DAS HYCARE-PROJEKT – EINSATZMÖGLICHKEITEN VON METALLHYDRIDEN IN DER ENERGIESPEICHERUNG

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HOST Speichertechnologien und Wasserstoff
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1/3
Coastal and Climate Research

Total budget
~ 100 Mio. €

Employees
950

2/3
Materials Research
MATERIALS FOR HYDROGEN TECHNOLOGIES

H₂ production by direct water splitting, reversible storage from the gas phase in metal hydrides

Photocatalytic Films for H₂ Production

Hierarchically porous and nanoimprinting structured photoelectrodes

Materials and Systems for H₂ Storage

Optimised Hydrides with Low Mass & Volume

Electrodes prepared by cold-gas spraying

high performance tank design, scale-up and system integration

0.1g 1g 5g 250g 8 kg
## COMPARISON OF STORAGE ALTERNATIVES

### Tank weight and volume for 500 km range (6 kg H₂ = 200 kWh)

<table>
<thead>
<tr>
<th>Temperature of operation, max. pressure</th>
<th>Efficiency</th>
<th>Storage Material</th>
<th>Weight</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40 – 65°C, 900 bar</td>
<td>-10%</td>
<td>H₂-gas 700 bar</td>
<td>133 kg</td>
<td>260 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Composite shell</td>
<td>= 1,5 kWh/kg</td>
<td>= 0,77 kWh/l</td>
</tr>
<tr>
<td>-253°C</td>
<td>-20 – 30%</td>
<td>liquid H₂</td>
<td>34 kg</td>
<td>167 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 5,9 kWh/kg</td>
<td>= 1,2 kWh/l</td>
</tr>
<tr>
<td>350 - 450°C, 50 bar</td>
<td>-20%</td>
<td>LiBH₄ / MgH₂</td>
<td>130 kg</td>
<td>92,9 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1,54 kWh/kg</td>
<td>= 2,15 kWh/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>eff. = 4,5 wt.% eff</td>
<td></td>
</tr>
<tr>
<td>300 - 350°C, 10 bar</td>
<td>-30%</td>
<td>MgH₂</td>
<td>175 kg</td>
<td>73 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120 - 160°C, 100 bar</td>
<td>-20%</td>
<td>NaAlH₄</td>
<td>285 kg</td>
<td>167 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 0,7 kWh/kg</td>
<td>= 1,2 kWh/l</td>
</tr>
<tr>
<td>RT - 70°C, 30 bar</td>
<td>-10%</td>
<td>FeTiH₂</td>
<td>435 kg</td>
<td>80 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 0,46 kWh/kg</td>
<td>= 2,5 kWh/l</td>
</tr>
<tr>
<td>RT/350°C, pressureless</td>
<td>-30%</td>
<td>LOHC</td>
<td>130 kg</td>
<td>130 l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>= 1,5 kWh/kg</td>
<td>= 1,5 kWh/l</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>eff. 200 kg</td>
<td>= 1 kWh/kg</td>
</tr>
</tbody>
</table>

### Metal Hydrides
- Temperature of operation: -40 to 63°C, 900 bar
- Liquid: -253°C, 900 bar
- Metal hydrides: 120 to 160°C, 100 bar, RT - 70°C, 30 bar

### Other Materials
- H₂-gas
- Composite shell
- LiBH₄ / MgH₂
- MgH₂
- NaAlH₄
- FeTiH₂
- LOHC
METAL HYDRIDES

Principle of operation of a metal hydride store

Pressure / temperature equilibrium of the hydrogenation reaction

- **Loading regime**
  - Isothermal loading / unloading by varying the tank pressure
    - High pressure ⇒ loading
    - Low pressure ⇒ release
  - Real H2 loading / release scheme

- **Unloading regime**
  - Isobaric loading / unloading by varying the tank temperature
    - Low temperature ⇒ loading
    - High temperature ⇒ release

Pressure / temperature equilibrium of the hydrogenation reaction
HEAT OF REACTION

High energy efficiency ⇔ heat management

- Process heat (e.g., electrolysis)
- Heat storage
- Internal combustion / FC

- Either
- Or

Hydride formation

$\text{H}_2$ release

- $\text{H}_2$

- Application specific heat management necessary!!!
THE HYCARE PROJECT

2019-2021, 2 Mio. €
FCH JU GA 826352
THE GOALS

- High quantity of stored hydrogen $\geq 50$ kg
- Low pressure $< 50$ bar, low temperature RT to $< 100^\circ$C
- Low foot print, comparable to liquid hydrogen storage ($\geq 60$ kg H$_2$/m$^3$)
- Hydrogen storage coupled with thermal energy storage $\Rightarrow$ Improved energy efficiency
- Integration with an electrolyser (EL) and a fuel cell (FC) $\Rightarrow$ Demonstration in real application
- Improved safety
- Techno-economical evaluation, Life Cycle Analysis (LCA)
- Exploitation of possible industrial applications
- Dissemination of results at various levels
- Engagement of local people and institution in the demonstration site
THE CONCEPT

Flow of HYDROGEN, HEAT and ELECTRICITY during hydrogen production (a) and use (b)
H$_2$-CARRIER AND PCM

- P-T relationship of the hydrogen carrier during the absorption A and desorption D steps
- E-T relationship for a phase change material during the absorption and desorption steps
THE INTEGRATION

Thermal management during the hydrogen absorption step from the electrolyzer

Thermal management during the hydrogen desorption step to the fuel cell
METAL HYDRIDES

Operation of a metal hydride compressor

Pressure / temperature equilibrium of the hydrogenation reaction

Loading regime

- Heating up of metal hydride
  - ⇒ output pressure increases
  - @high temperature
  - ⇒ hydrogen release

unloading regime

Loading at low temperature and low pressure

Heating / cooling

Temperature

Pressure / temperature equilibrium of the hydrogenation reaction

Output

Input
METAL HYDRIDE COMPRESSORS
Compression without moving parts

200 bar MH compressor for refuelling of fork lifters
HYSA Systems, SA, 2015

200 bar, 10 Nm³/h, smaller prototype integrated in Lillestrom refuelling station, NO
Hystorsys, 2013
HYDROGEN PURIFICATION

Advantages:
- Just driven by gas pressure (high enough for MH loading!)
- No extra heating
- Selective reaction of the MH with $H_2 \Rightarrow$ extraction from gas mixtures

Challenges:
- Poisoning of the MH (O, CO, ...)
- Optimal reactor design for required hydrogen flow
- Cost of the metal hydride
- Critical raw materials

Basic reactor design (from [1])

Reduction of water level from 3000 ppmv to 190 ppmv (99.98%) @ 100 sccm $H_2$ flow (from [1])

Ref. 4 (1987) in [2]: ammonia process exhaust (50.4 vol.% $H_2$, 25.5 vol.% $N_2$, 9.9 vol.% Ar, 12.4% $CH_4$, 1.8% $NH_3$) $\Rightarrow$ 99.9% $H_2$

Ref. 6 (1994) in [2]: $NH_3$ decomposition gas (50% $H_2$) with 12 Nm$^3$/h and 24 Nm$^3$/h $\Rightarrow$ 99.9999% $H_2$

SUMMARY

Metal hydrides for hydrogen storage, compression and purification

- Lower volume than high pressure gas stores
- Direct loading with H2 gas at pressures of 10 – 100 bar (depending on MH)
- No separate reactor for H₂ extraction
- No off-board regeneration necessary
- Low loading pressure ⇒ lower or no effort for compression
- Use as extra mass with energy storage function ⇒ forklifter, ships, mine locomotives
- Thermodynamic properties ⇒
  - Thermal compressors (supply from waste heat, minimised maintenance)
  - Hydrogen purification (practically no extra heat necessary, no compression)
- Challenge: materials cost – at present no large scale commercial production (except MH for NiMH batteries)
- Challenge: heat management simple to complex (depending on application and MH)
FOR PEOPLE AND THEIR FUTURE ENVIRONMENT

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VIELEN DANK!

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