Baker Hughes

Reti di distribuzione e stoccaggio di H_2

La transizione ecologica del sistema automotive

7-8 Luglio, Livorno

Francesco Bini –H2 Growth Area

July 6, 2022

We were one of the first in the oil and gas industry to make a net-zero carbon commitment

And we hope we're not the last.

Baker Hughes is committed to reducing our emissions by 50% by 2030 and net-zero by 2050

15%

reduction in scope 1 and scope 2 emissions year-over-year versus 2019 baseline

22%

of our electricity comes from renewables and zero-carbon sources

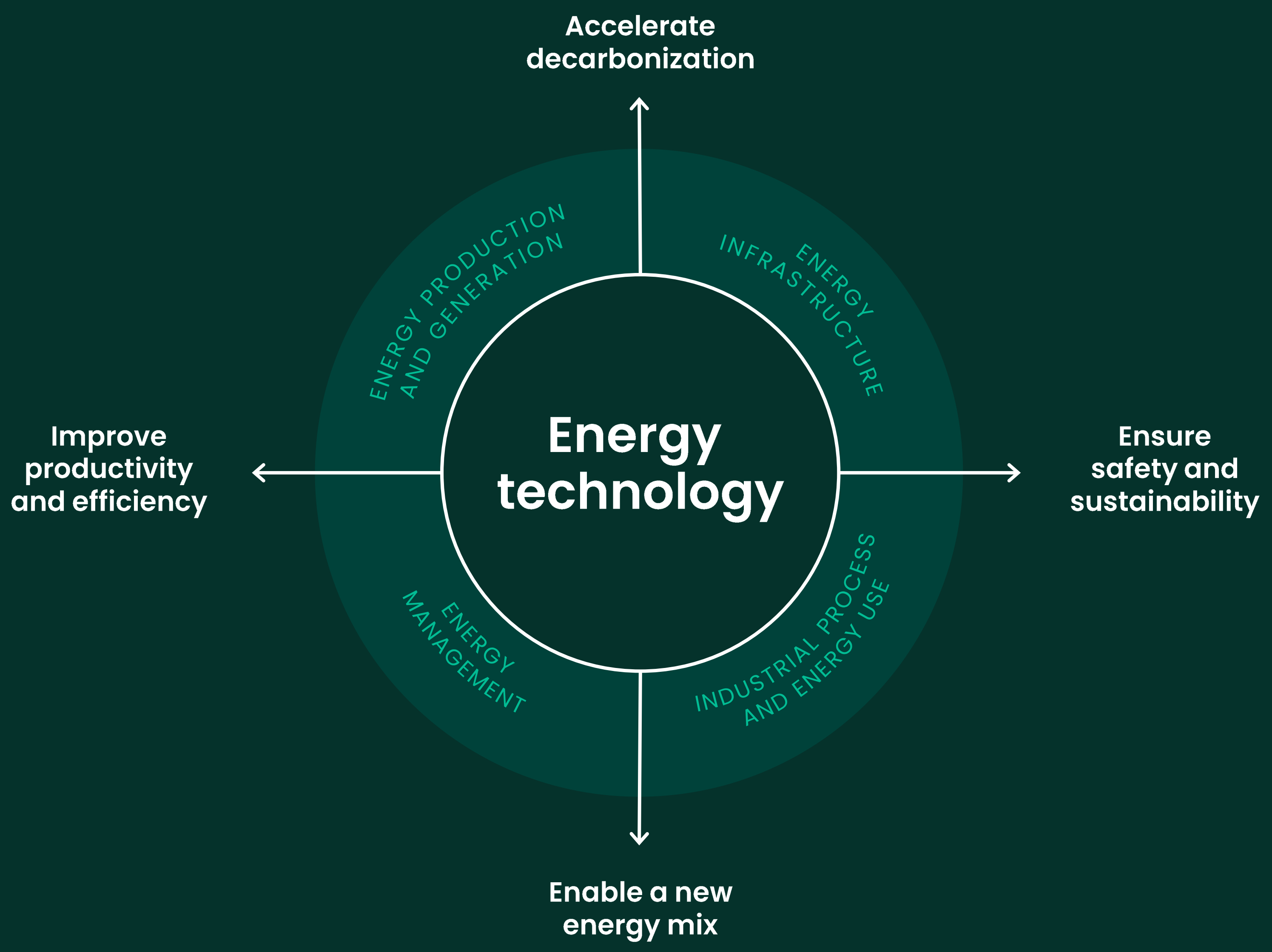
850+

global facility energy audits and weekend energy walk-throughs completed in the last two years

Baker Hughes

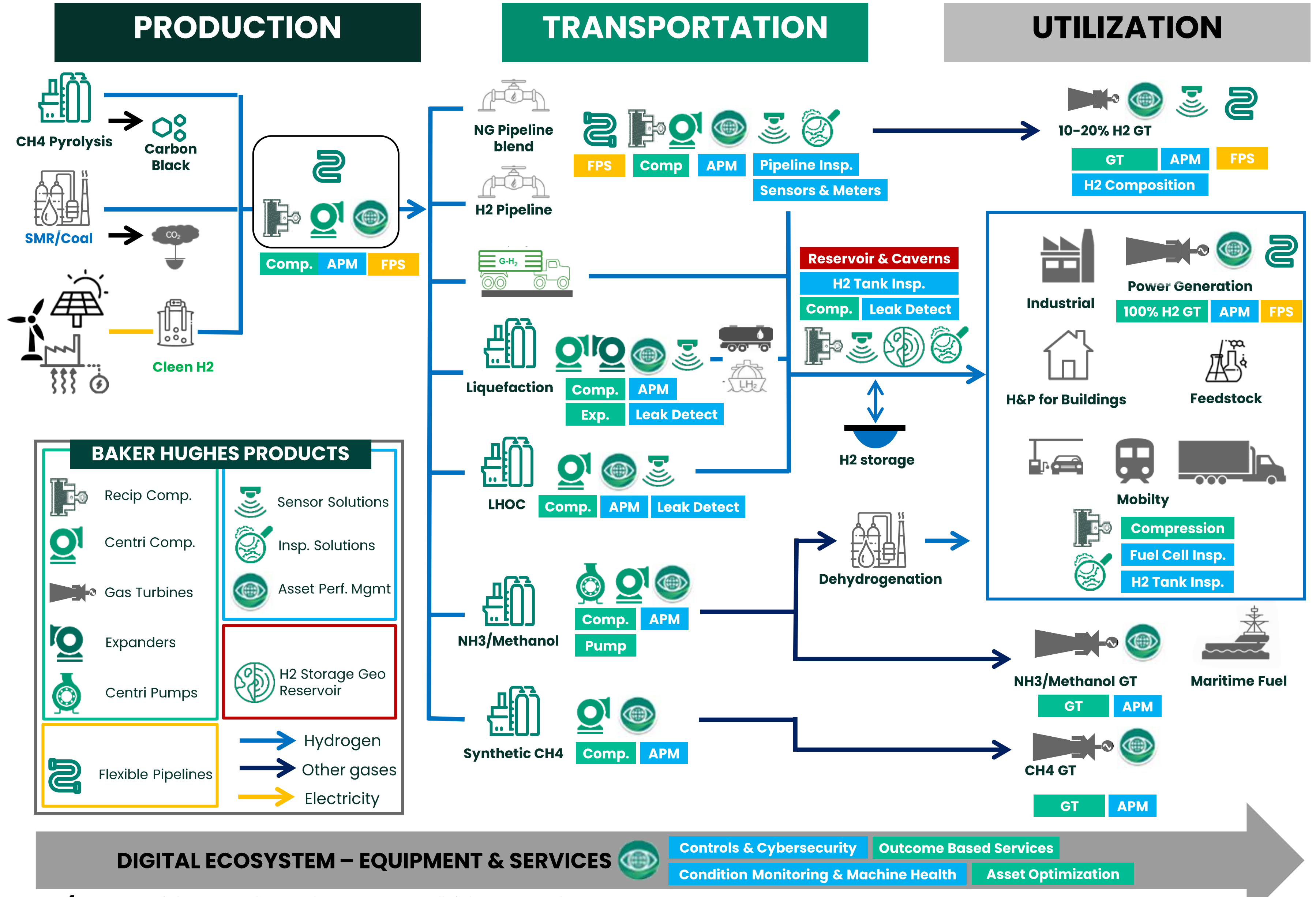
Energy technology is the heart of the energy ecosystem, and it has never been more vital.

Our capabilities are critical to the future of energy.



Baker Hughes

Baker Hughes portfolio across the Hydrogen value chain



- Almost 60 years of experience working with hydrogen
- Critical applications across production, transportation, and storage
- Ability to work with intermittent energy sources to provide grid support
- Digital Portfolio of solutions across the whole H2 value chain

Baker Hughes

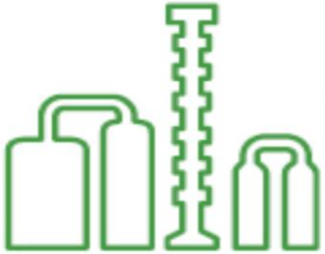
Baker Hughes

H2 Transportation

Overview

How to transport Hydrogen?






PROS / CONS

Electrical grid

No shipping or storage needed

Flexibility for H2 production

-

Capex

Losses in electricity

H2 prod in site

Natural Gas

Low impact on existing infrastructures

High Energy content

-

CO2 emissions

Variable pricing

Ammonia

Easy to transport

Well established process

High H2 density

-

Conversion Cost

Impact on downstream infrastructure

LOHC

Suitable for large scale and long term storage

Minimal losses

Lesser safety and reliability risks

-

Efficiency

Technology gaps in process and catalysts

LH2

Minimal processing requirements

Transportation model similar to LNG

-

High energy costs

Transportation for LH2 not mature

Safety risks due to leakages

GH2

Minimal processing requirements

Well established technology

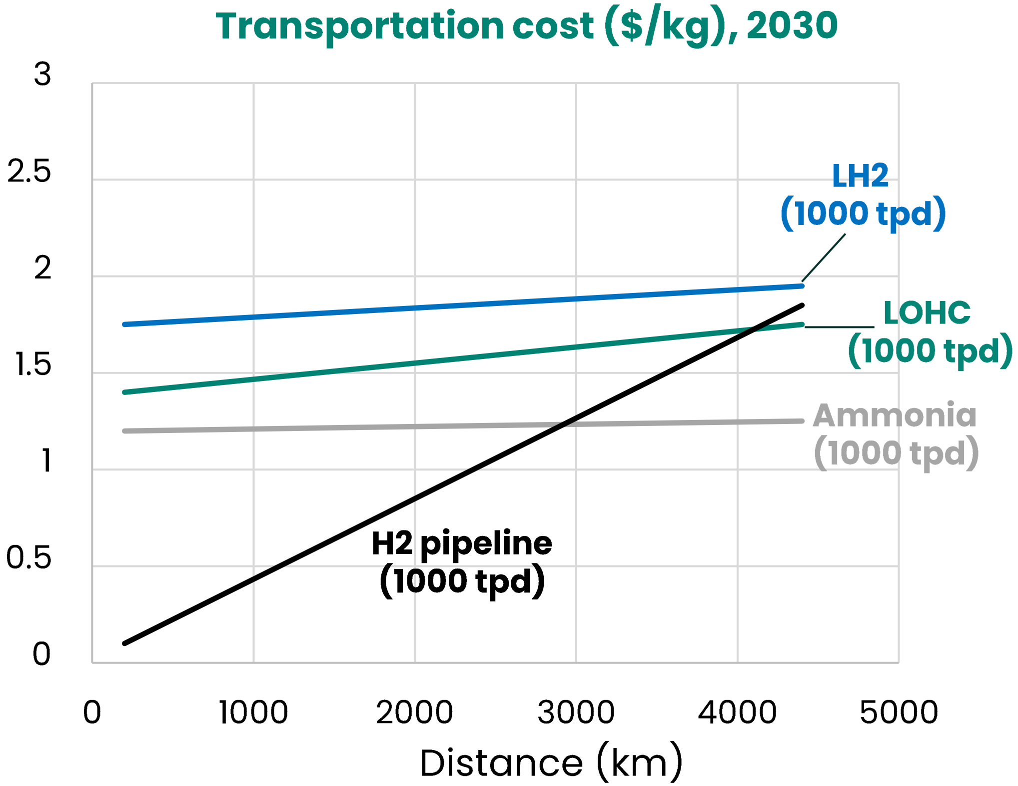
-

Material requirement (H2 embrittlement)

Very low density an poor specific volume energy density

Baker Hughes

Cost Effectiveness for H2 Transportation



Includes conversion, export terminal, shipping, import terminal and reconversion costs for each carrier system. Storage costs are included in import and export terminal expenses. The pipeline cost assumes construction of a new pipeline

Technology	Description
H2 Pipeline	Most economical way to transport H2 for distance <3000 km
Ammonia	Most convenient route and become competitive for land transportation >3000 km
Liquid H2	Still not competitive vs other form of large H2 transportation. Current max size 30 tpd, need 30x scale up to become competitive
LOHC	low TRL technology, still to be proven

LH2: Liquid Hydrogen; LOHC: Liquid Organic Hydrogen Carrier

Baker Hughes

Source: IEA Global Hydrogen Review 2021

European Hydrogen Backbone

31 European gas infrastructure companies to plan a pan-European dedicated H2 transport … **28000 km** by 2030 …**53000 km** by 2040

80-143 billion € for the infrastructure

100% full decarbonization

DECEMBER '21: SNAM announced 3 billion euros investment in H2 transport by repurposing 2,700 km of network **from Tunisia to Italy**

Source: www.gasforclimate2050.eu/ehb/

Mission

The EHB initiative aims to accelerate Europe's decarbonisation journey by defining the critical role of hydrogen infrastructure – based on existing and new pipelines – in enabling the development of a competitive, liquid, pan-European renewable and low-carbon hydrogen market.

The initiative seeks to foster market competition, security of supply, security of demand, and cross-border collaboration between European countries and their neighbours.

Baker Hughes

H2 Transportation

Technology

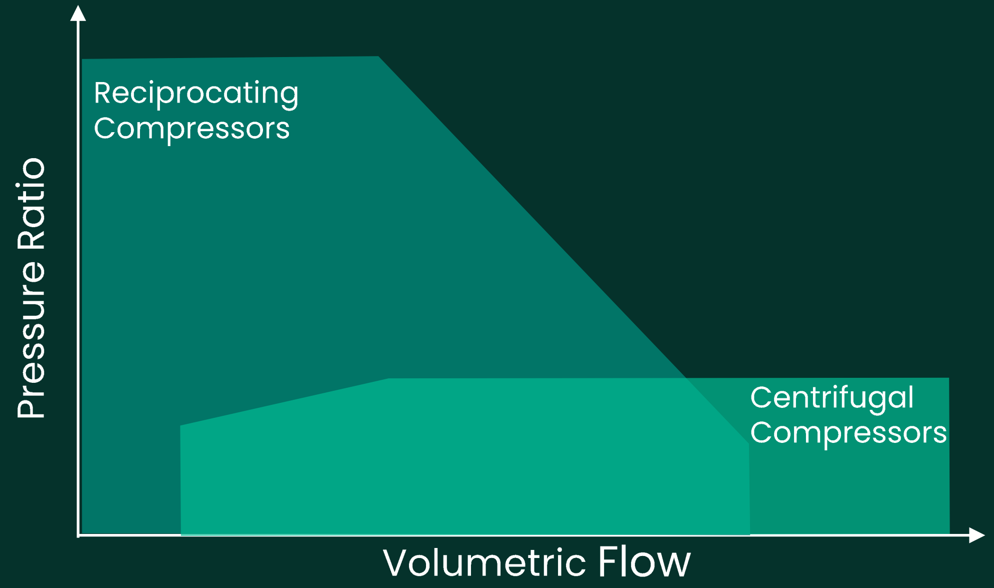
H_2 Compression

Expanding our compression leadership to hydrogen

We are established leaders in compression technology and our **High Pressure Ratio Compressors (HPRC)** provide significant improvements in overall green H_2 plant footprint, reliability, availability and weight.

Main achievements

- Long history of handling applications rich in H2
- First H2 application in 1962, a hydrogen compressor
- 2,250+ compressors installed
- Largest compression portfolio tailored to the hydrogen value chain, for production, transportation, and distribution



Hydrogen services	Technology	Installed Units	Max Flow (NM3/Hr)	Max Power (MW)
+2250 Installed units	Recips	+2000 (+800 with H2 >95%)	190.000	20
	Centrifugal	+250	1.200.000	19.4

Baker Hughes

Impact of hydrogen on centrifugal compressors

Material

- ***Hydrogen Attack***

Affect Carbon and low alloy steels, T > 200°C
usually not applicable for pipeline CC

- **Hydrogen Embrittlement (HE)**

Affect high-strength steels and titanium alloys, T < 150°C
applicable for pipeline CC

↓

Hydrogen dissociates in atoms and penetrates the material → local plasticization and brittle failure

↓

LIMITS ON MAXIMUM YIELD STRENGHT AND HARDNESS

Thermodynamic performances

When Hydrogen content increases..

↓

- Head increases
- Power increases
- Discharge temperature increases

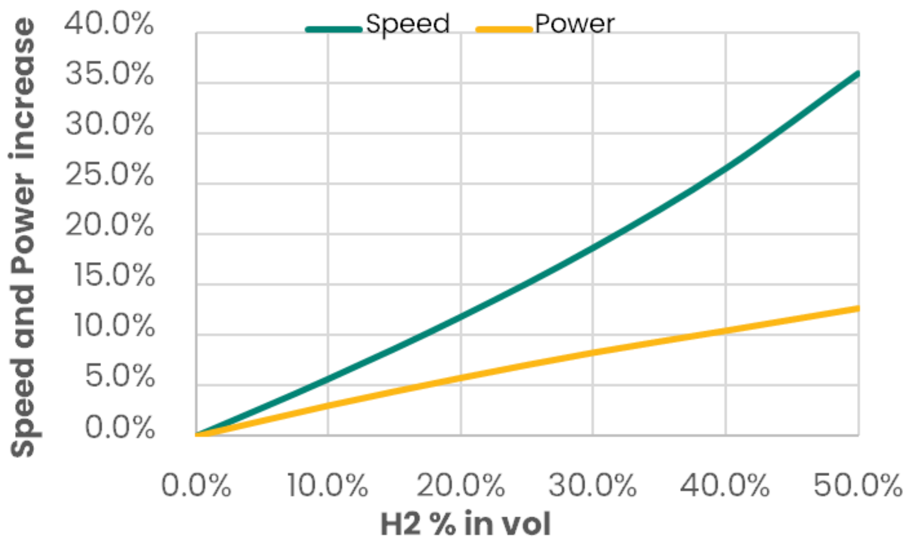
↓

MAIN CHALLENGE → COMPACT SOLUTION

Baker Hughes

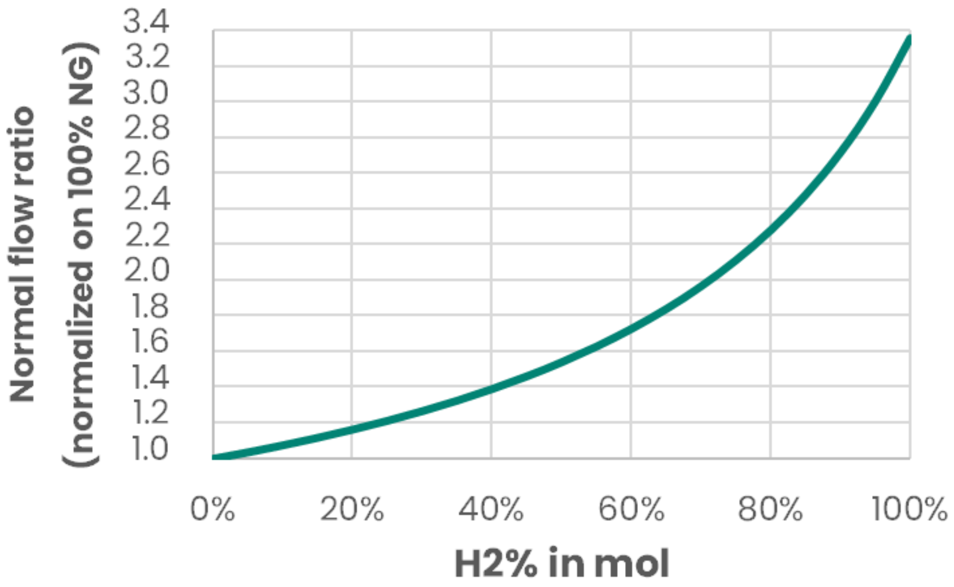
Performances impact – General

Impact on speed and power (at constant Nm3/h)



When the H_2 content raises, both operating speed and absorbed power increase as indicated in the graph above

Impact on Nm3/h (at constant gas energy)



At constant gas energy, higher is the H_2 content, larger will be the flow, demanding more speed and power

Baker Hughes

Centrifugal Compressors

HPRC: High Pressure Ratio Compressor

Increased tip speed

Increase head capability achieved with high speed, high efficiency impellers on a stacked rotor.

Increased rotating speed

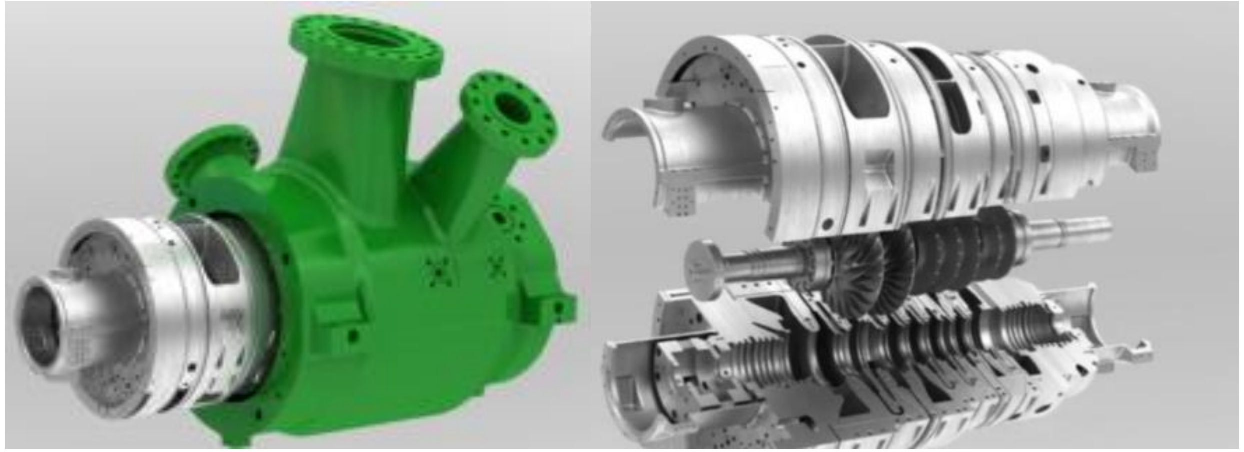
Parallel shaft gears to approx. 9X gear ratio and beyond with epicyclic technology.

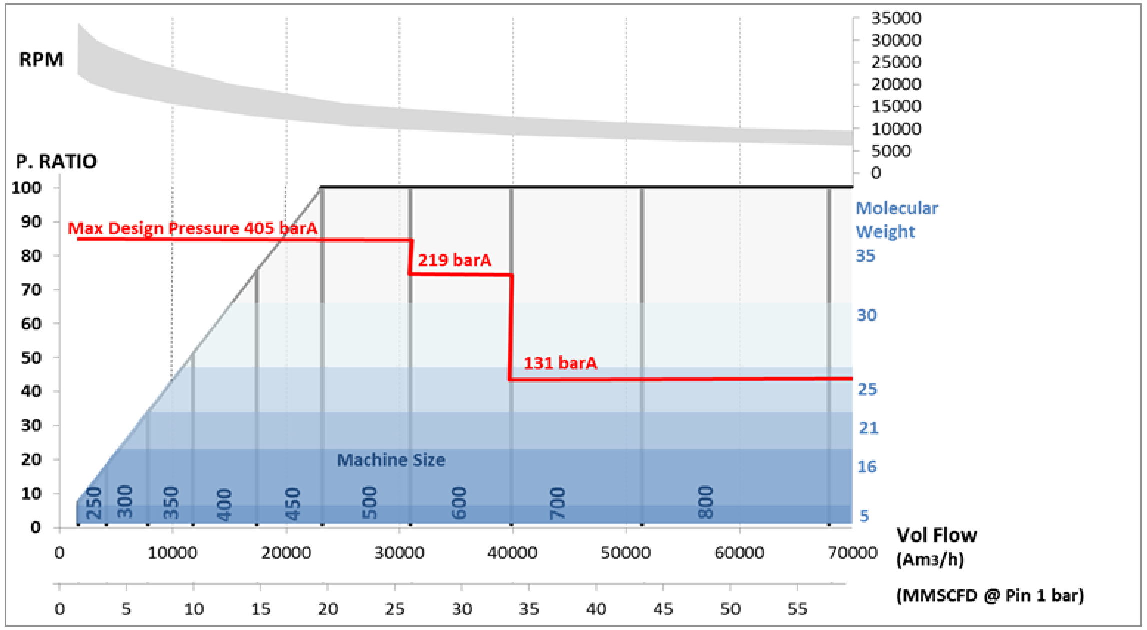
Compressor design optimization

Optimized inlet and outlet flanges for a 'single body' design

Reduced number of bodies

A significant reduction of stages and up to 3 sections in 1 compressor body resulting in a compact solution.





Baker Hughes

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=450 m/s	1	2	2	2	2	2	9

100%
28
18
9

HPRC solution is a great option when H_2 content is predominant

Baker Hughes

H_2 fueled Gas Turbines

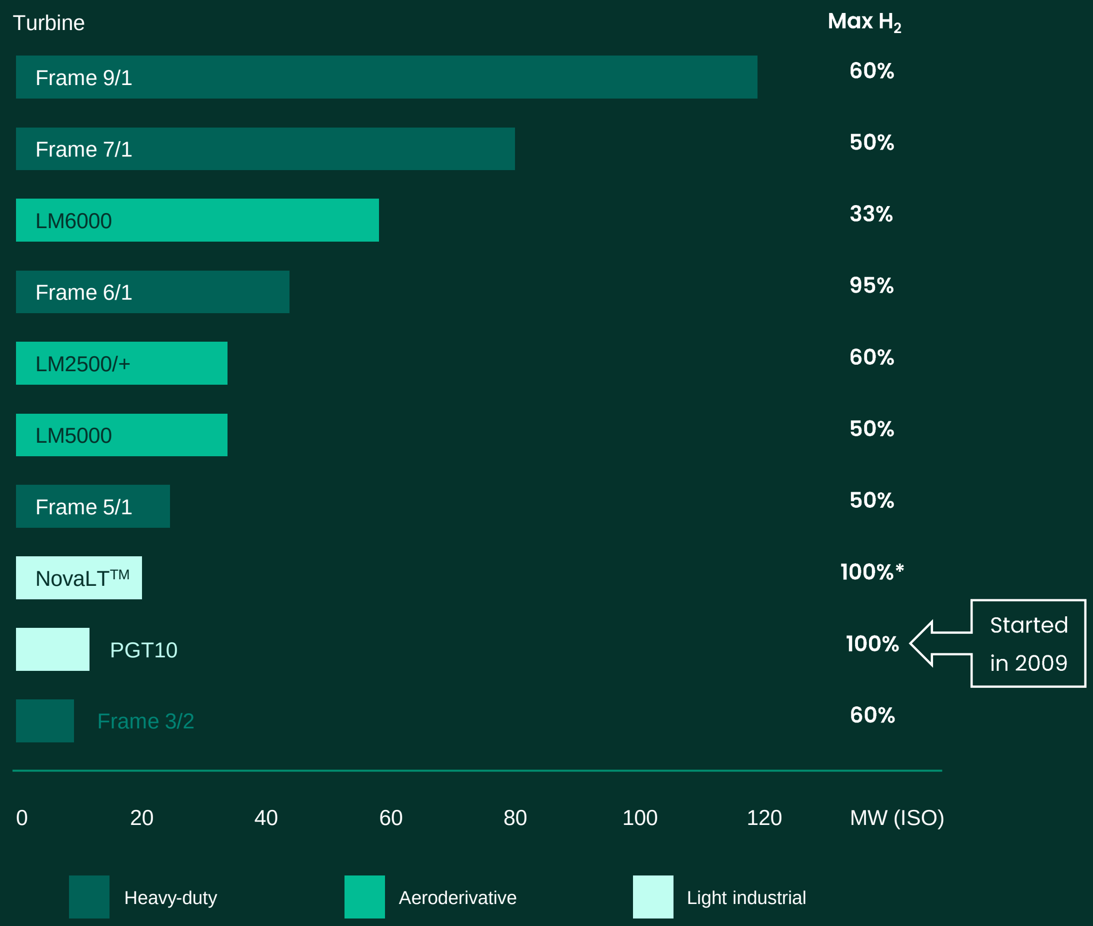
Proven and available today – **up to 100% hydrogen turbine**

Fuel gas blends with 10% to 100% hydrogen. Our turbines are ready for integration and adaptation into existing gas infrastructure, specifically designed to facilitate deployment.

Main achievements

- **70+ units installed** highlighting experience with frame and aeroderivative designs burning H2 rich fuel
- **Complete turbine portfolio** for current and future H2 Market needs. Full scale PGT10 demonstrative plant (100% H2)
- **NovaLT™ turbine technology*,** the H2 Flagship, dedicated LT combustion test @100% H2, able to start and run @ 100% H2

WIDE RANGE OF EXPERIENCE IN BURNING HYDROGEN



*Demonstrated on a combustion test bench

NOVALT™ is a trademark of Baker Hughes or its affiliate.

Challenges of Hydrogen Utilization in Gas Turbines

Engine and package modifications are needed for hydrogen fuel

Combustion

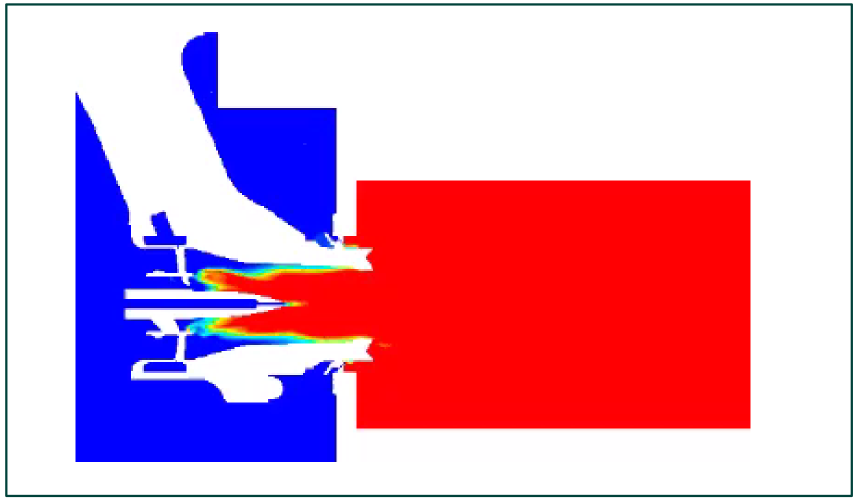
- High flame speeds
- Wide flammability limits
- High flame temperatures
- Flashback
- Combustion dynamics

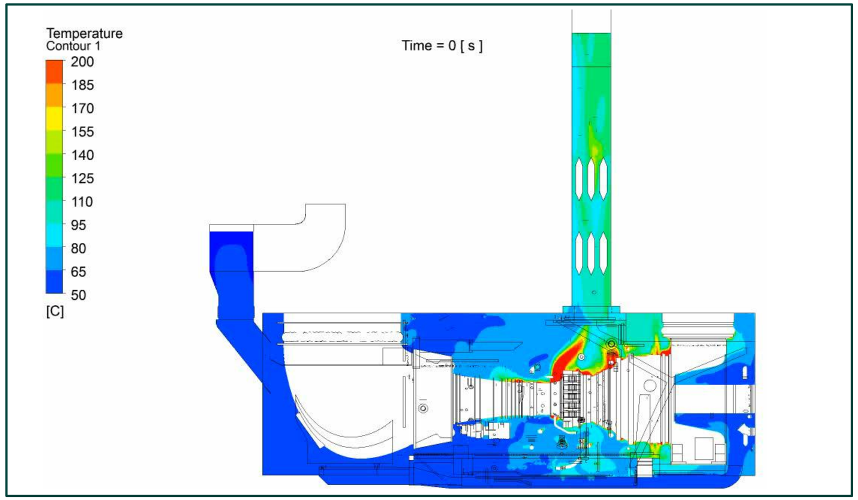
Delivery & Package

- Storage
- Sealing
- Material compatibility
- Equipment validation & ATEX certification

Operation

- Start-up and shut-down procedures
- Fuel system/engine/package purge requirements
- Flame detection
- Gas detection
- Performance/durability (high % H2)

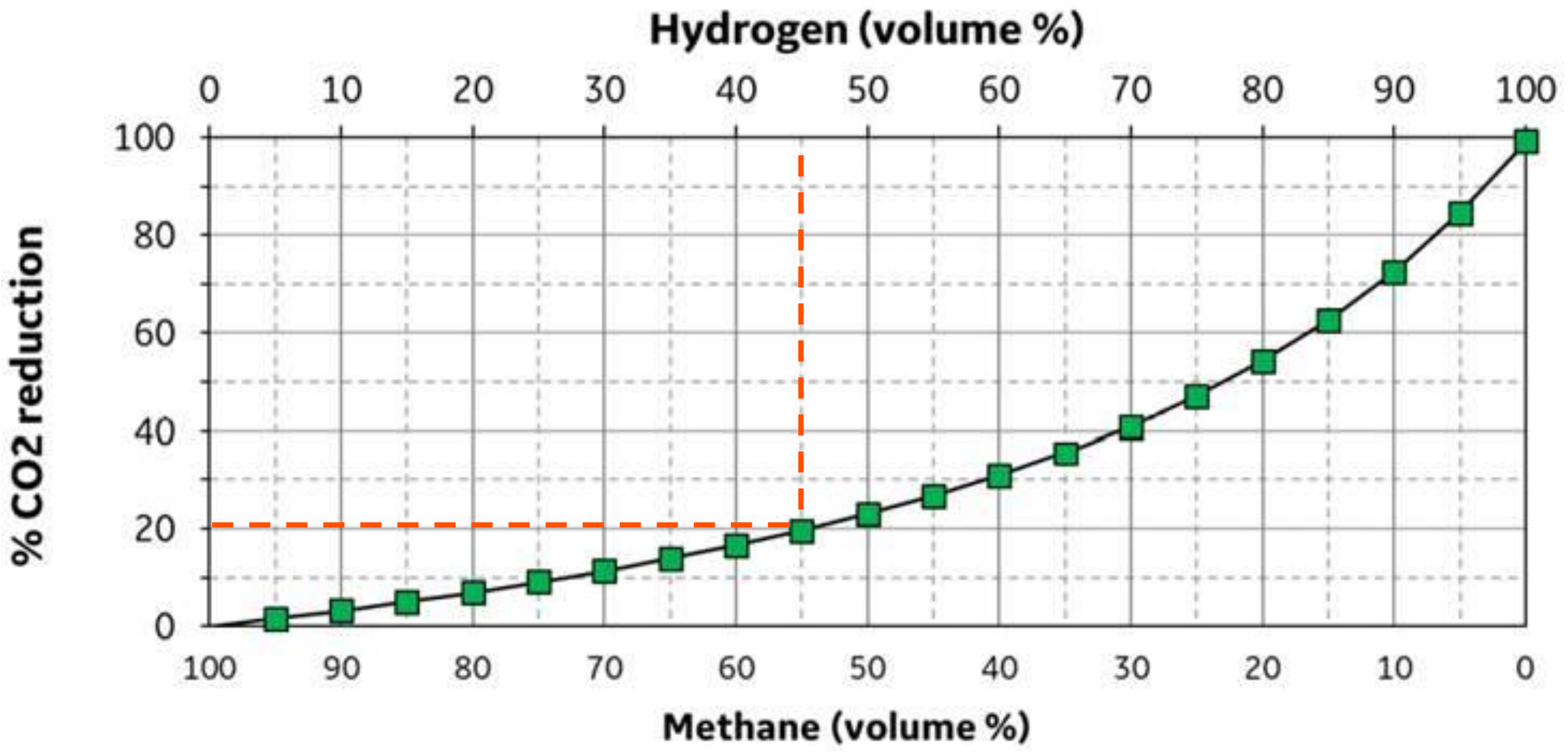




Baker Hughes

Hydrogen Blends with Natural gas

CO_2 Emission Reduction From Gas Turbine at varying blends of hydrogen in fuel gas

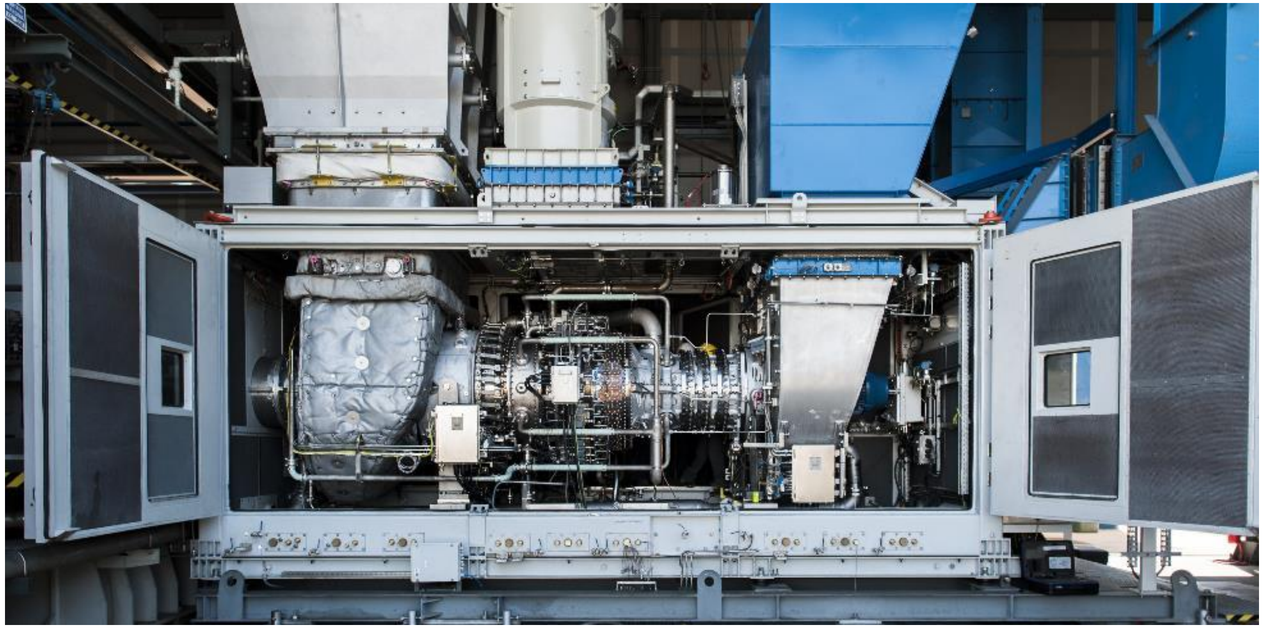


High % of Hydrogen blend in Natural gas needed to achieve significant CO2 reduction

Baker Hughes

Snam and Baker Hughes test world's first hydrogen blend turbine for gas networks

- In July 2020, Baker Hughes and Snam successfully completed testing of the world's first "hybrid" hydrogen turbine designed for a gas network.
- The test paves the way to implement adoption of hydrogen blended with natural gas in Snam's current transmission network infrastructure.



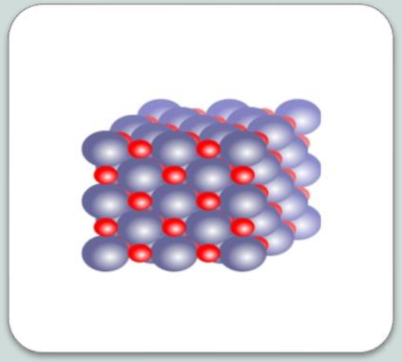
- Powered by blend of up to 10% hydrogen, the NovaLT 12 turbine was designed and manufactured by Baker Hughes in Italy
- NovaLT 12 will be installed at Snam's gas compressor station in Istrana, Italy
- Project represents new milestone for Italian infrastructure as it continues to adapt to transport hydrogen and reduce CO_2 emissions
- Today 70% of Snam's pipelines are already built with "Hydrogen ready" pipes

Baker Hughes

H2 Storage

Overview

How to store Hydrogen?

	CGH2	**Ammonia**	**Metal Hydrides**	**Cavern**	**LH2**
PROS	Minimal processing requirements Well established technology	Easy to transport Well established process High H2 density	Easy to transport Lesser safety and reliability risks	Suitable for large scale and long term storage Minimal losses Lower storage cost for extensive volumes	Minimal processing requirements Transportation model similar to LNG
	-	-	-	-	-
CONS	Material requirement (H2 embrittlement) Very low density and poor specific volume energy density	Conversion Cost Impact on downstream infrastructure	Challenges with weight of storage Poor speed of H2 release	Geographical availability Extensive plant/equipment	High energy costs Transportation for LH2 not mature Safety risks due to leakages

H2 Storage

Technology

H_2 Storage

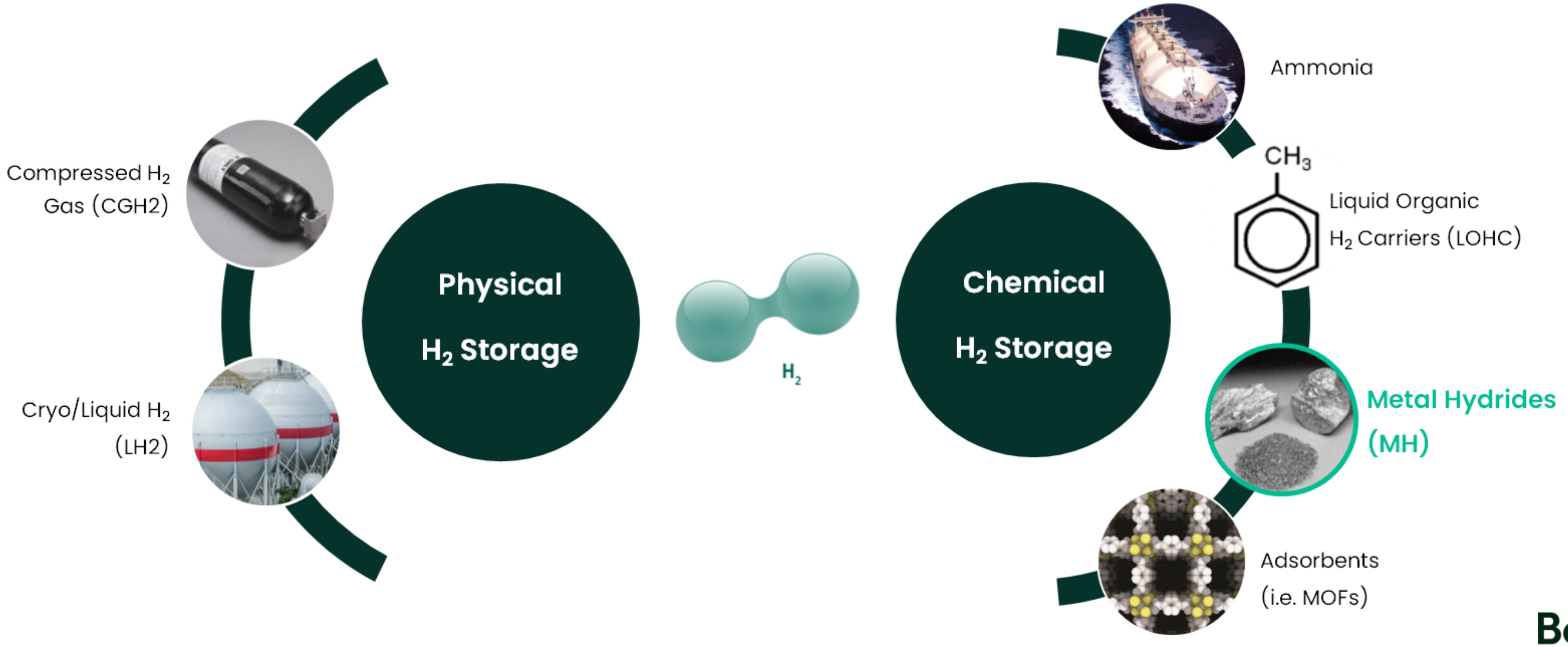
Technology context

Compared to other **fuels**, the Hydrogen molecule possesses:

- the highest energy content by **weight**
- a low energy density by **volume**

Storing sufficient quantities of hydrogen with convenient footprints is then achieved through **three main strategies**:

- high storage **pressure**
- low storage **temperature**
- storing H_2 molecules within different **materials**

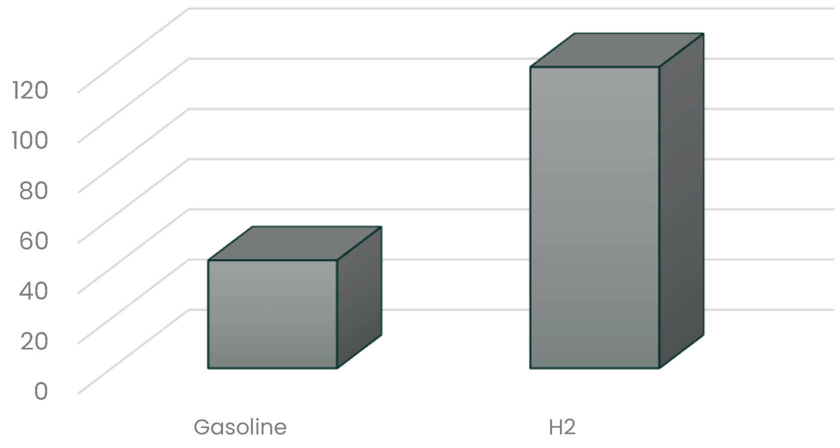


LOHC: Liquid Organic Hydrogen Carrier; MOF: Metal-Organic frameworks

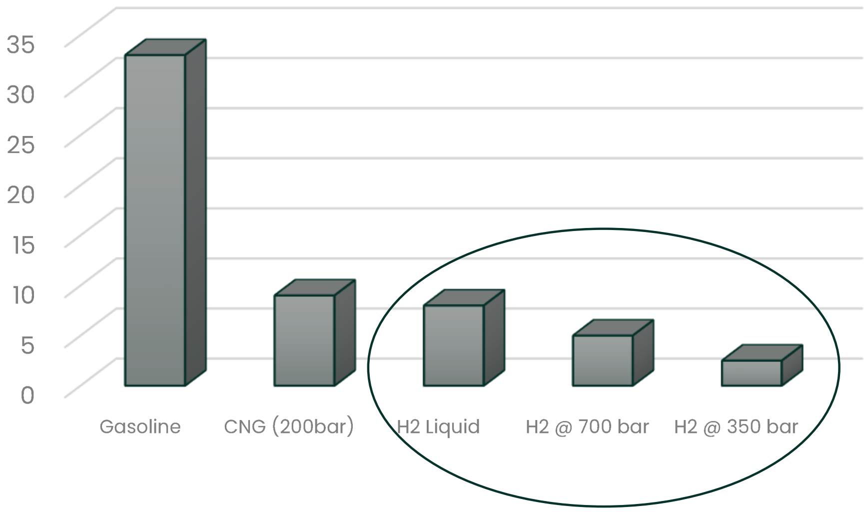
Baker Hughes

Focusing on H_2 Compression

Mass Energy Density [MJ/kg]



Volume Energy Density [MJ/L]



1kg of H_2 embeds ~3x the energy of same mass of Gasoline!

and there is not Carbon inside → CO_2 free combustion
… but
1kg H_2 @ atm. Press. needs ~3000x volume for 1 kg of Gasoline….

To have decent energy content in a reasonable volume:

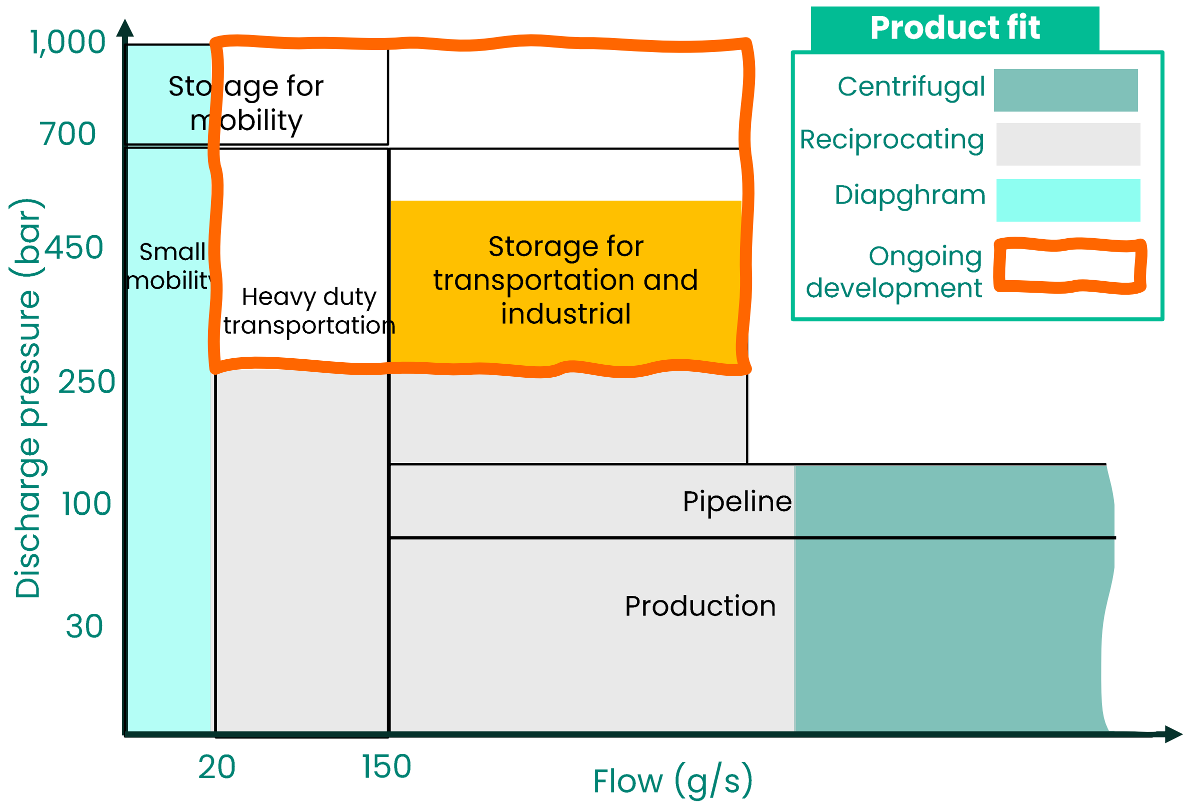
- Liquefaction → Requires compression anyway to mitigate high cost of cryo-conditions (-253°C for H_2 Liquid @ atm. Pressure)
- High-Pressure tanks/storages → Requires compression after production (Electrolyzer output only 1÷30 bar range)

Compression will be of paramount importance in the H_2 Era

Baker Hughes

Compression for H2 storage

Hydrogen compression



- Diapghram compressor max flow: 300-500 Nm3/h
- Refueling station for trucks and train will require 15x-20x compressors
- Currently no cost-effective technology for large refueling stations
- Ongoing development of new solution to enable efficient reliable and sustainable H2 distribution system

Baker Hughes

Reciprocating compressor for H2 applications

The Nuovo Pignone reciprocating compressors have been designed for the compression of process gases according to the stringent API618 regulations, in particular for the compression of hydrogen for various uses.
Since 1962, our compressors have been installed for hydrocracking, hydrotreating, hydrodesulphurization processes and for all refinery applications that include hydrogen.
We have 60 years of history and 1000 running units with H2 that testify our well proven design, our engineering skills and our technical innovation on reciprocating compressors

1911	First reciprocating compressor
1962	**First Hydrogen compressor**
1964	First Hypercompressor for LDPE
1966	First compressors for re-injection of associated gas
1976	Highest working pressure, in a Hypercompressor for LDPE: 3,500 bar
2006	Highest installed power for a single LDPE compression unit, 33 MW
2020	**One of the largest API 618 compressors…20MW in H2 process**
2021	Large HG reciprocating compressor on-skid
2022	**Development of compressor for HRS with 550 bar discharge pressure**

Baker Hughes experience in hydrogen services: over 1000 units

Q&A

Baker Hughes