

Hydrogen storage

Different types								
	Process	Energy involved in the process	Storage pressure	Temperature (°C)	Volumic density	mass ratio (%)	specific energy	Energy needed for H ₂ release
compressed	Mutiple steps adiabatic compression + cooling	3.3 kWh / kg H ₂	200-350 to 800 bar	25 °C	max. 33 kg H ₂ /m ³	1,1 à 2,6 (200 bar) 11,5-13 (700-800 bar)	0.45 à 5 kWh/kg	0
Underground storage	Aquifers Salt caverns		80 – 160 bar					
liquefied	Liquid N ₂ cooling + Mutiple steps adiabatic compression	10 kWh / kg H ₂	No data	- 253 °C	71 kg H ₂ /m ³	26	14 kWh/kg	0 1 to 3 % loss per day
NaBH₄ <i>Hydrogen on demandTM</i>	NaBH ₄ + 2 H ₂ O + catalyst ⇒ NaBO ₂ + 4 H ₂	No data	No data	No data	No data	No data	No data	0
Metal hydrides	chimisorption / desorption	No data	2 to 10 bar	0-100 °C	max. 150 kg H ₂ /m ³	2	0.8 à 2.3 kWh/kg	No data
Active carbons	physisorption / desorption	No data	250 bar	25 °C	18 kg H ₂ /m ³	No data	2,2 kWh/kg	No data
Carbon nanofibres & nanotubes	physisorption / desorption	No data	125 bar	25 °C	No data	1.5	1.7 à 3 kWh/kg	No data
fullerens	chimisorption / desorption	100kJ/mol (14 kWh/kg of H ₂ ?)	27 bar	100-200 °C	No data	6 –7.7	2.5 kWh/kg	160kJ/ mol (22 kWh/kg H ₂ ?)

Hydrogen storage

Environmental impact		Economic data																					
<p>Safety</p> <p>- Explosion threshold : H₂ in air concentration not to exceed 4% in mass</p>		<p>Current costs :</p> <p>Compressed : $\cong 3 \text{ € / kWh}$; <i>Air Liquide</i> price for a B20 bottle ($\cong 4 \text{ Nm}^3$)</p> <p>Liquefied : 0,18 - 0,65 € / liter of liquid H₂ (0.08 to 0.29 € / kWh)</p> <p>A 50 l bottle (9 Nm³) costs from 35 to 70 €</p>																					
Type	Development status	<p>Metal hydrides : from 0,35 to 1 € / g of store H₂ (80 et 280 € / kWh)</p> <p>Active carbons : 2 € / kg</p> <p>Carbon nanofibres & nanotubes : from 55 to 550 € / g of nanocomposants</p> <p>Fullerens : for C₆₀ : 80 - 300 € / g (it depends on compounds purity)</p> <p>Manufacturers active on the market:</p> <p><u>Compressed:</u> Air Liquide, Linde Gas, Air Products, Praxair, Mannesman, Dynetek, Thiokol, Quantum</p> <p><u>Liquefied:</u> Air Liquide, Linde Gas, Messer Griesheim, Praxair</p> <p><u>Metal hydrides:</u> Ovonic, HERA, Millenium Cell (GfE, Hydro Quebec, Shell Hydrogen).</p> <p><u>Active carbons:</u> Erachem</p> <p><u>Carbon nanofibres & nanotubes:</u> Hyperion Catalysis International, MER Corporation</p> <p><u>Fullerens :</u> MER, SES Research</p> <p>R&D Institutes involved in the field:</p> <p>CNRS, CEA, CENERG, Rice University...</p>																					
<i>compressed</i>	available																						
<i>liquefied</i>	available																						
<i>Metal hydrides</i>	development / available																						
<i>Active carbons</i>	development																						
<i>Carbon nanofibres & nanotubes</i>	development																						
<i>Fullerens</i>	development																						
<p>Application example : Takamatsu hydrogen station</p> <table border="1" style="width: 100%; border-collapse: collapse; margin: 10px 0;"> <thead> <tr> <th colspan="2" style="text-align: center;">Metal Hydrides</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">alloy</td> <td style="text-align: center;">(TiZr)(CrFeMn)₂</td> </tr> <tr> <td style="text-align: center;">Absorption capacity</td> <td style="text-align: center;">1 % in mass</td> </tr> <tr> <td style="text-align: center;">Absorbed volume</td> <td style="text-align: center;">2 x 30 Nm³</td> </tr> <tr> <td style="text-align: center;">Absorption pressure/speed/temperature</td> <td style="text-align: center;">5 bar / 30 Nm³/h / 28 °C</td> </tr> <tr> <td style="text-align: center;">Release pressure/speed/temperature</td> <td style="text-align: center;">9 bar / 150 Nm³/h / 80 °C</td> </tr> <tr> <th colspan="2" style="text-align: center;">Compressed gas storage</th> </tr> <tr> <td style="text-align: center;">Volume</td> <td style="text-align: center;">30 Nm³</td> </tr> <tr> <td style="text-align: center;">Pressure</td> <td style="text-align: center;">400 bar</td> </tr> <tr> <td style="text-align: center;">Weight</td> <td style="text-align: center;">5200 kg</td> </tr> </tbody> </table> <p style="text-align: center;">R&D Perspectives</p> <p>- To decrease material costs and to develop manufacturing processes</p> <p>- To increase storage material performances (energy density, storage/release efficiency...etc)</p>		Metal Hydrides		alloy	(TiZr)(CrFeMn) ₂	Absorption capacity	1 % in mass	Absorbed volume	2 x 30 Nm ³	Absorption pressure/speed/temperature	5 bar / 30 Nm ³ /h / 28 °C	Release pressure/speed/temperature	9 bar / 150 Nm ³ /h / 80 °C	Compressed gas storage		Volume	30 Nm ³	Pressure	400 bar	Weight	5200 kg		
Metal Hydrides																							
alloy	(TiZr)(CrFeMn) ₂																						
Absorption capacity	1 % in mass																						
Absorbed volume	2 x 30 Nm ³																						
Absorption pressure/speed/temperature	5 bar / 30 Nm ³ /h / 28 °C																						
Release pressure/speed/temperature	9 bar / 150 Nm ³ /h / 80 °C																						
Compressed gas storage																							
Volume	30 Nm ³																						
Pressure	400 bar																						
Weight	5200 kg																						