High Hydrogen Retrofits and Partnerships

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Gas Turbine Services – Thomassen Energy / PSM

Field Service

Repair

Upgraded Components

Global M&D w/with Digital and Service Engineering

Service with Innovation

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Filling The Renewable Gap

• The Gas Turbine Advantage
• Flexible fast load coverage
• Cleanest of the fossil fuels
• Ability to run on wide range of fuels, including green fuels such as **hydrogen**

• Excess renewable energy can be harvested, stored and released in gas turbines

• Existing gas turbine power plants available for retrofit with cost effective carbon free upgrades

• Ability to follow the transition to renewable World at a pace which is flexible and dependent on local & regional market drivers

**H₂ = **

Gas Turbines can meet the flexibility need … and go green

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Hydrogen solutions for low CO₂ Energy Transition

2 steps to full hydrogen operation (1st step already in commercial operation)

Proven in Operation:
Combustor hydrogen upgrade + AutoTune

Stage 1 (complete):
- Existing TDLN/LEC
- Natural gas
- Up to 25% hydrogen by volume

Stage 2:
- FlameSheet™
- Natural gas
- Up to 100% hydrogen by volume

Next step:
FlameSheet™ Combustor + AutoTune
Hydrogen Retrofit scope on the Gas Turbine

Combustor retrofit (new drop in combustor)

Turbine evaluated for potential higher heat load, hardware can be exchanged if needed/requested

Exhaust unchanged but check is done to ensure adequate margin for exhaust and steam cycle

• Compressor and other engine components remain unchanged
• Fuel delivery manifolds and fuel lines may need to be re-sized if needed based on hydrogen content
• Control system and Fuel delivery skids upgraded as required

Complete retrofit scope available
9E Hydrogen in Commercial Operation – Key Package Elements

1. Fuel skid

2. Control System / AutoTune

3. Premix Combustion system (more than 100 natural gas E-class installations, 3 with H₂)

High hydrogen Secondary fuel nozzle upgrade

DOW Netherlands – 3 x 9E machines

3 years stable and flexible sub-9ppm NOx Operation from 0% to 35% H₂
FlameSheet™ Commercial Machine Experience

- 8 FlameSheet™ (7 FlameTOP) - enabled machines in operation, 6 years of experience
- Up to **20% additional load turndown** and **fuel flex** with sub 9ppm NOx and CO
- Hardware in excellent condition after 28,000 hours and 400 starts
- Up to **60% by vol H2** F-class firing condition in test rig; up to 40% C2+'s*
Objective:

- Develop a low emission gas turbine combustor retrofit for fuel flexible operation from 100% Natural Gas to 100% Hydrogen and any mixture thereof
- Flexible fast load balancing capability

Dutch subsidy awards won:
- Phase 1 awarded April 2019
- Phase 2 awarded March 2021

1MW to 300MW with 0% to 100% Hydrogen with 1 Scalable Combustor Platform
High Hydrogen – High pressure rig testing

100% Natural Gas
OP16 Full Load
< 6 ppm NOx

100% Hydrogen
OP16 Full Load
< 10 ppm NOx

Operations from 100% natural gas to 100% hydrogen with dry low emissions
A turnkey package for clean energy – just supply water and power grid connection:

1. **Electrolyser** absorbs low cost electricity from grid AND/OR Solar/Wind
2. **Hydrogen** is made by electrolyser and accumulated in high pressure storage vessel (included)
3. **Gas turbine** releases energy back to the grid when electricity prices rise to fill gap in renewable generation

Energy storage and flexible balancing package with zero carbon capability
Solutions for the Energy Transition

• The gas turbine advantage:
  • Rapid flexibility for power grid balancing
  • Opportunity for clean energy storage with hydrogen

• Partnership advantage:
  • Shared expertise
  • Shared risk
  • Cost effective and commercially applicable solutions

• Package solutions:
  • Hydrogen supply, storage and safety
  • Fuel mixing/handling, controls, combustion, hot end assessment

• Planned 100% hydrogen flexible engine demonstrations:
  • Small engine 2022/23 → 2MW
  • Medium engine 2023/24 → 20 - 40MW
  • Large engine 2024/25 → 100 - 300MW

High hydrogen retrofits/partnerships for carbon free power generation and energy storage
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