Enagás H2 Technical Day

The challenges on the development and sustainable construction of infrastructures

H2 Technology Readiness

Francesco Bini

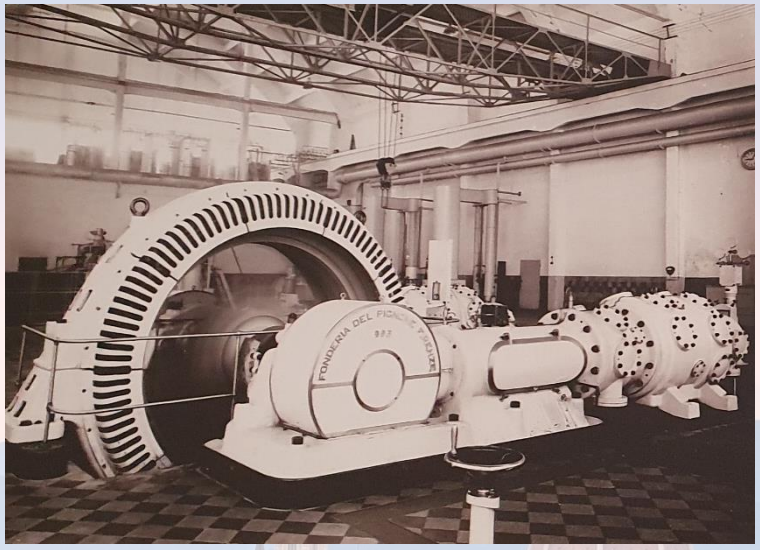
April 9th, 2024

Copyright 2024 Baker Hughes Company. All rights reserved. The information contained in this document is company confidential and proprietary property of Baker Hughes and its affiliates.
It is to be used only for the benefit of Baker Hughes and may not be distributed, transmitted, reproduced, altered, or used for any purpose without the express written consent of Baker Hughes.

150+ years of experience in hydrogen!

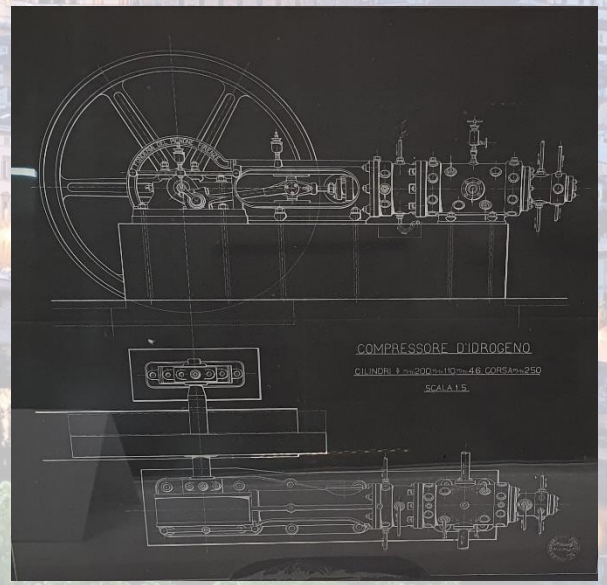
First combustion engine, running with H2, ***1854***

Ammonia compressor ***1910***



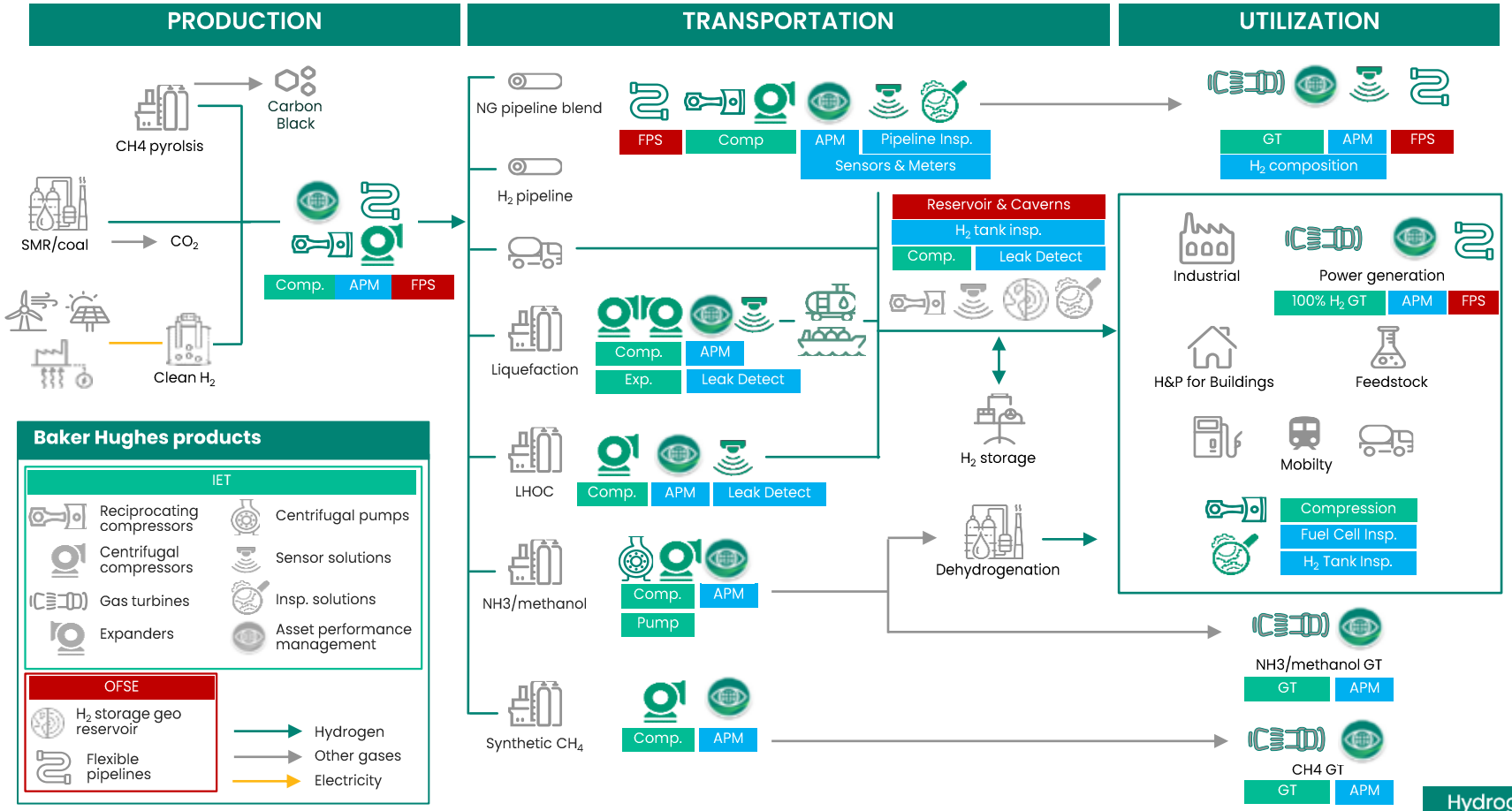
Ammonia compressor, ***1930***

Hydrogen compressor ***1915***



Copyright 2024 Baker Hughes Company. All rights reserved.

Technology Enabling H2 economy



- **Compression is a key technology** from production to transportation and utilization.
- **Proven and referenced technology** Hydrogen is one of the main feedstocks in Refinery, Ammonia and Petrochemical processes.
- Available compression technology based on **reciprocating and centrifugal compressors**, API618 and API617 design, with referenced metallurgy.
- Available **H2 fueled gas turbines** for mech drive and power generation.

Hydrogen services	Technology	Installed units	Max Flow (NM3/Hr)	Max Power (MW)
+2,250 installed units	Recips	+2,000 (+800 with H2 >95%)	190.000	20
	Centrifugal	+250	1.200.000	19.4

~150 years of experience working with hydrogen

Copyright 2024 Baker Hughes Company. All rights reserved.

Baker Hughes

H2 role evolution

Oil&Gas applications

- Hydrogen molecule as feedstock or output to/from process (hydrocracking, PDH, etc)
- Hydrogen used in Refinery, Petrochemical and Fertilizer industry, limited to industrial plants
- Mainly used where produced
- Produced from NG by reforming
- Specific guidelines for H2 compression service addressed in reference design Code (API 617 & 618)

New Energy applications

- Hydrogen molecule as energy carrier
- Hydrogen also becoming a player outside Oil&Gas environment
- large scale distribution required for new applications (fuel, heating, industrial processes)
- Green H2 produced by electrolysis powered with renewables
- Necessity for storage system and transportation
- Industry setting requirements in terms of high purity of Hydrogen for new applications (99.99%, no contaminants)

New role of H2 molecule is driving compression & combustion technologies evolution

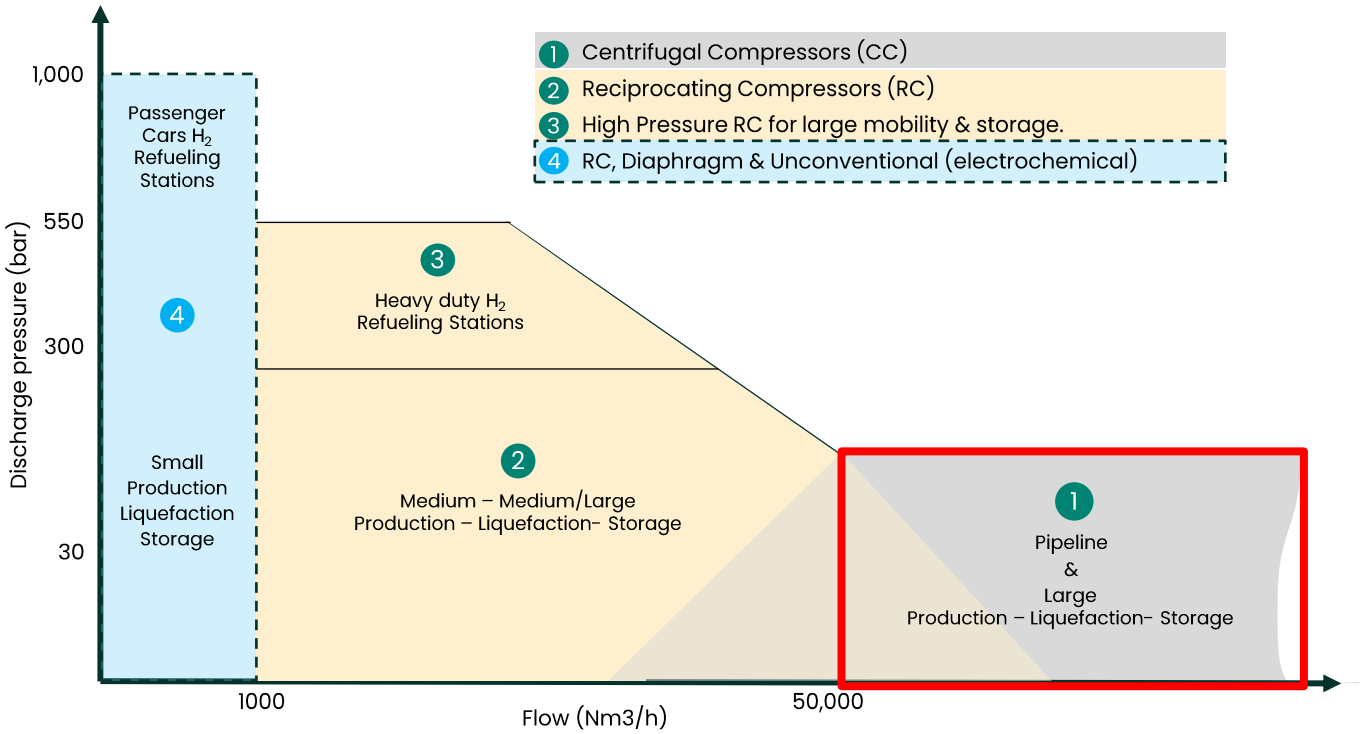
Copyright 2024 Baker Hughes Company LLC. All rights reserved.

Technology Portfolio Compression

Copyright 2024 Baker Hughes Company. All rights reserved.

Baker Hughes

H_2 Compression development



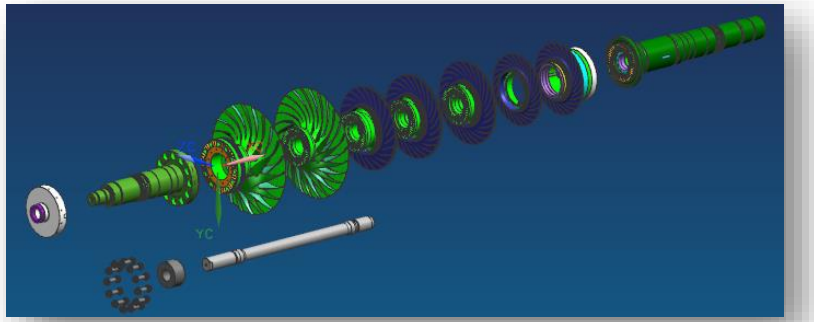
NEW Requirements from the Market:

- **Large volumetric flows** to be processed (H2 pipeline, LH2)
- **High pressure applications** (from 300 to 500-700 bar and above for storage and refueling stations)
- **Oil-free compressors** to meet H2 purity level (no contaminants)
- Deal with **intermittent/fluctuating operation** (green H2 production coupled with Renewable power)

Advanced compression technology for H2 applications:
→ Large flow Compression
→ High pressure Compression

Copyright 2024 Baker Hughes Company. All rights reserved.
Baker Hughes

High Pressure Ratio Compressor - BASE PRINCIPLES



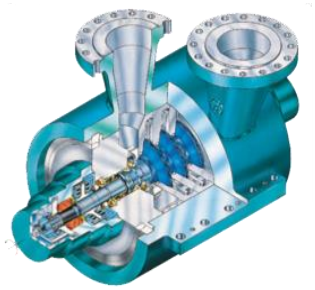
INCREASE TIP SPEED
Increase head per stage with use of stacked rotor and combination of open and close impeller.

INCREASE ROTATING SPEED
Parallel shaft gears to approx. 9X gear ratio and epicyclical gear for higher requirements.

COMPRESSOR DESIGN OPTIMIZATION
Optimized inlet and outlet flanges to fit “one body” design

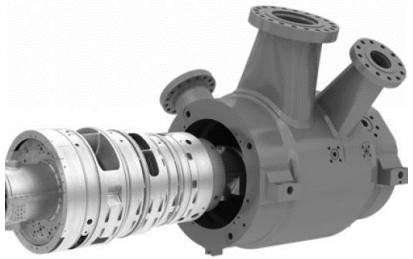
REDUCED # OF BODIES
Reduce drastically number of stages (typically factor 2) …up to 3 section in 1 casing

Standard Compressor



- Casing PR w/ 100% (dry): ≤ 1.3
- Impeller tip speed: +

HPRC Compressor



- Casing PR w/ 100% (dry): ++
- Impeller tip speed: ++

Next Step

- Casing PR w/ 100% (dry): +++
- Impeller tip speed: +++

Copyright 2024 Baker Hughes Company LLC. All rights reserved.

Baker Hughes

Baker Hughes Confidential

Case study – Pipeline Compression Station

Case study

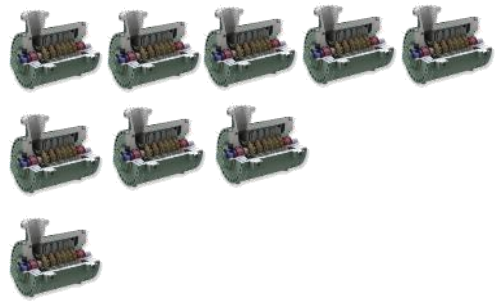
Flow constant: 2000 MMSCFD,

Inlet Pressure: 60 bar

Outlet Pressure: 110 bar

Hydrogen Blend [% mol]	0%	10%	20%	30%	40%	50%	100%
	Number of impeller required						
Standard PCL impellers U2 = 250 m/s	3	4	4	5	5	6	28
High head impellers U2 = 300 m/s	2	3	3	3	4	4	18
HPRC impellers U2=420 m/s	1	2	2	2	2	2	9

100%
28
18
9



HPRC solution is a great option when H2 content is predominant

Copyright 2024 Baker Hughes Company. All rights reserved.

Baker Hughes

Baker Hughes Confidential

Technology Portfolio
Gas Turbines

Copyright 2024 Baker Hughes Company. All rights reserved.
Baker Hughes Confidential
Baker Hughes

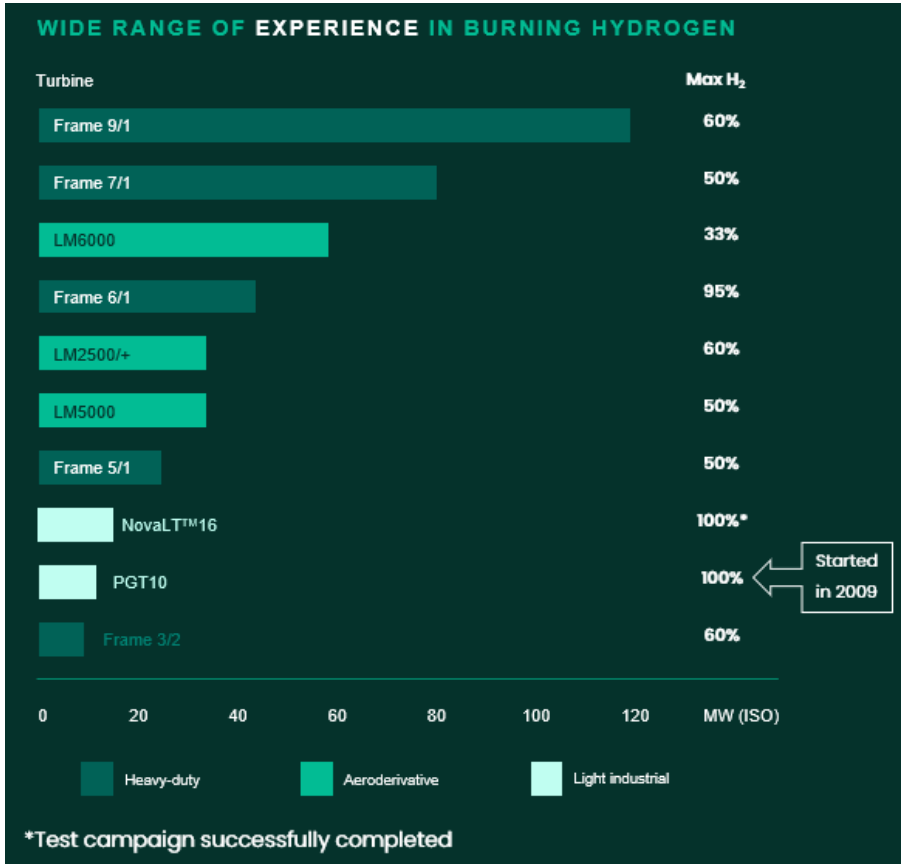
Advancing the Hydrogen Revolution

100+
Years of experience with H_2

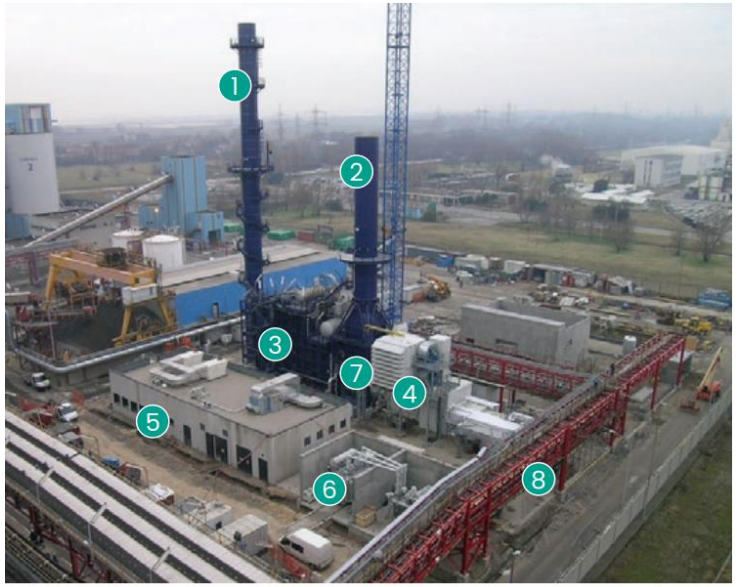
70+
Installed GTs burning H_2 up to 100%

2009
First 100% H_2 fueled gas turbine in commercial project

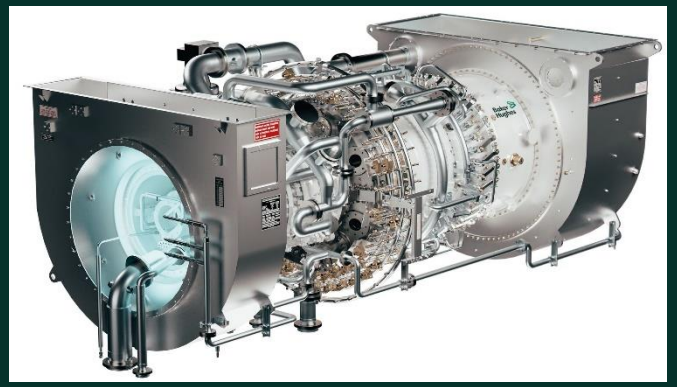
2023
NovaLT™16



Hydrogen power plant in Fusina (Italy)



1. Dry flue gas stack
2. Bypass stack
3. Heat recovery steam generator (HRSG)
4. PGT10 gas turbine
5. Control room
6. Transformer
7. Diverter
8. Piping rack



State-of-the art gas turbine
100% H_2 Ready GT Package

Copyright 2024 Baker Hughes Company. All rights reserved.

Baker Hughes

NovaLT^{TM}16 Gas Turbine burning 100% Hydrogen

POWERGEN SIMPLE CYCLE

16.9 MWe 36.4% Elect. efficiency

MECH DRIVE SIMPLE CYCLE

17.5 MW 37.5% Efficiency

COMBINED CYCLE

22.0 MWe

48% Elect. efficiency

COGENERATION (CHP)

31tph Steam output

80% CHP Efficiency

MAINTENANCE

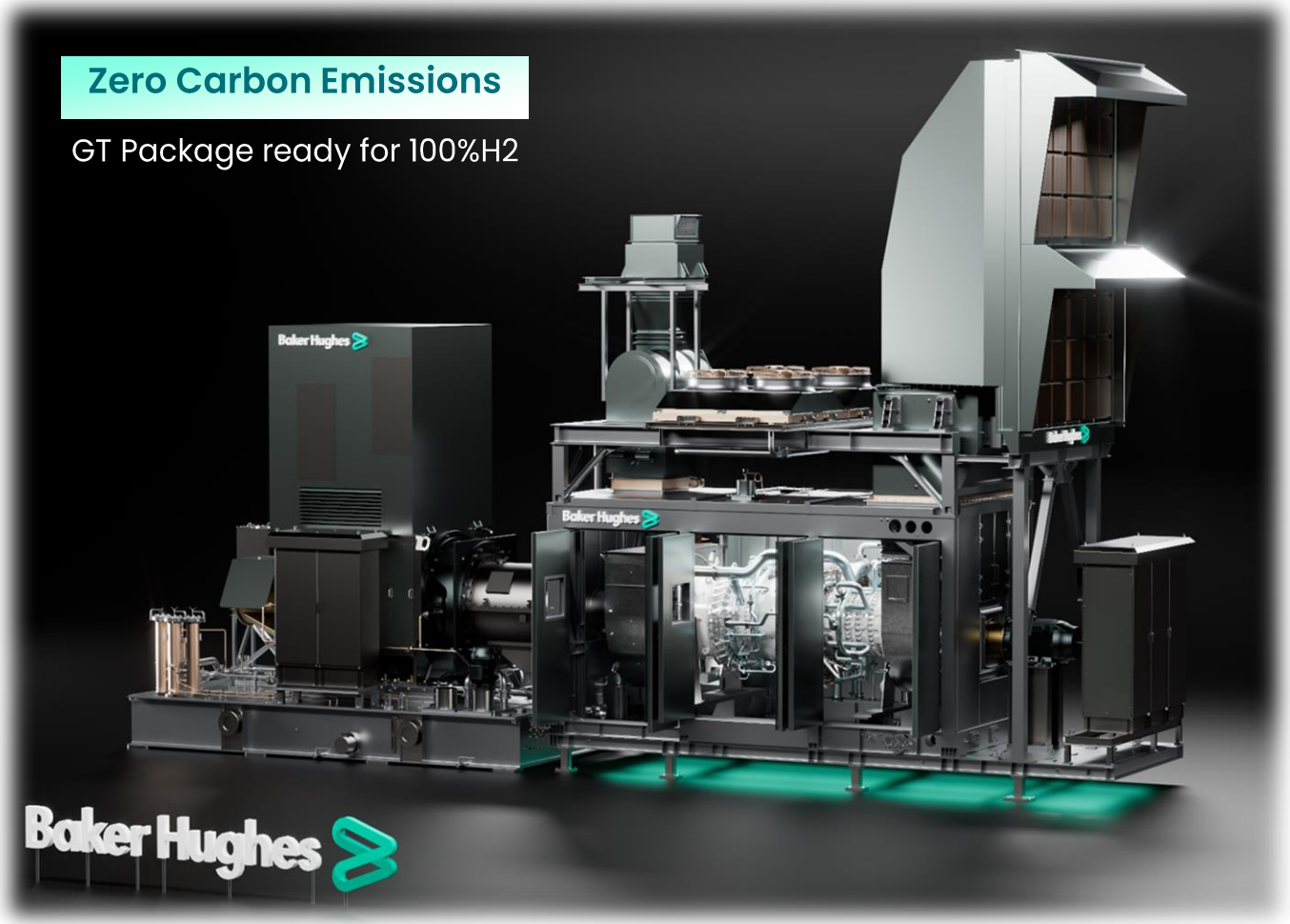
35k – 70k (FFH)

No annual inspection,
fast engine exchange,
minimized inventory

NO_x EMISSIONS

15 ppm with SCR at exhaust (today)

15 ppm DLN (from 2026)



Start up with blends up to 100% H2. Switch from NG to gas blends up to 100% H2 on the fly

Copyright 2024 Baker Hughes Company. All rights reserved.

Strategic hydrogen collaborations

H_2/NG Pipeline—Istrana, Italy

Snam and Baker Hughes successfully **completed First Trial** for the use of H_2 as Fuel in a Gas Compression Station

Green H_2—NEOM, Saudi Arabia

Providing **advanced hydrogen compression** technology to Air Products

Blue H_2—Edmonton, Canada

Providing **100% hydrogen fueled NovaLT16** gas turbine technology to Air Products

Partnering with world hydrogen industry leaders to lower the cost of production and accelerate the adoption of hydrogen as a zero-carbon fuel

Copyright 2024 Baker Hughes Company. All rights reserved.

Baker Hughes

Baker Hughes Confidential

Summary

H2 compression and combustion technologies:

- Available today
- Reliable and tested
- Supporting projects feasibility and de-risking

2000+	70+	1915	2009
Compressors working with H2 rich gases	Gas Turbines burning H2 up to 100%	First Reciprocating Compressor for H2	First 100% H2 GT in commercial project

Copyright 2024 Baker Hughes Company. All rights reserved.

Copyright 2024 Baker Hughes Company. All rights reserved.

Baker Hughes

Baker Hughes Confidential