COMPRESSOR TECH² HYDROGEN SUMMIT

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Methods and the future of Hydrogen Compression

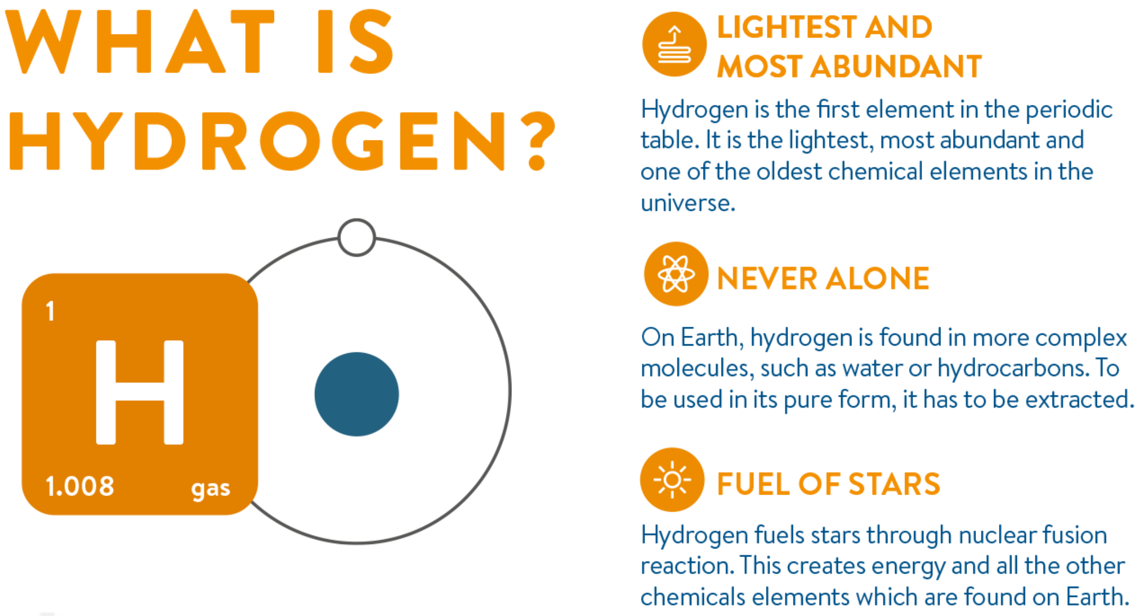
COMPRESSOR TECH²

DEDICATED TO GLOBAL GAS COMPRESSION PRODUCTS AND APPLICATIONS

POWERED BY khl

- What is Hydrogen?
- How is Hydrogen produced?
- Where is it used - Hydrogen Applications?
- Why do we need Compression for Hydrogen?
- What Types of Compressors are used in Hydrogen service?
- Upcoming Trends/Technologies in Hydrogen
  - Electro Chemical Compression
  - Hydride Compression
  - Linear Compressor
  - White Hydrogen
  - Gaseous vs. Liquid Storage/Dispensing/Transportation
- Q & A

What is Hydrogen?

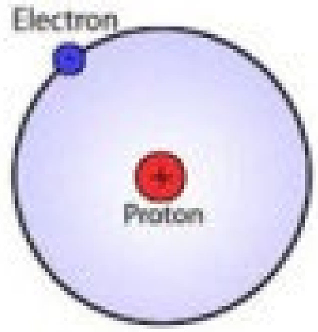


- **Hydrogen** is the first element in the periodic table and has an atomic number 1
- Hydrogen is one of the most common elements in living things, together with carbon, oxygen, and nitrogen.
- It is also the most-abundant element in the universe
- On our planet – Hydrogen is found in more complex molecules such as water or hydrocarbons and has to be extracted

- Hydrogen is H2 instead of H, as atomic hydrogen is highly unstable and does not exist under normal conditions.
- Hydrogen exists as diatomic molecule
- To achieve a stable configuration, there must be two electrons in this shell.

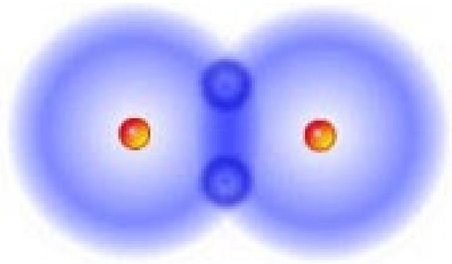
H = Atomic Hydrogen

Molecular Weight – 1.008



H_2 = Molecular Hydrogen

Molecular Weight – 2.02



1. Natural Gas Reforming
   A. Steam Reforming
   B. Partial Oxidation
   C. Autothermal Reforming
2. Electrolysis
3. Coal Gasification
4. Biomass Gasification
5. Reversible fuel Electrolyzer
6. Solar Thermal production
7. Biological Production

Commercial

Farthest from Market

Colors of Hydrogen / IRA 2022

	Terminology	Technology	Feedstock/ Electricity source	GHG footprint*
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind | Solar | Hydro Geothermal | Tidal	Minimal
PRODUCTION VIA ELECTRICITY	Purple/Pink Hydrogen	Electrolysis	Nuclear	Minimal
PRODUCTION VIA ELECTRICITY	Yellow Hydrogen	Electrolysis	Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS Gasification + CCUS	Natural gas | coal	Low
PRODUCTION VIA FOSSIL FUELS	Turquoise Hydrogen	Pyrolysis	Natural gas	Solid carbon (by-product)
PRODUCTION VIA FOSSIL FUELS	Grey Hydrogen	Natural gas reforming	Natural gas	Medium
PRODUCTION VIA FOSSIL FUELS	Brown Hydrogen	Gasification	Brown coal (lignite)	High
PRODUCTION VIA FOSSIL FUELS	Black Hydrogen	Gasification	Black coal	High

What everybody wants to see (Green Hydrogen)

Most produced (Grey, Brown, Black Hydrogen)

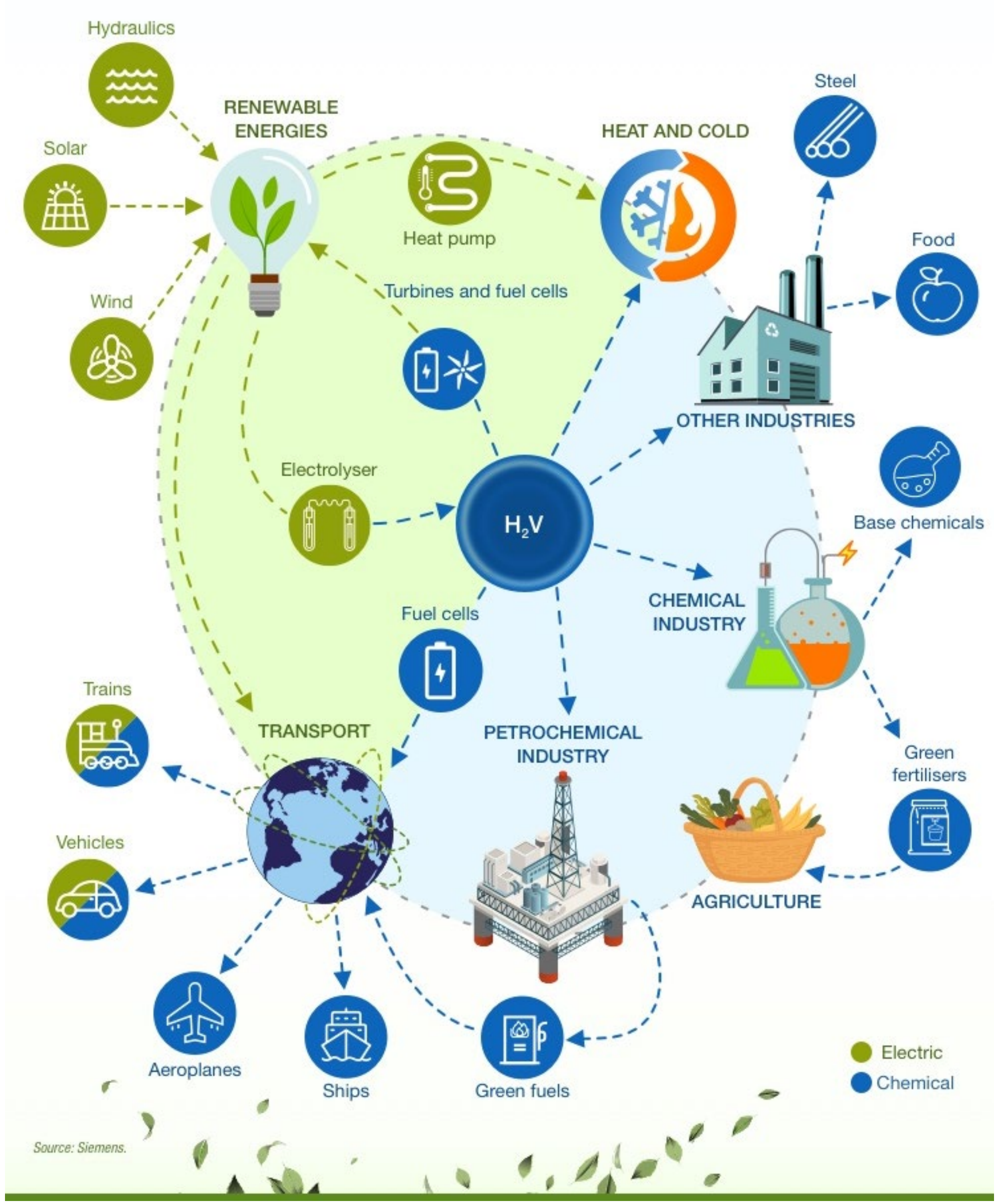
*GHG footprint given as a general guide but it is accepted that each category can be higher in some cases.

Tax Credits for low-emission Hydrogen:

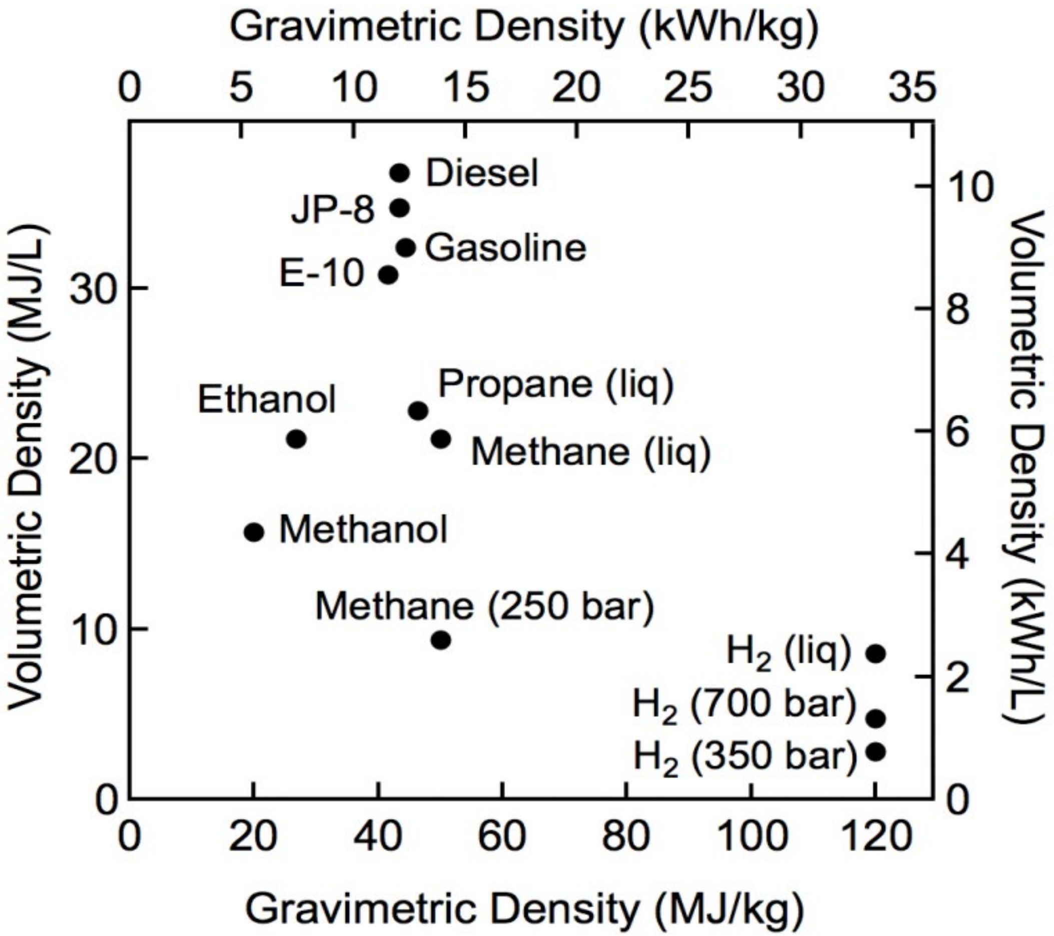
> Under the law, renewable electricity and clean hydrogen plants in 2023 can receive a production tax credit of 2.6 cents per kWh and up to $3 per kg of hydrogen, respectively, for the first 10 years of operation

Hydrogen Applications

- Renewable energy (Fuel Cells and Turbines)
- Transportation (Bus, Cars, Marine, Air etc.)
- Steel Production (Blast furnace H2 powered)
- Basic Chemicals (Green Ammonia, Green Methanol)
- Green Fertilizers
- Petrochemical and Refineries (Hydrocracker, Hydrotreater)



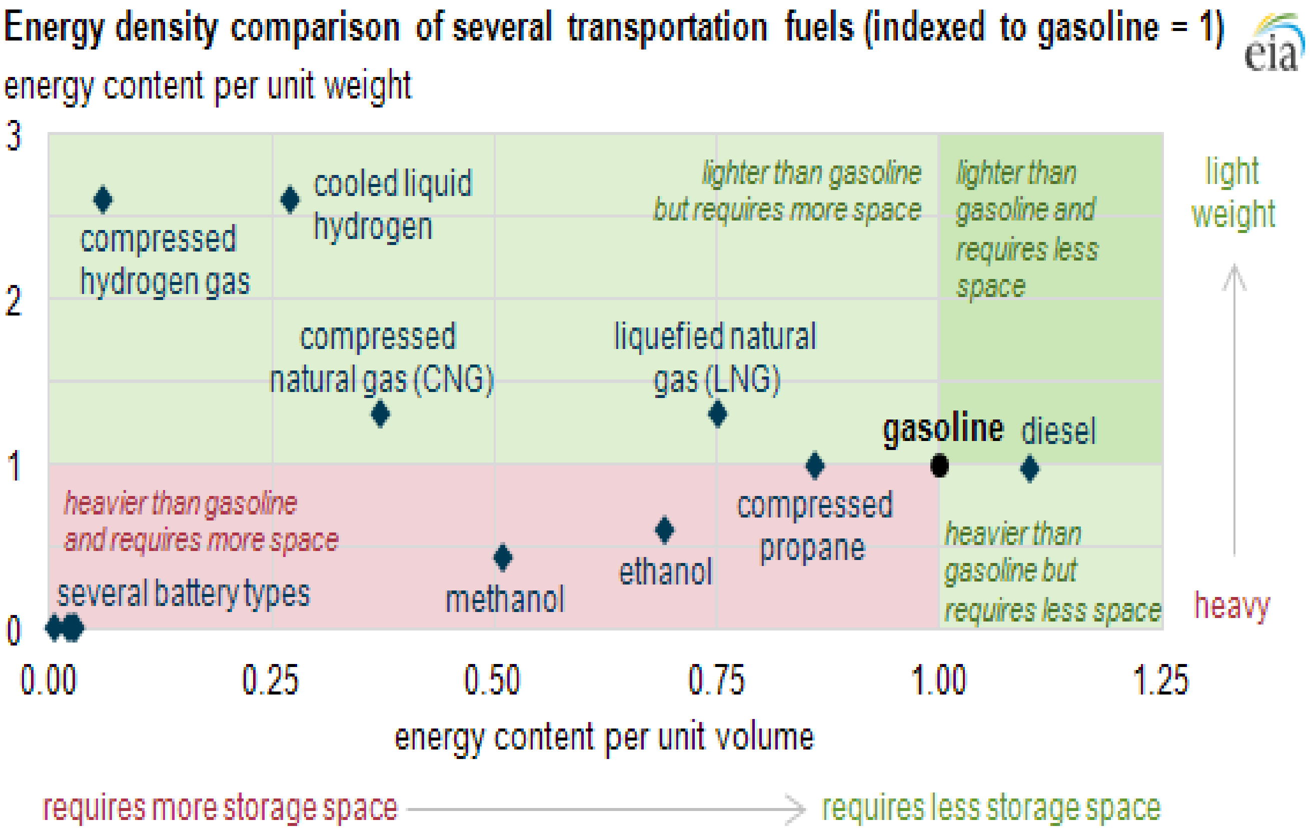
Why do we need to compress Hydrogen?



Comparison of specific energy (energy per mass or gravimetric density) and energy density (energy per volume or volumetric density) for several fuels.

- On a mass basis, hydrogen has nearly three times the energy content of gasoline—120 MJ/kg for hydrogen versus 44 MJ/kg for gasoline.
- On a volume basis, however, the situation is reversed; liquid hydrogen has a density of 8 MJ/L whereas gasoline has a density of 32 MJ/L, as shown in the figure comparing energy densities of fuels

Why do we need to compress Hydrogen?



A volume of around 11 m3 (389 cu ft), which is the volume of the trunk of a large utility or commercial vehicle, is needed to store just 1 kg of hydrogen, which is the quantity needed to drive 100 km (62 miles).

SMR / Electrolyzer have limited range of gas generation pressure and storage, transportation, refinery and chemical processes, refueling etc. require higher pressures.

Most compressors used today for gaseous hydrogen compression are either:

- ❖ Centrifugal compressors.

or

- ❖ Positive displacement compressors

    Positive displacement compressors used for H2 are commonly Diaphragm or Reciprocating type

Centrifugal Compressor

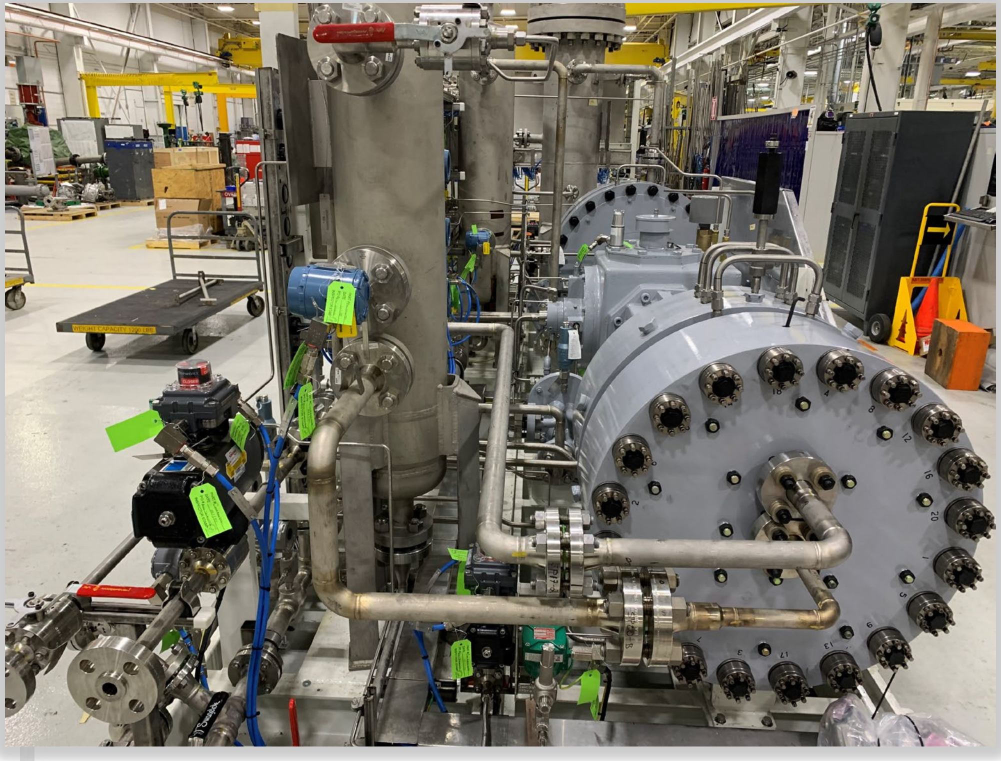
Strengths

- Can handle very large gas flows
- Ideal for pipeline, recirculation, drying applications
- Reliable design in accordance with API 617 (min. 5-year MTBO)

Weaknesses

- Moderate Pressure Ratio

Diaphragm Compressor



Strengths

- Absolutely no leakage to atmosphere
- Non-contaminating gas compression, assurance of gas cleanliness – absolutely no oil →This is critical for fuel cell applications – as even the slightest contamination can damage a fuel cell.
- No purging/venting needed
- Low maintenance requirements
- High Reliability
- High Compression Ratio (up to 10 per stage)

Weaknesses

- not feasible for larger flows

Reciprocating Compressor

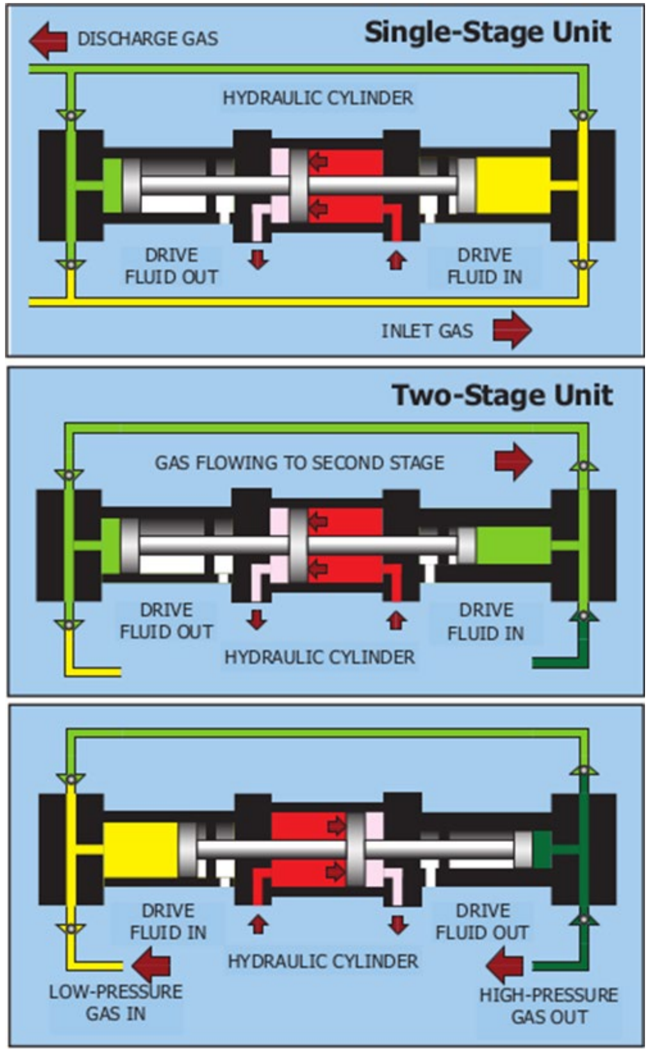
Strengths

- Can handle larger gas flows than Diaphragm compressors
- Pressure ratios 3,5 -4 per stage (lower than diaphragm type but higher than centrifugal)

Weaknesses

- Contamination of gas possible (oil lubricated piston)
- Non-lubricated design experience up to 250 bar (500 bar in development phase)
- Leakage of Gas to atmosphere (1-2%)
- External Buffer gas (N2) needed – Source?
- More compression stages needed than diaphragm type

Hydraulic Booster



Strengths

- Range of modular double acting single stage and two stage models allow compression up to 14,500psi (1,000 bar)
- High efficiency design for minimal energy

Weaknesses

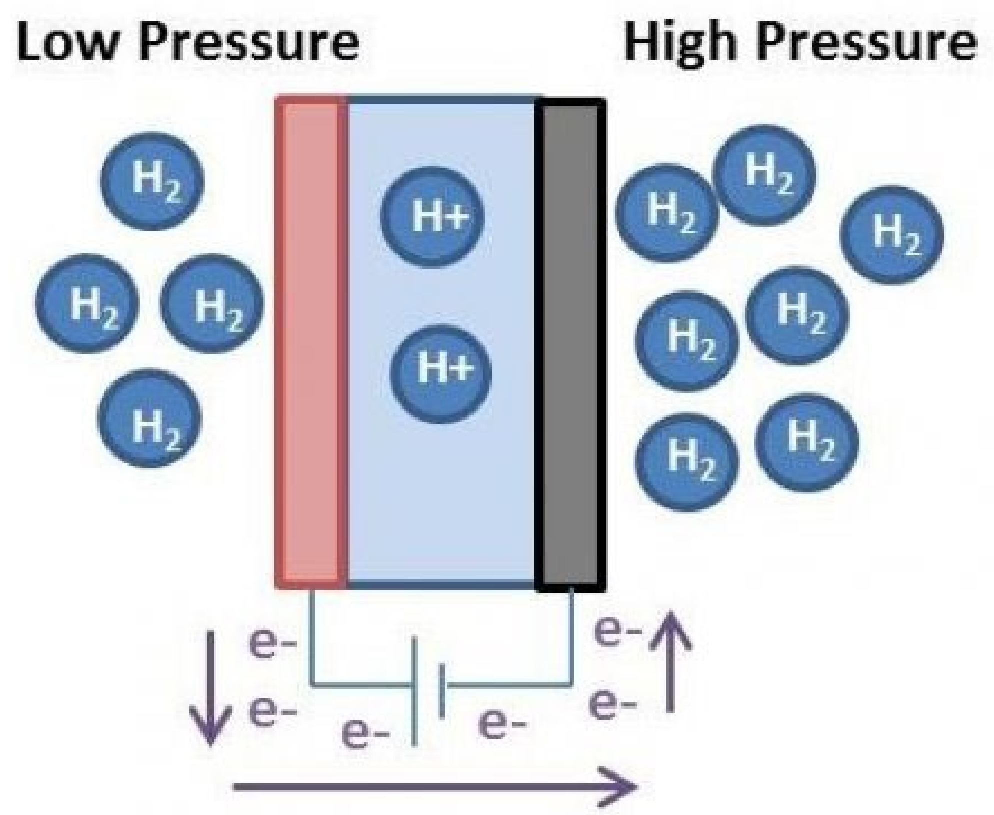
- Oil Contamination of gas possible (99% Purity guarantee only)
- Possible gas losses
- Not feasible for larger flows (similar limits as Diaphragm compressor)

Electrochemical compression

(not commercialized yet)

A more modern method of compressing hydrogen, which doesn't require mechanical force, is electrochemical compression.

Electrochemical compressors use proton exchange membranes (PEM) flanked by electrodes and an external power source to drive the dissociation of hydrogen at the anode and its recombination at higher pressures at the cathode.

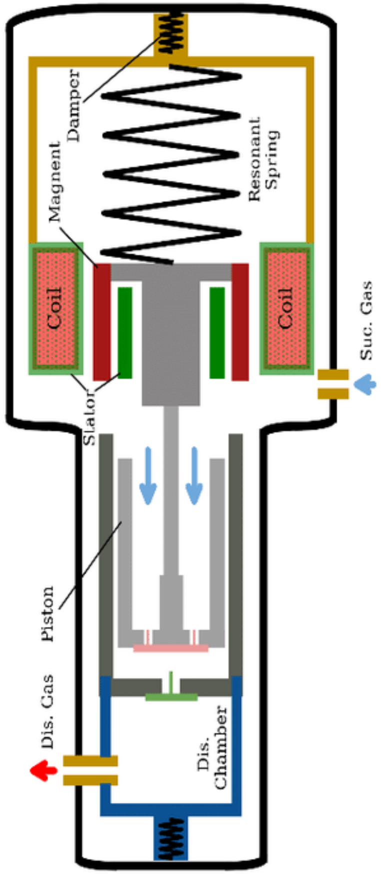


Hydride compressor
(not commercialized yet)

Metal hydride compressors use metals that form hydrides (a binary compound of hydrogen with a metal) via exothermic reactions and then release hydrogen at higher pressures when heat is applied.

Linear compressor
(not commercialized yet)

The single-piston linear compressor uses dynamic counterbalancing, where an auxiliary movable mass is flexibly attached to a movable piston assembly and to the stationary compressor casing using auxiliary mechanical springs with zero vibration export at minimum electrical power and current consumed by the motor



Hydrogen From Natural Sources? - White' hydrogen Lurks Under the Ground and Under the Radar

While hydrogen as a future fuel is gaining popularity, one of its biggest hindrances revolves around its production--or separation into a useful state.

But building enough plants to make any color hydrogen is expensive and consumes a lot of energy just in the processing end--which does not include storage and shipping.

Too bad hydrogen can't just be drilled for like oil and gas. Or can it? More and more scientists and agencies, including the U. S. Geological Survey (USGS), the Advanced Research Projects Agency (also a government entity), are considering whether what's called variously "natural," "white" or "geologic" hydrogen could be available in significant quantities for commercial development

Gaseous vs. Liquid Storage/Dispensing

Hydrogen is the lightest gas in the universe (0.090 kg/m3). Therefore, it occupies a very large volume at atmospheric pressure. To be stored and transported efficiently, the volume of the gas must be reduced.

Hydrogen can be **stored physically** as either a gas or a liquid.

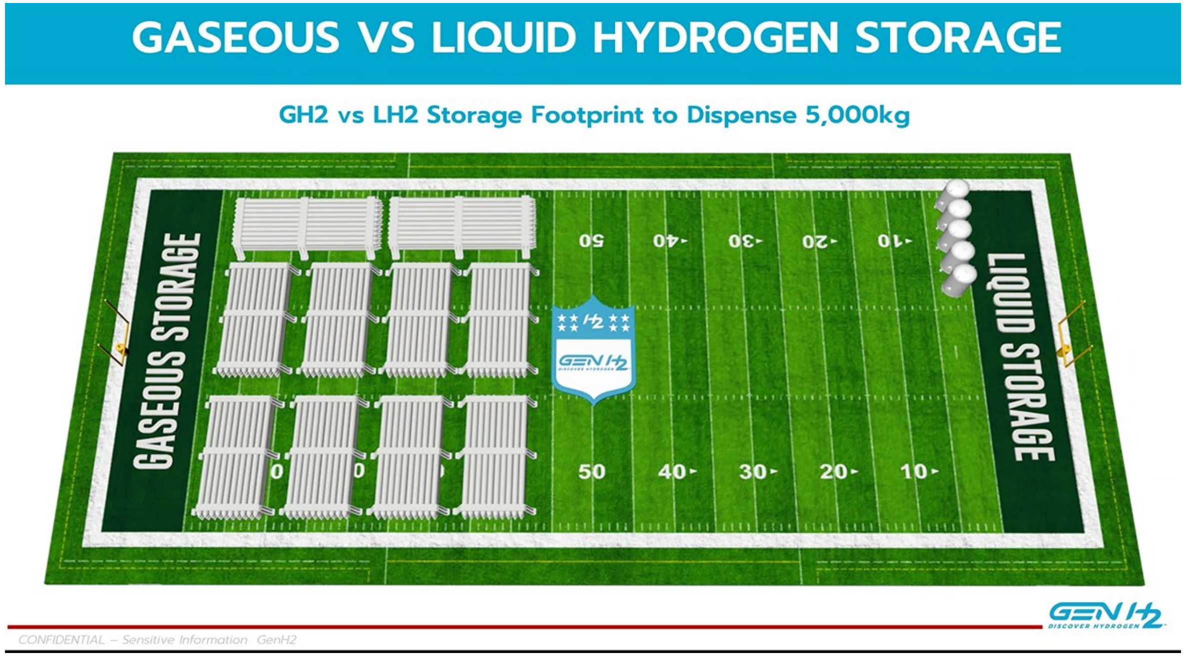
Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure).

Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C (-423F)

Storing H_2 as liquid takes less space than storing it as a gas at normal temperature and pressure. Liquid Hydrogen requires cryogenic storage technology such as special thermally insulated containers and requires special handling common to all cryogenic fuels.

Drawbacks:

- Energy intensive conversion to liquid - Cost
- Cryogenic storage tank technology *(Boil-off rate – vapor recompression)*



Options to store and **transport** Hydrogen:

1. Gaseous storage – transport either in pressure vessels or in a pipeline
2. Liquid storage – transport in an LH2 tank either on a truck or on a ship
3. Chemical storage – transport depending on the storage technology.

- “Small amount of hydrogen + short distance → Gaseous storage and transport”
- “Larger amount of hydrogen + longer distance → Liquid storage and transport”
- “Very large amount of hydrogen + long storage duration + very long distance → Chemical storage and transport”

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Thank You

Questions?