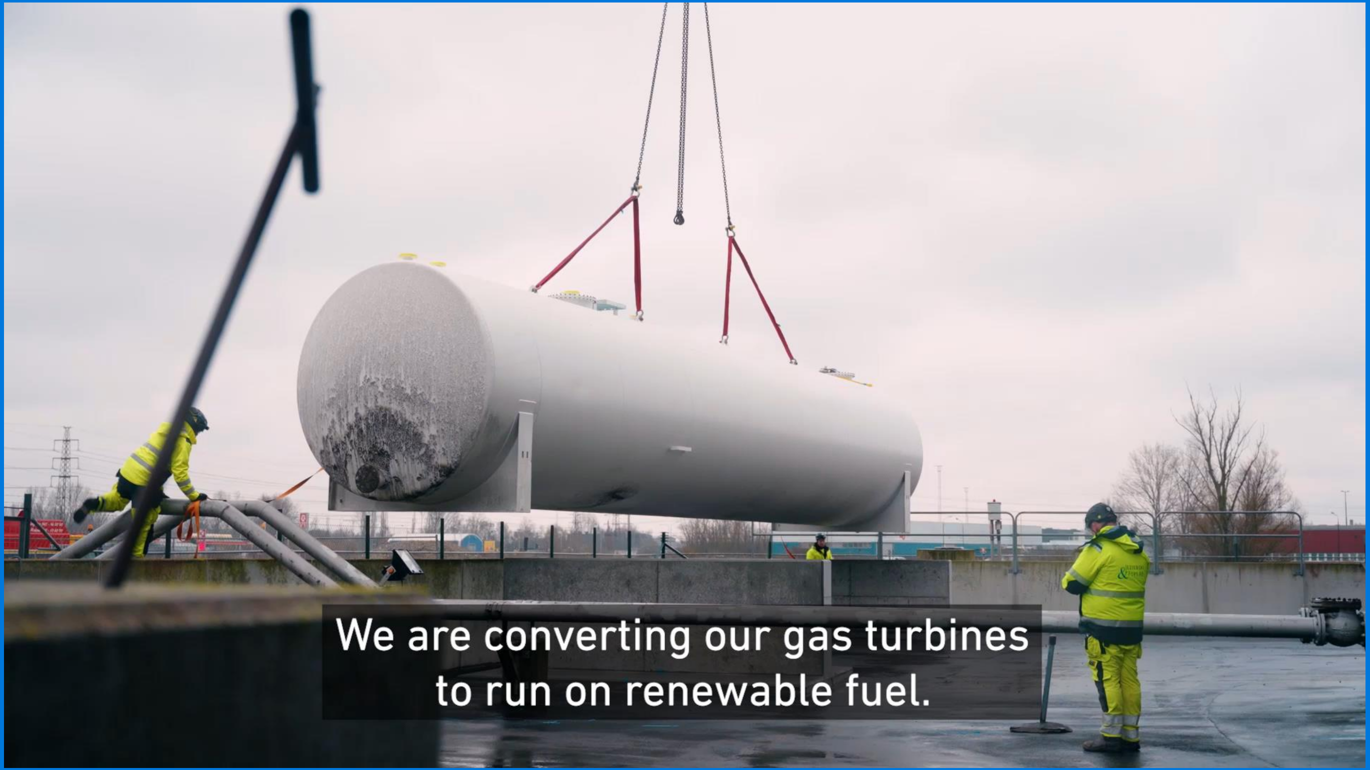
- Uniper has demonstrated the world's first use of HVO in an industrial gas turbine (V93.0), in a gas turbine in Germany (V93.1) and in a gas generator in the UK (Olympus).
- HVO is considered acceptable for use in these gas turbines.
- Gas turbine performance is not expected to be negatively impacted by using HVO.
- No immediate concerns that HVO will negatively impact on emissions compared with fossil gas oil or diesel.
  - Some parameters (e.g., SO_2 and dust) expected to improve considerably due to improved fuel quality.
  - NO_x emissions expected to be nominally similar to gas oil operation, in agreement with Siemens SGT-800 trial at Rya Combined Heat and Power Plant in Gothenburg, Sweden (November 2021)[2].
- 80-90% lifecycle CO_2 reduction achievable ***today*** (equiv. to >90%vol hydrogen cofiring).

2 Vella, H., "Green biofuels: A proven fuel for gas turbines," Diesel & Gas Turbine Worldwide, April-June 2022. Available online: https://assets.siemens-energy.com/siemens/assets/api/uuid:73b33ec1-946d-43ef-aa6b-86616f9421e5/2204-dgtw-green-biofuels-a-proven-fuel-for-gasturbines.pdf?ste_sid=70d518e70f18096521edc12c60245dcf

Key Considerations for Use of HVO in GTs

- Produced to a transport fuel specification (EN 15940) which does not include all necessary properties for gas turbines (e.g., trace metals).
- Fuel availability and competition from the transport sector.
- Certification of lifecycle greenhouse gas reduction and feedstock sustainability.
- For retrofit/conversion from diesel, Jet A-1, or heating oil, HVO may cause shrinkage of seal materials in the fuel supply system due to the lack of aromatics.
  - Conduct seal materials audit, increase monitoring of fuel system post-conversion.
- No long-term reliability or maintenance data available for GT operation with HVO.
  - Reduce initial gas turbine inspection interval to obtain baseline condition.
- Odourless and colourless causing a potential leak detection issue.
- Social/political acceptance of using bio-derived fuels for power generation.

The future is now…HVO commissioned at Malmö in September 2023[1]



https://youtu.be/lmQgXsbGg5s?si=0FGuOk980SmzpD2n

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[1] https://www.uniper.energy/sverige/nyheter/uniper-foerst-ut-med-foernybart-braensle-i-stoerningsreserven/

Questions?

Field Demonstrations of Hydrotreated Vegetable Oil as Biofuel for Gas Turbine Decarbonisation

For any further questions, please contact me at:

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