
# HYDROGEN TECHNICAL STUDY

31/08/2023 Benoît Mayol Cork

# PRESENTATION PLAN

## I. The properties of hydrogen

- Physical properties
- Dangers of hydrogen

## II. Impact on engines

- Engine ranges
- Impact on energy production
- Running costs

## III. Hydrogen storage solutions

- Choice of storage solution
- Steel embrittlement
- Gas storage
- Case studies

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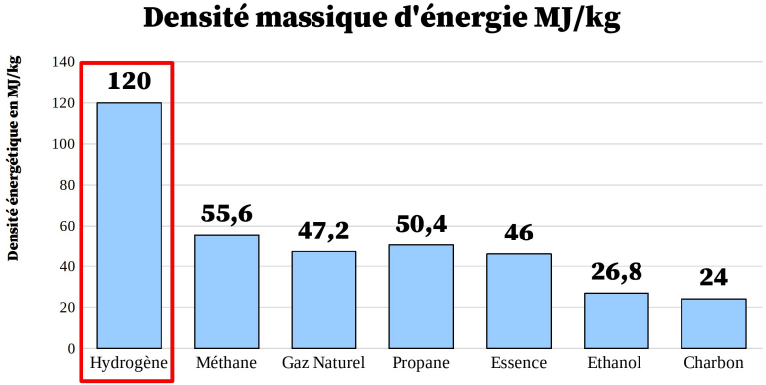
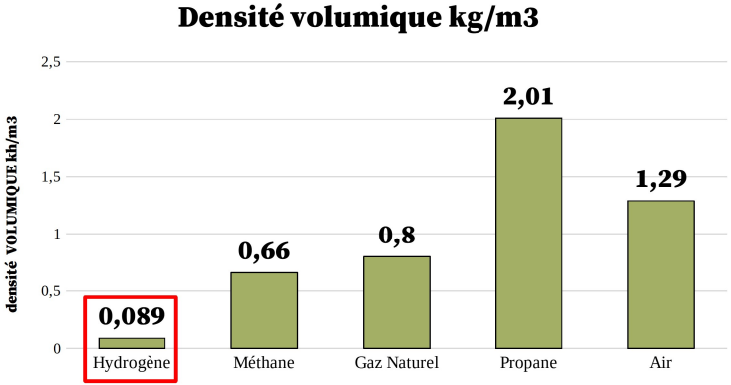
# I. THE PROPERTIES OF HYDROGEN

## ENERGY MASS DENSITY



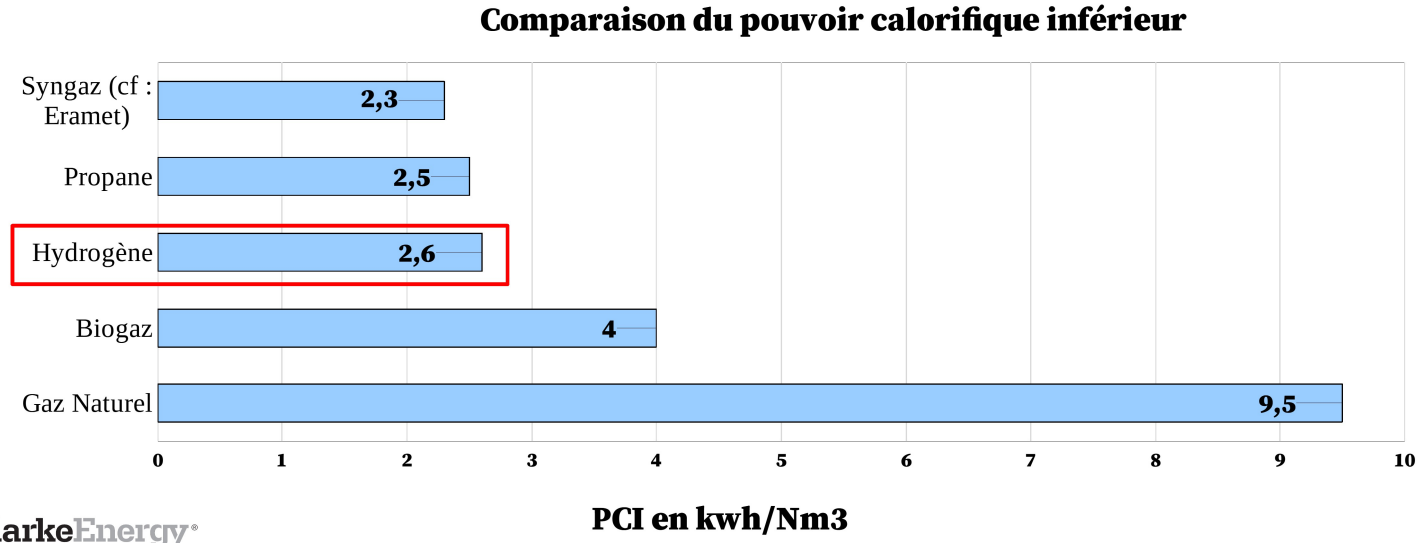

**Energy/mass ratio: 2.2 higher than methane**

## VOLUME DENSITY




**7 times less dense than methane**

# LOWER CALORIFIC VALUE

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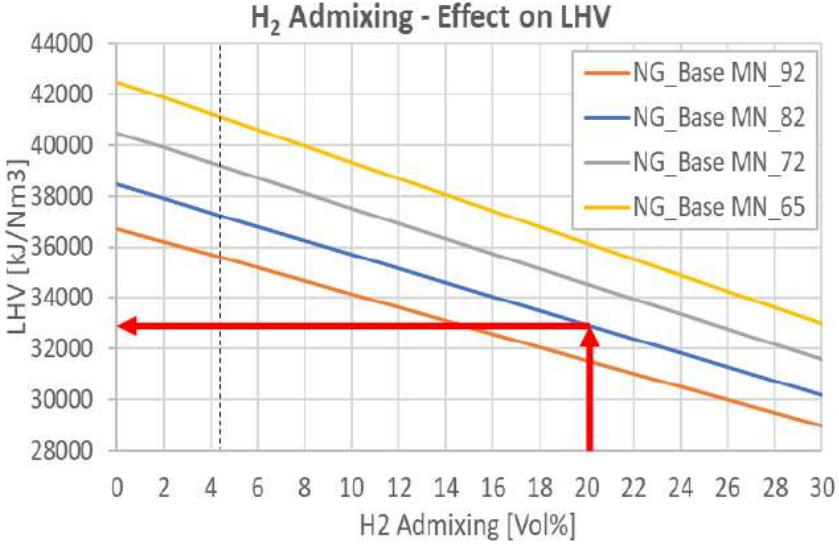
## I. The properties of hydrogen

# CHANGES IN CALORIFIC VALUE




**This graph shows that natural gas with a MN of 82 and an initial LHV of 10.7 kWh/Nm3 mixed with 20% hydrogen will have an LHV of 9.2 kWh/Nm3.**

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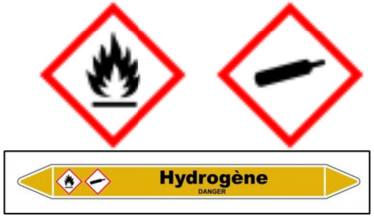
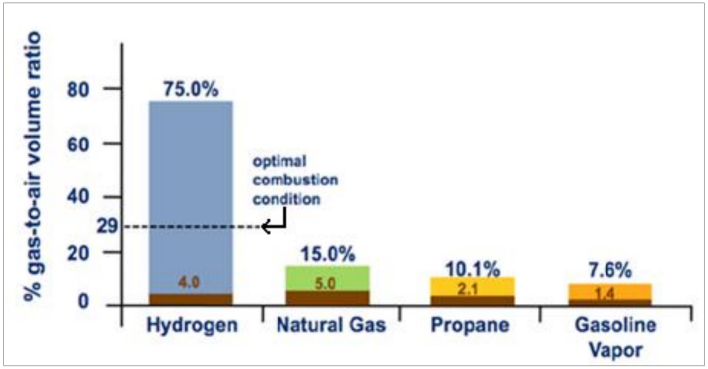
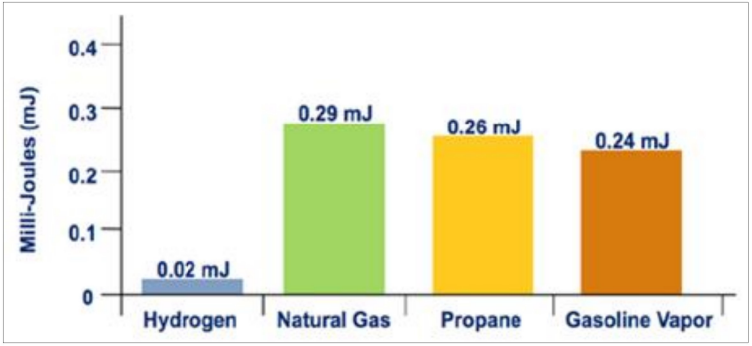
# THE DANGERS OF HYDROGEN

- **Explosive limit : 4-76 %**
- **Auto ignition energy : 0,017 mJ**
- **Can lead to a reduction in oxygen concentration in a closed environmen.**
- **Odourless and colourless.**
- **Neither toxic nor corrosive / To date, no carcinogenic effects are known.**

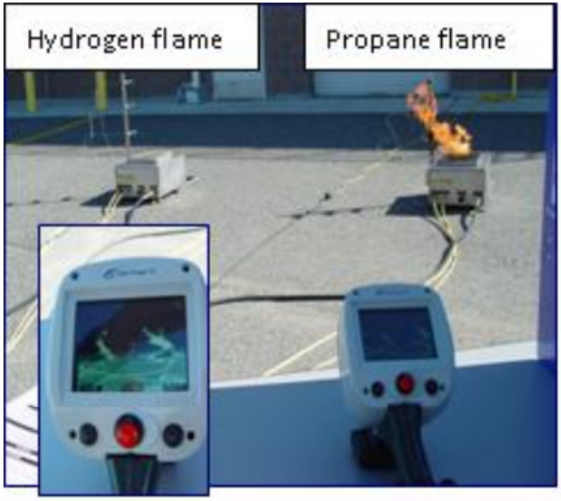
SGH criteria :



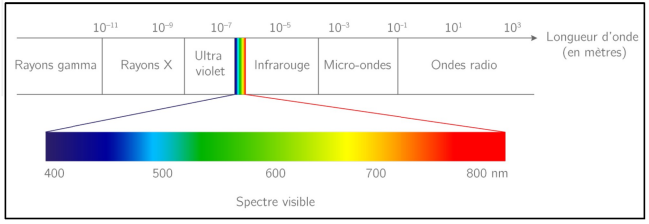



# THE DANGERS OF HYDROGEN





**Hydrogen flames are difficult to see with the naked eye.**




**<u>Radiation :</u>** between 2700 and 3200 nm

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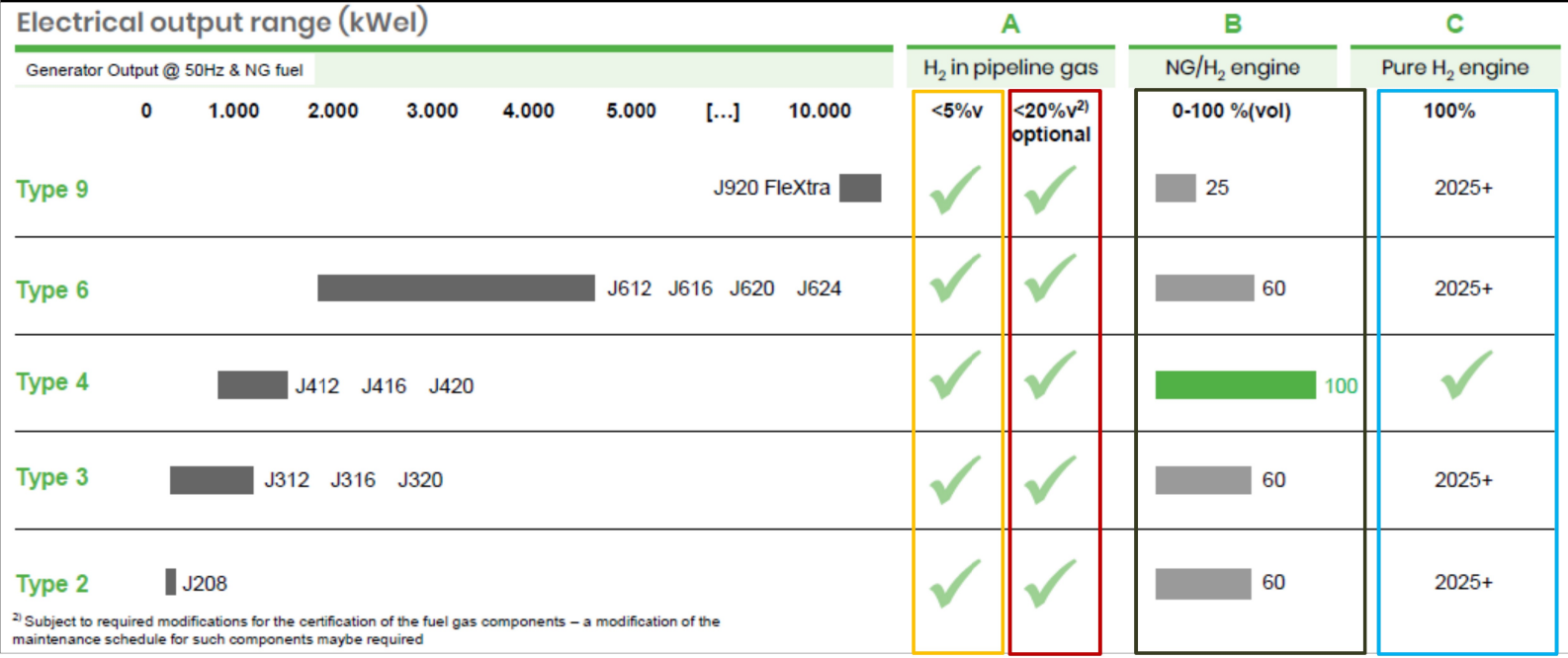
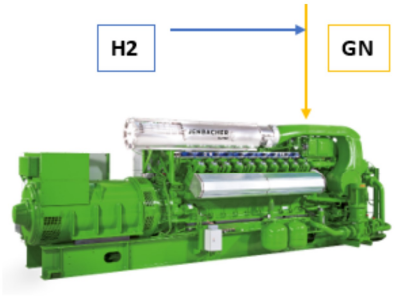
# II. ENGINE RANGES

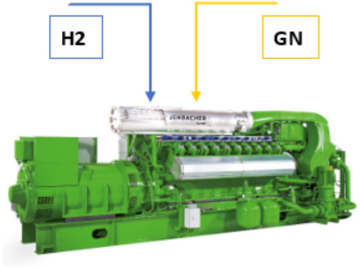


# THREE CONFIGURATIONS

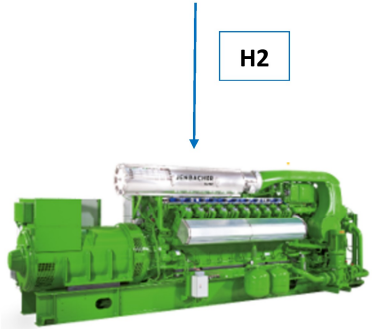
**Up to 20% hydrogen**




**Up to 60 or 100% hydrogen and the rest NG**




**100 % hydrogen**

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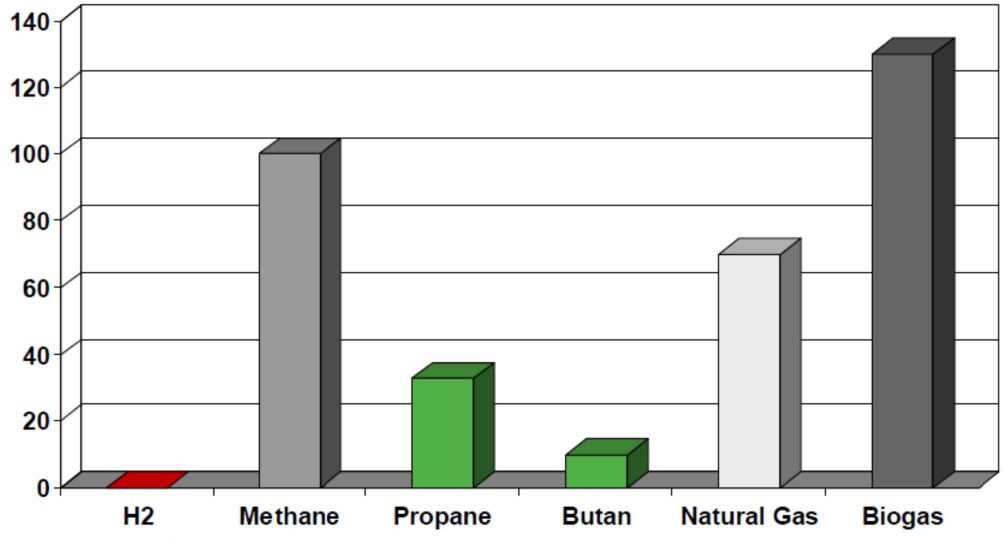
# METHANE NUMBER (MN)




**The lowest value**

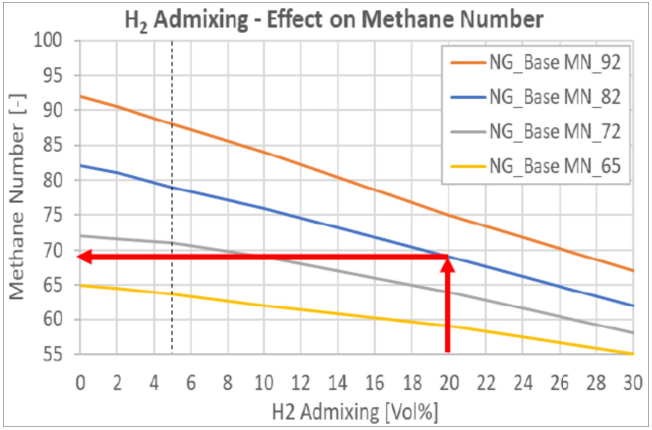
1. Used to measure the detonability of a gas with reference to methane.

2. The lower this value, the more likely the gas is to generate uncontrolled combustion or self-ignition.

**Requires the use of a second gas ramp.**

# PROPERTIES OF GAS MIXTURES

## Methane Number :




### Recommandations :

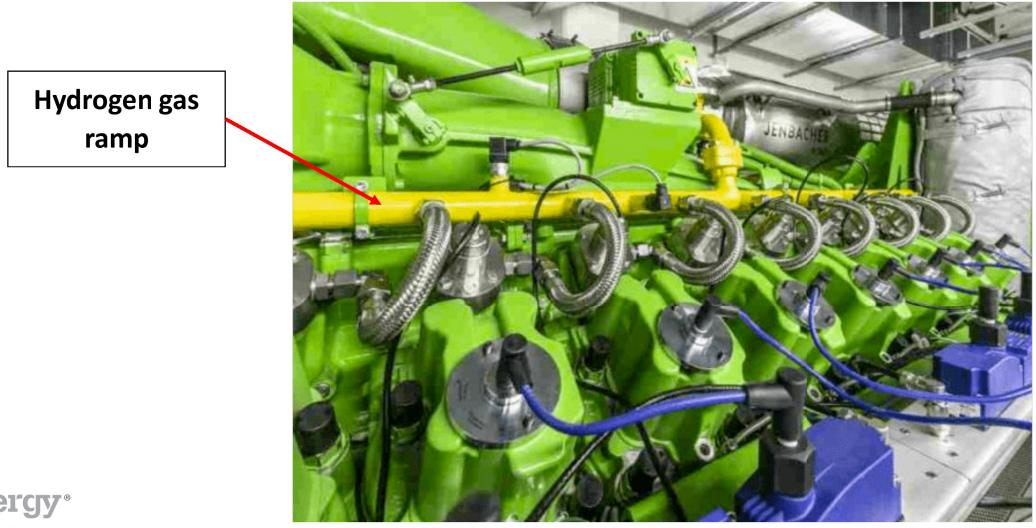
MN must not be < 70

MN variation < 10 / minute

- Above 20% hydrogen, the gas must be fed to the engine via an independent manifold, as it becomes too explosive to pass through the turbocharger

# DIRECT INJECTION INTO CYLINDERS

*Source : Jenbacher engine in Hans Werk Natur J416 - C202*



# GAS ENGINE COMPARISON

| Site | Engine | Combustible | MEP | Calorific Value | Gas flow | Electric power (best effort) |
|---|---|---|---|---|---|---|
| **COGE Kellerman** | JMS-420-GS-N.L-BE68 | **Natural Gas** | **20,17 bar** | **9,5 kWh/Nm3** | **379 Nm3/h** | ***1501 kW*** |
| **CSD Grange 3** | JMS-420-GS-LL-B21 | **Biogas** | **19 bar** | **4 kWh/Nm3** | **844 Nm3/h** | ***1414 kW*** |
| **TS moteur Hydrogène** | JMS-420-GS-S.L-E900 | **Hydrogen** | **12 bar** | **2,6 kWh/Nm3** | **780 Nm3/h** | ***889 kW*** |

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# CALCULATION HYPOTHESES

**Cost of producing H2 : 4,5 €/kg**

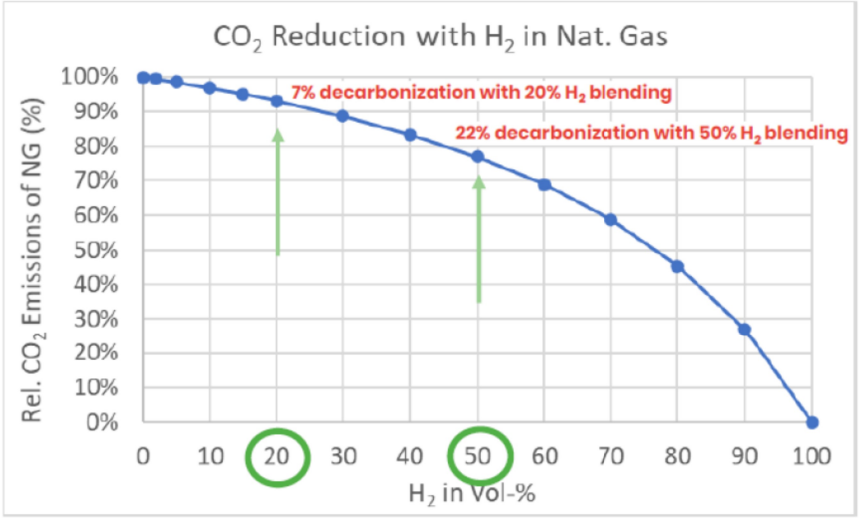
**Gas purchase costs : 40 €/MWh**

## Cost of fonctionnement :

**Operating cost doubled for hydrogen.**

# EMISSION DATA SHEET :

## All engines :

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# IN SUMMARY

## TO ASSESS :

- The energy properties of this gas are inferior to those of natural gas.

- Engines are less powerful than their natural gas equivalents (production costs twice as high).

- Hydrogen does not generate CO2 during combustion (but does generate NOx).

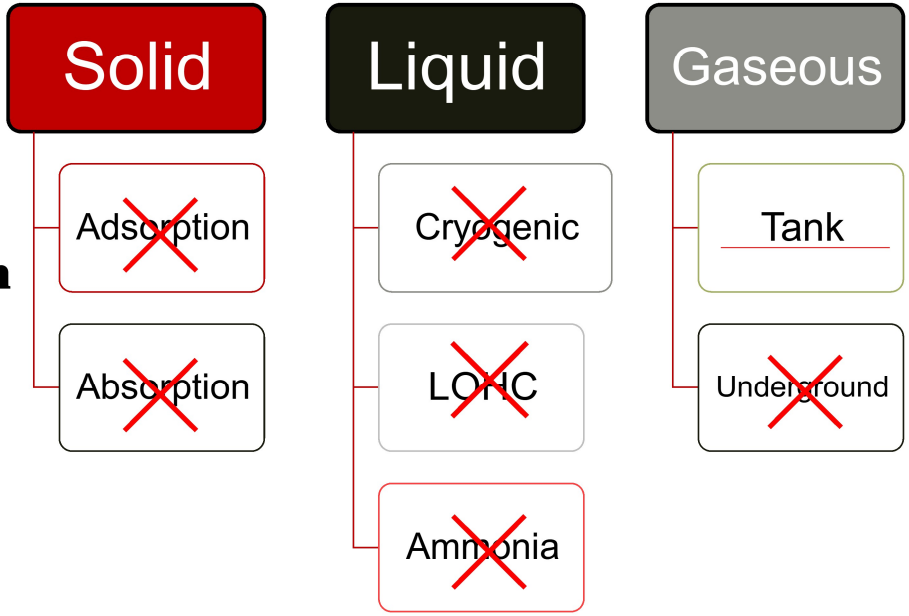
- More dangerous to operate (but the danger is manageable).

N°17

# HYDROGEN STORAGE

# III. HYDROGEN STORAGE SOLUTIONS :

**What state should hydrogen be stored in ?**

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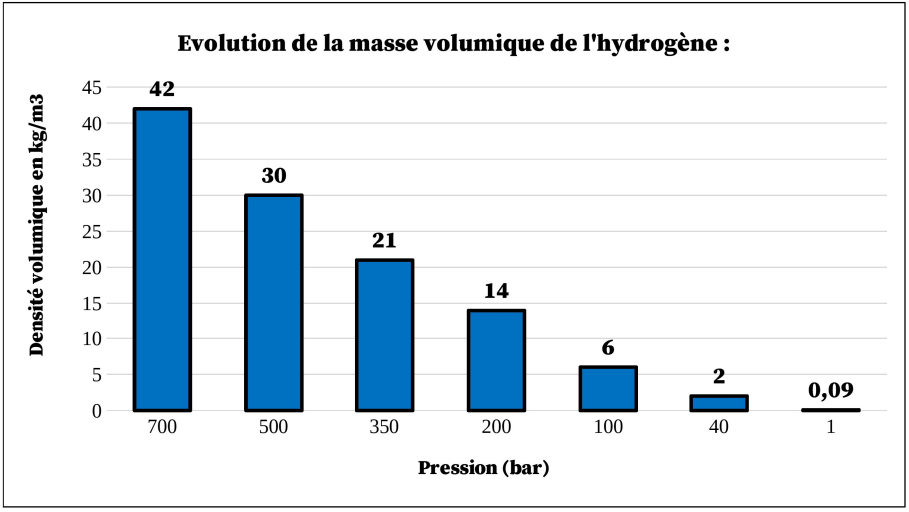
# GAS STORAGE

**Low volume density ⇨ requires hydrogen compression.**




**Mechanical compression :**

- Choice of materials ⇨ adapted to H2
- Lubrica,ts used ⇨ hydrocarbon-free
- Hydrogen quality ⇨ 98,98 %

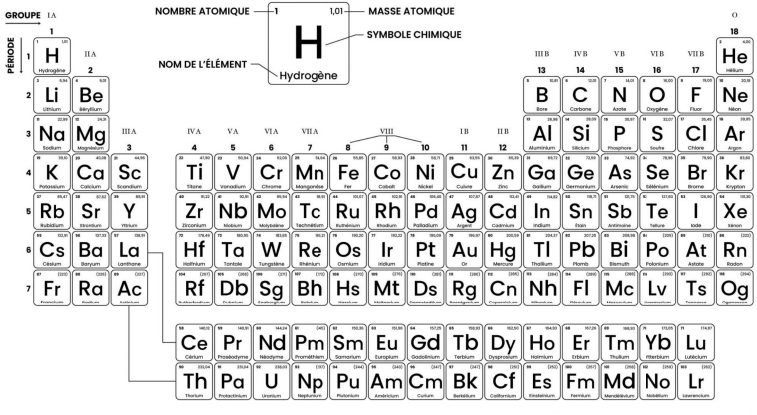
**Centrifugal compressor :**

- Unsuitable because the density of hydrogen is too low.

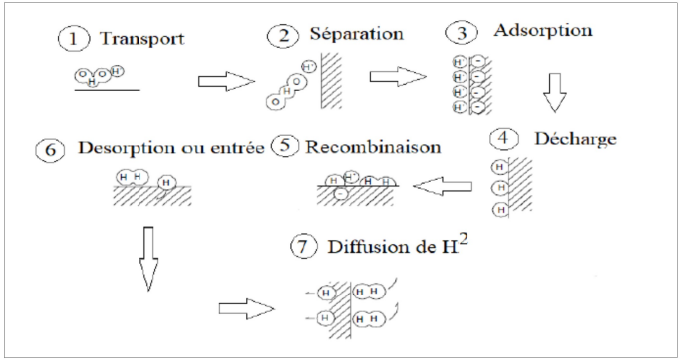
**Electrochemical compressor :**

- Low rate of flow.

# HYDROGEN EMBRITTLEMENT




## Hydrogen diffusion in steels :

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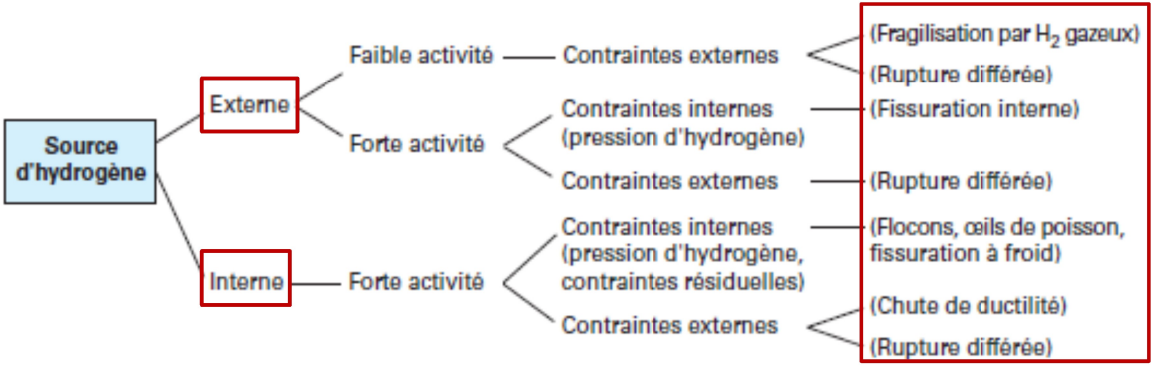
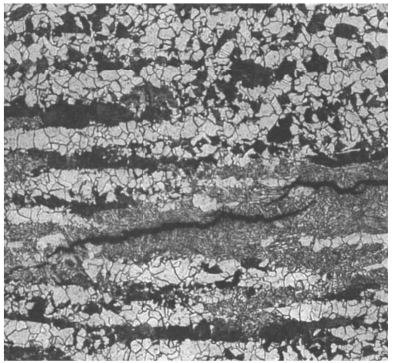
# HYDROGEN EMBRITTLEMENT

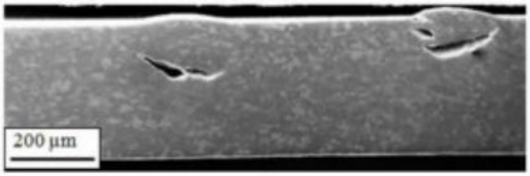


→ WEAKENING OF ATOMIC BONDS.

→ FORMATION OF METAL HYDRIDES.

→ DECREASE IN DUCTILITY.




*Source : Techniques de l'ingénieur - M175*

# CHOICE OF MATERIALS

## Austenitic stainless steel 316L :

- Higher levels of Chromium and Nickel (to improve the ductility of the steel).

- Minimum 10% nickel according to ASTM (American society for testing and materials).

- Reduce the diffusion coefficient of hydrogen in steels by modifying: the thickness of the hydrogen piping and the grain size of the steel ($cm^2/s$).

- Standard NF EN 11114 summarises the compatibility of hydrogen with materials.

- Standard NF EN 13480-2 specifies three test methods in appendix B to validate or not the choice of a steel.

# TYPES OF COMPRESSED HYDROGEN TANKS :

**Hydrogen tanks must be designed to fulfil two functions.**

↓

**Mechanical resistance to pressure and tighness.**

**Four types of tanks :**

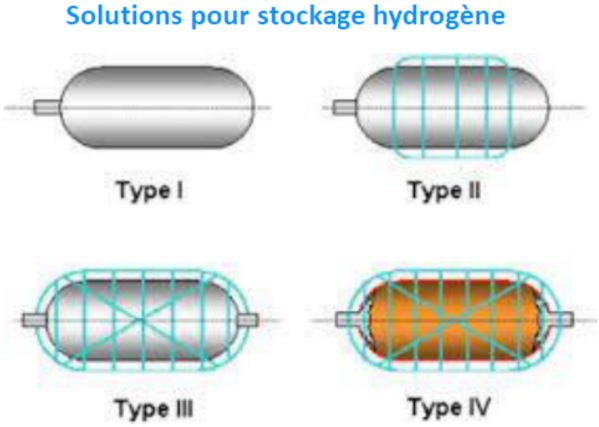
Type I: stainless steel liner.

Type II: stainless steel liner reinforced with composite winding.

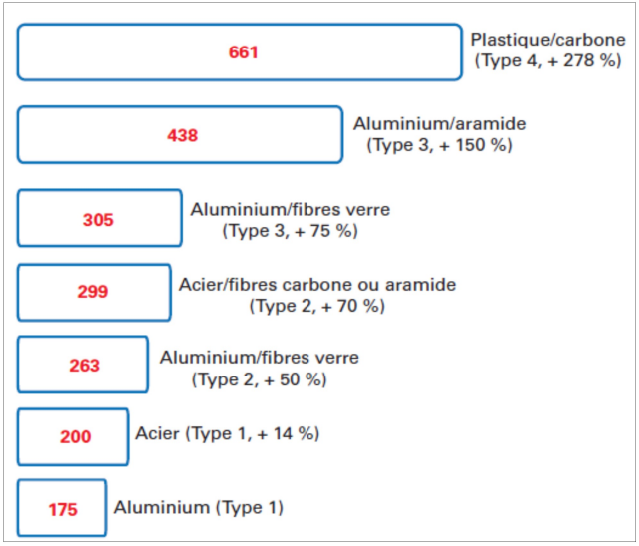
Type III: reinforced aluminium liner with composite winding.

Type IV: thermoplastic polymer liner with composite winding.

*source : France hydrogène*



# PERFORMANCE INDEX

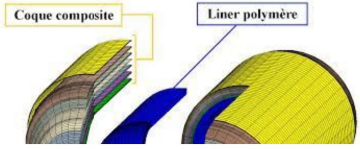



$\frac{bar \times L}{kg}$

*source : Techniques de l'ingénieur TRP1108 V1*

*Type II tank, Fibatech*

*Type IV tank, Mahytec*



# MANUFACTURING COSTS OF COMPOSITE TANKS

**Tanks prices :**

Type I at 200 bar : 380 – 450 €/kg

Type I at 300 bar : 400 – 500 €/kg

Type II and III of 300 – 500 bar : 500 - 700€/kg

Type IV of 500 – 700 bar : 600 – 1000 €/kg

**Consultations returns :**

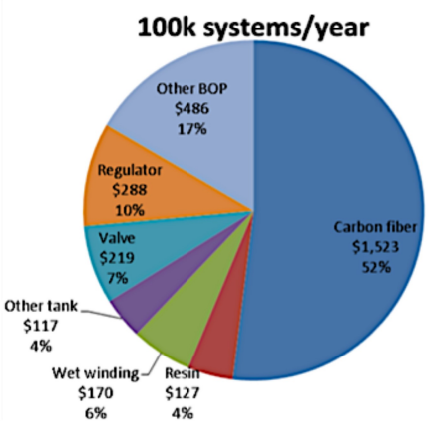
- 60 bottles/type III frame with 390 kg at 350 bar ⇨ €485,000

- 106 cylinders/type IV container with

1192 kg at 500 bar ⇨ €1,190,000

~50% of the price depends on the fibres used to design the tanks.

*cf : France hydrogène*



# TANKS CONFIGURATIONS

**Four configurations :**


Bottles

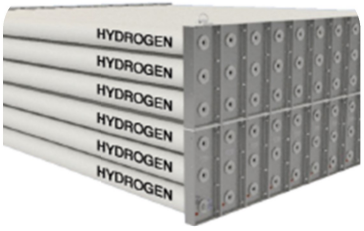
200 bar

Composite Bottles

350 – 700 bar

Tanks

40 – 100 bar




Tubes

200 – 350 bar

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# SCHÉMA DE PRINCIPE DE LA STATION DE STOCKAGE

**Hydrogen supplied by truck at 200 bar** → **Storage station** → **Gas grid** → **Generator set**

## Generator set :

- MN minimum 70
- MN variation < 10 MN / minute
- Variation in hydrogen content < 4% / minute
- Variation in calorific value < 4% / minute
- Temperature < 40°C

*Source : TS Chêne des Anglais JMS 420 GS NL B02*

| **Engine data J420** | |
|---|---|
| Maximal flow rate H2 (20%) | 76 Nm3/h |
| | 6,8 kg/h |
| **Nominal flow rate H2 (10%)** | **38 Nm3/h** |
| | **3,4 kg/h** |
| Minimal flow rate GN (80%) | 304 Nm3/h |
| Nominal flow rate GN (90%) | 342 Nm3/h |
| **Total flow rate** | **380 Nm3/h** |
| **Gas ramp pressure** | **120 - 200 mbar** |


# THANK YOU FOR YOUR ATTENTION