Using Metal Hydride to Store Hydrogen

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Fuel Cells 2003 - Third Annual BCC Conference
Stamford, CT
March 31 - April 1 2003

Outline

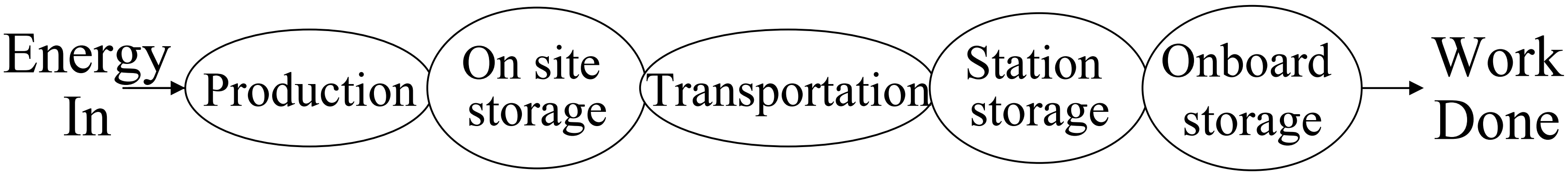
- Challenges of hydrogen storage & its importance to the fuel cycle
- Comparing present storage methods from energy point of view
- Challenges of using metal hydrides for hydrogen storage
- Metal hydride vessel design
- Demonstrated applications: city bus & utility vehicle
- Summary

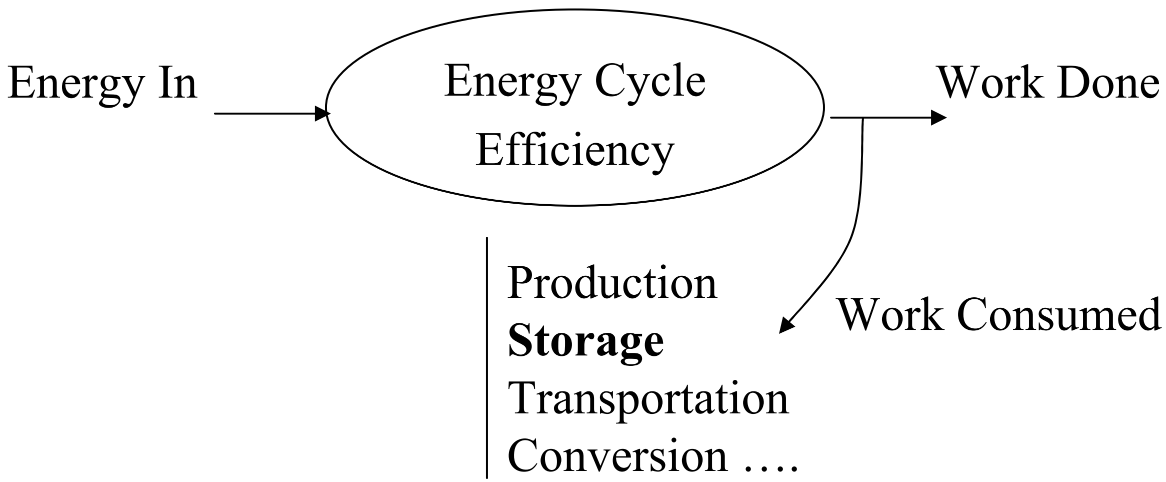
Challenges of Hydrogen Storage

- Low energy content (by volume) compared to hydrocarbon fuel

	H_2	CH_4	C_8H_{18}	$H_2 : C_8H_{18}$
Heat of combustion MJ/kg	120	50	45	2.7:1
Heat of combustion MJ/liter at ambient	0.011	0.036	31.4	0.00035:1
Heat of combustion MJ/liter at liquid state	8.5 (-253 ^{o}C)	20.7 (-161 ^{o}C)	31.4	0.27:1
Density at ambient g/liter	0.09	0.072	703	1:10,000
Density at liquid kg/liter	0.071	0.415	0.703	0.1:1

Importance of Hydrogen storage



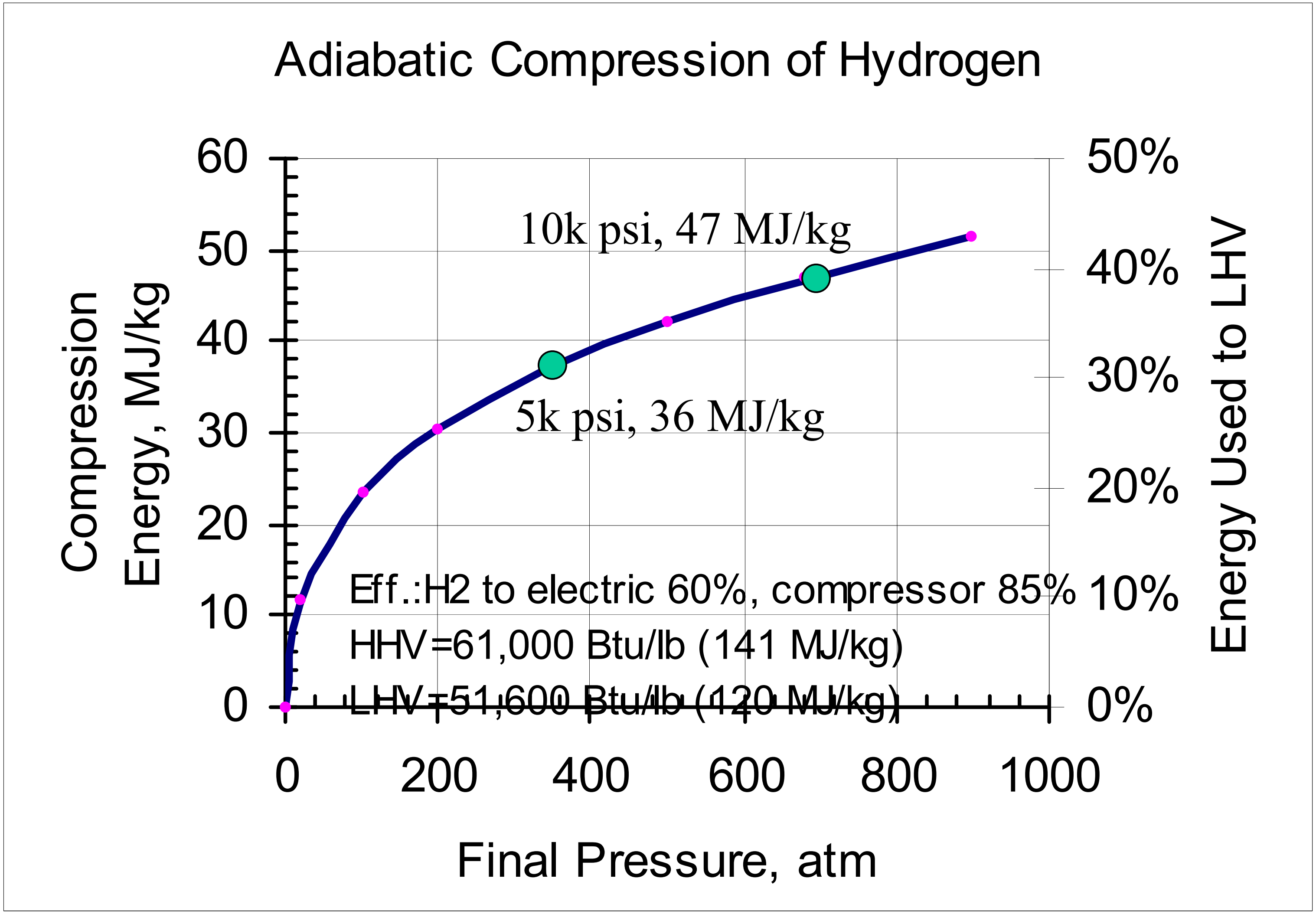


$$\text{Efficiency} = \frac{\text{Energy In - Consumed}}{\text{Energy In}} \qquad (\text{Must} > 0)$$

Present Storage Options

- Compressed hydrogen (5,000; 10,000 psi)
- Liquid hydrogen (-253 ^oC)
- Adsorbed hydrogen (MH, others)

Energy to Compress H_2



SRS savannah river site

Energy to Liquefy H_2

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Theoretical:

Gas from 25 C to 20 K:	2.94 MJ/kg
Gas to liquid @ 20 K:	0.45 MJ/kg
Total:	3.4 MJ/Kg (MJ=1,055 Btu)

Actual:

Refrigeration efficiency:	7.2 %*
Energy for refrigeration:	0.45/7.2% = 47 MJ/kg
Vaporization & warm up:	3.4 MJ/Kg
Total:	**50.4** MJ/kg (42% of LHV)

* Reversed Carnot cycle: T1/(T2-T1) = 20/(298-20) = 7.2%

Energy to Operate Metal Hydride

$$M + 1/2\ H_2 \underset{}{\overset{T,\ P}{\rightleftharpoons}} MH + \text{Energy}$$

Compress H_2 to 20 atm: 12 MJ/kg

Heat of absorption = ~ 7 kcal/mol (14.6 MJ/kg)

Refrigeration for 10 ^{o}C COP = 5

Cooling energy: 14.6/5 = 3 MJ/kg

Energy for desorption: 0 (use waste heat)

Total: **15** MJ/kg (12.5% LHV)

Comparing Storage Options

	Gas Hydrogen (340-atm)	Liquid Hydrogen	Metal Hydride
Energy Required MJ/kg	36	50	15
% LHV	30	42	13
Conditions	very high P	very low T	moderate P & T
Hydrogen density, kg/liter	0.03	0.07	~0.06
Hydrogen wt%	100	100	~1.5

Using MH to Store Hydrogen

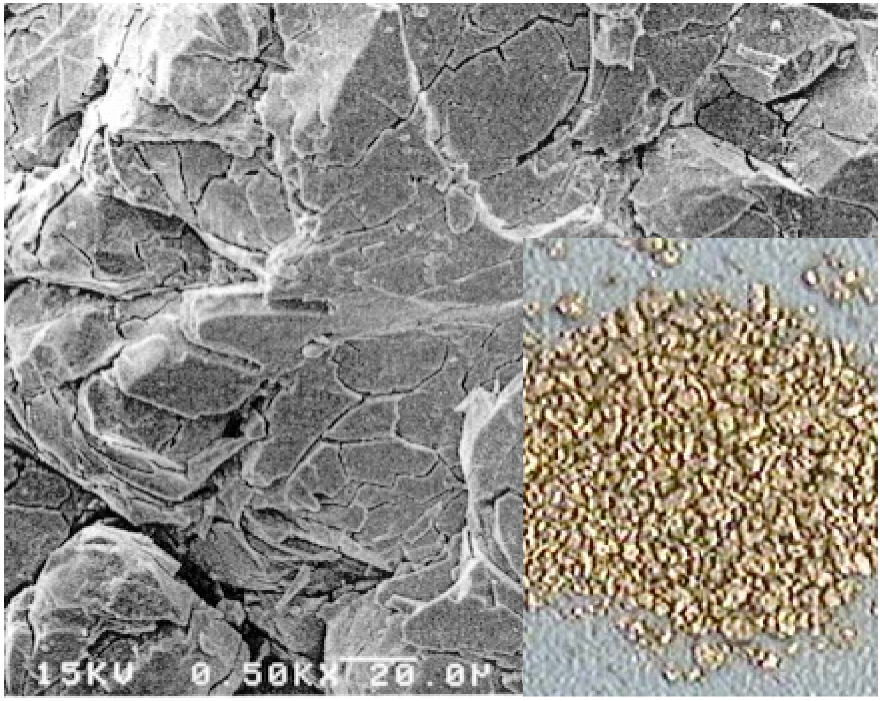
- Advantages:
  - Low operation energy
  - High density without high pressure & low temp
- Disadvantages:
  - Heavy (low wt% hydrogen)
  - Sensitivity to impurities
- R&D Needed:
  - Lighter material (higher wt% hydrogen)
  - Resistance to impurities

Challenges of Using MH

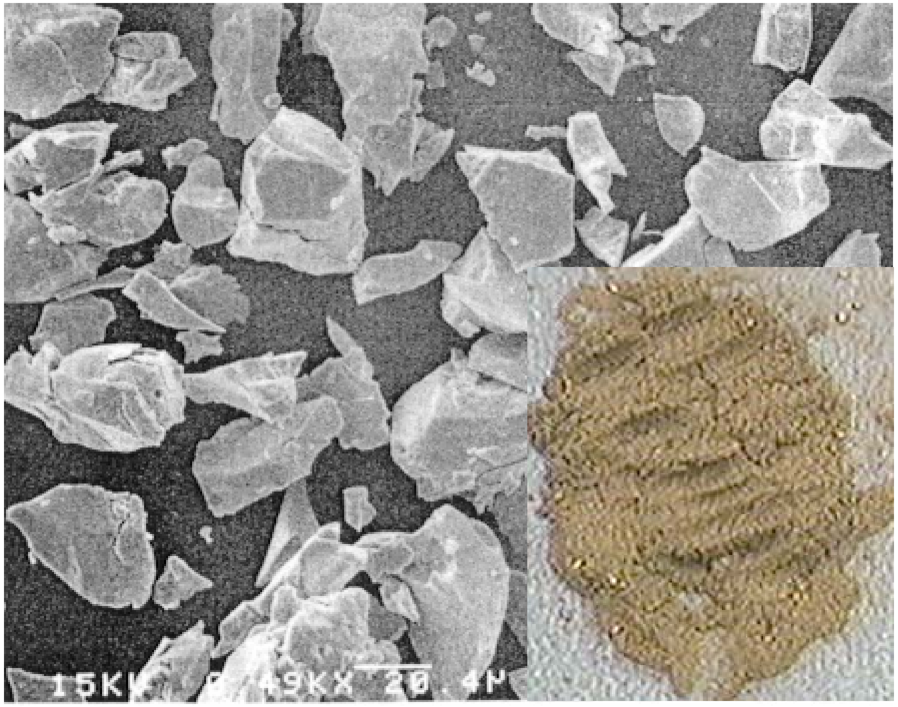
- Fines confinement
- Expansion & Contraction
- Hydrogen density - gravimetric & volumetric
- Heat transfer

Fines Confinement

- Filter of proper pore size and area must be used. (10 µ, 5 cm^2/kg H_2)

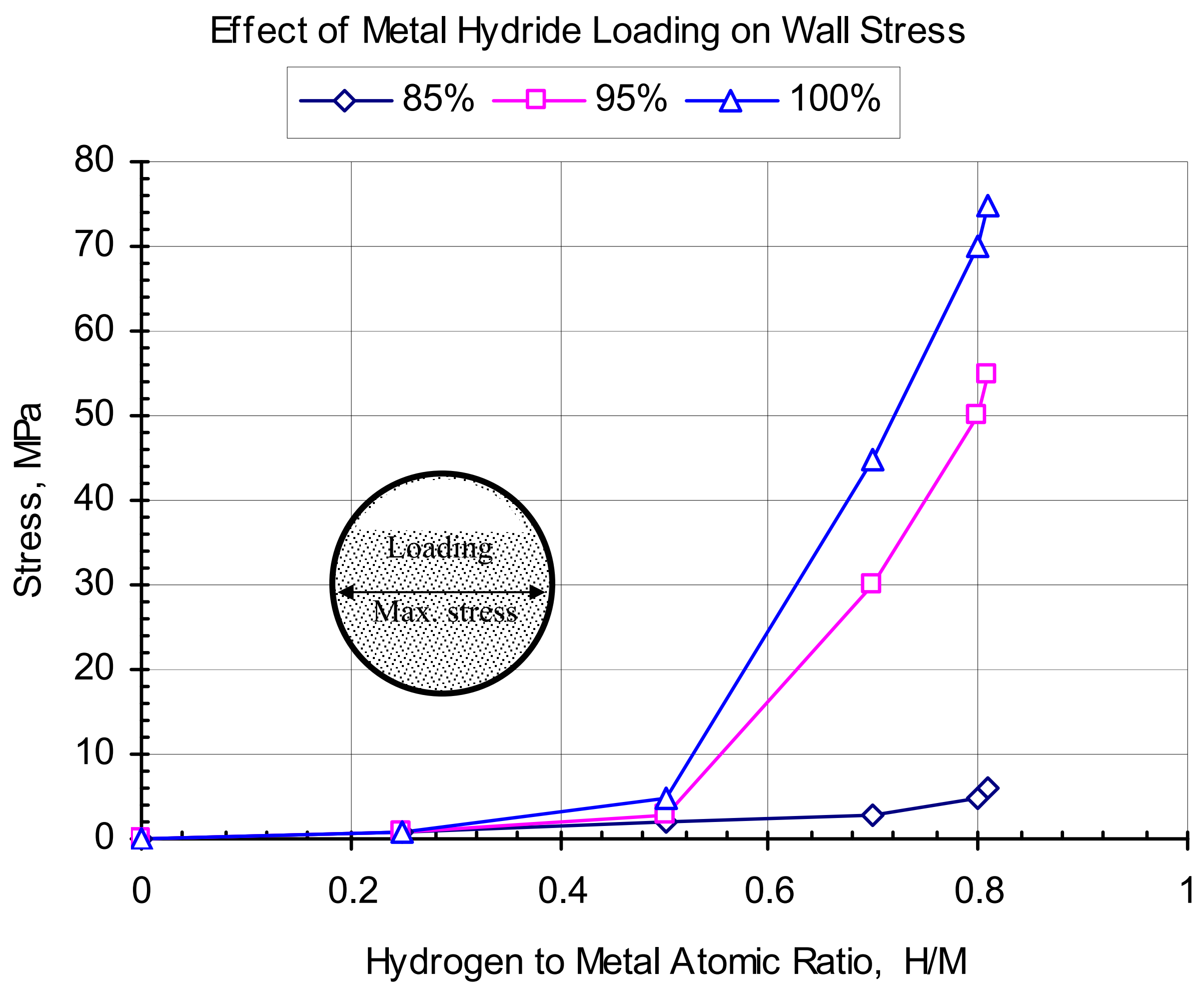


mm size particle after
1 absorption



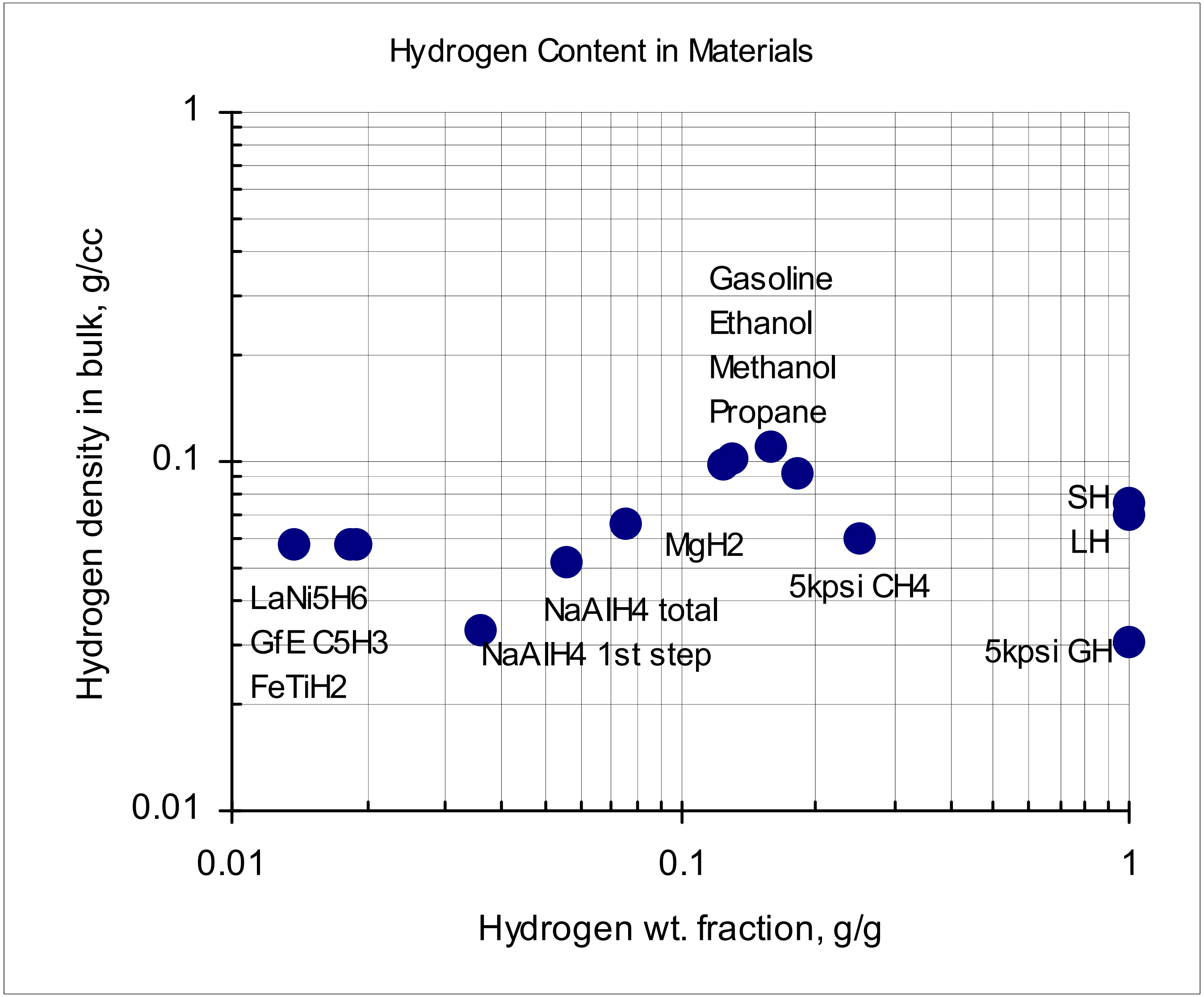
After 10 absorptions
particles size ~10 micron

Expansion/Contraction Stress on Container Wall

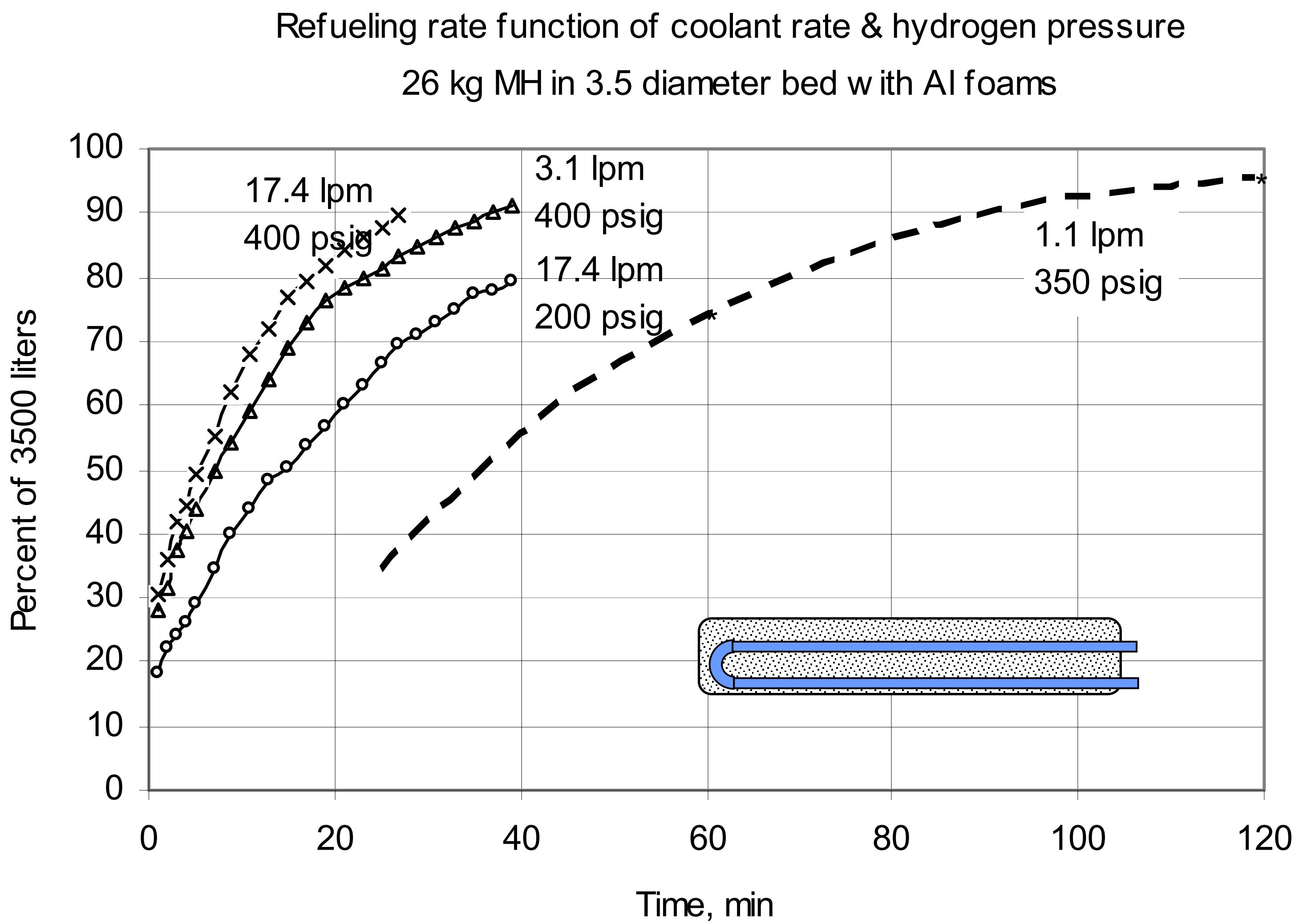


Reference:Mckillip et al, Fusion Technology, vol.21, March 1992, p1011.

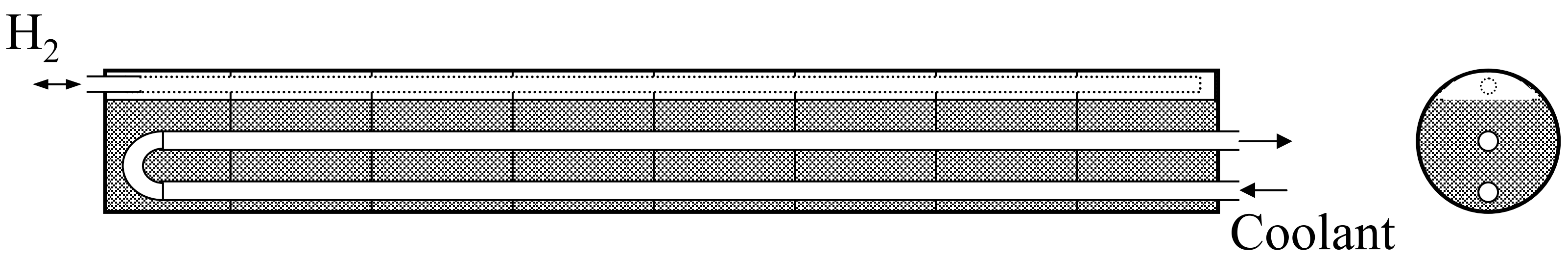
Gravimetric and Volumetric Densities

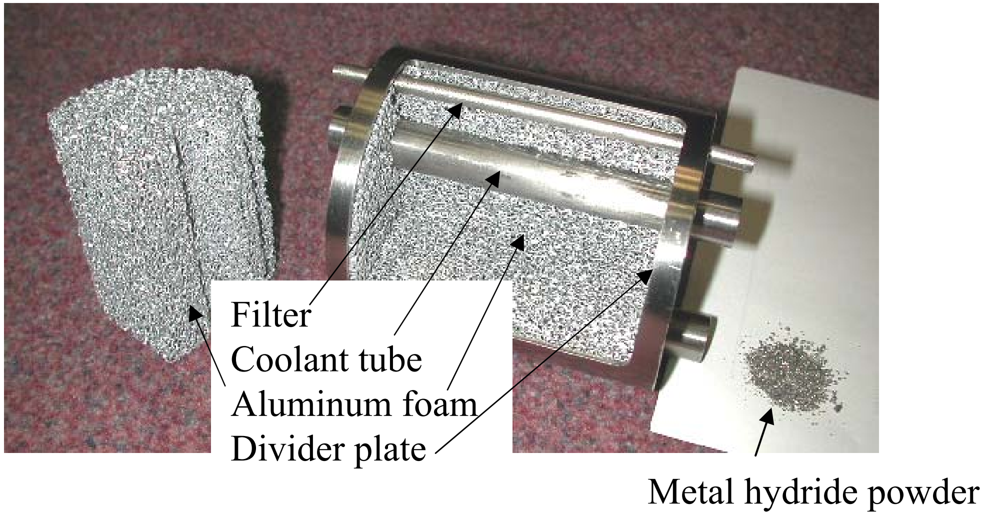


Heat Transfer



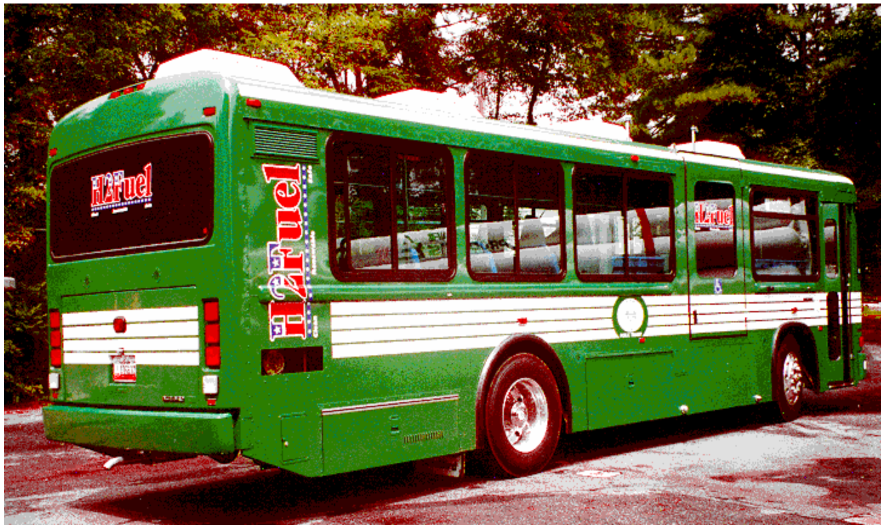
Design of MH Storage Vessel



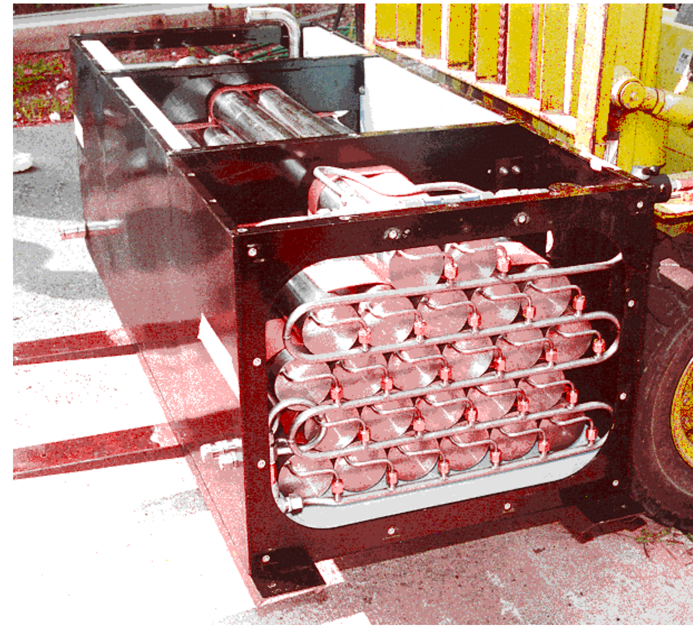


US patent 6,015,041
EP 0 891 294 B1

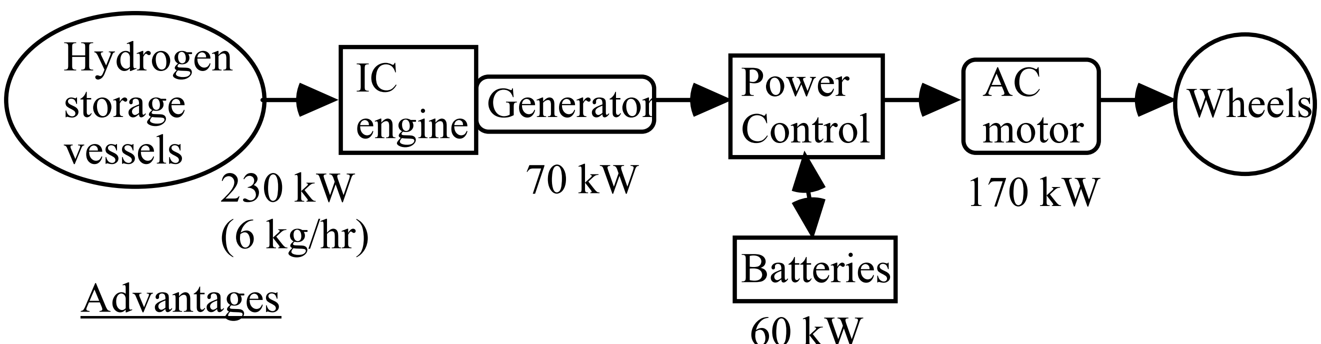
Demonstration of Storage Vessel



City transit bus with hydrogen powered IC-generator hybrid (33-ft, 27 passenger)



Half of 15-kg hydrogen



Advantages

- IC engine at high efficiency
- Ultra low emission

Metal Hydrides Demonstrated

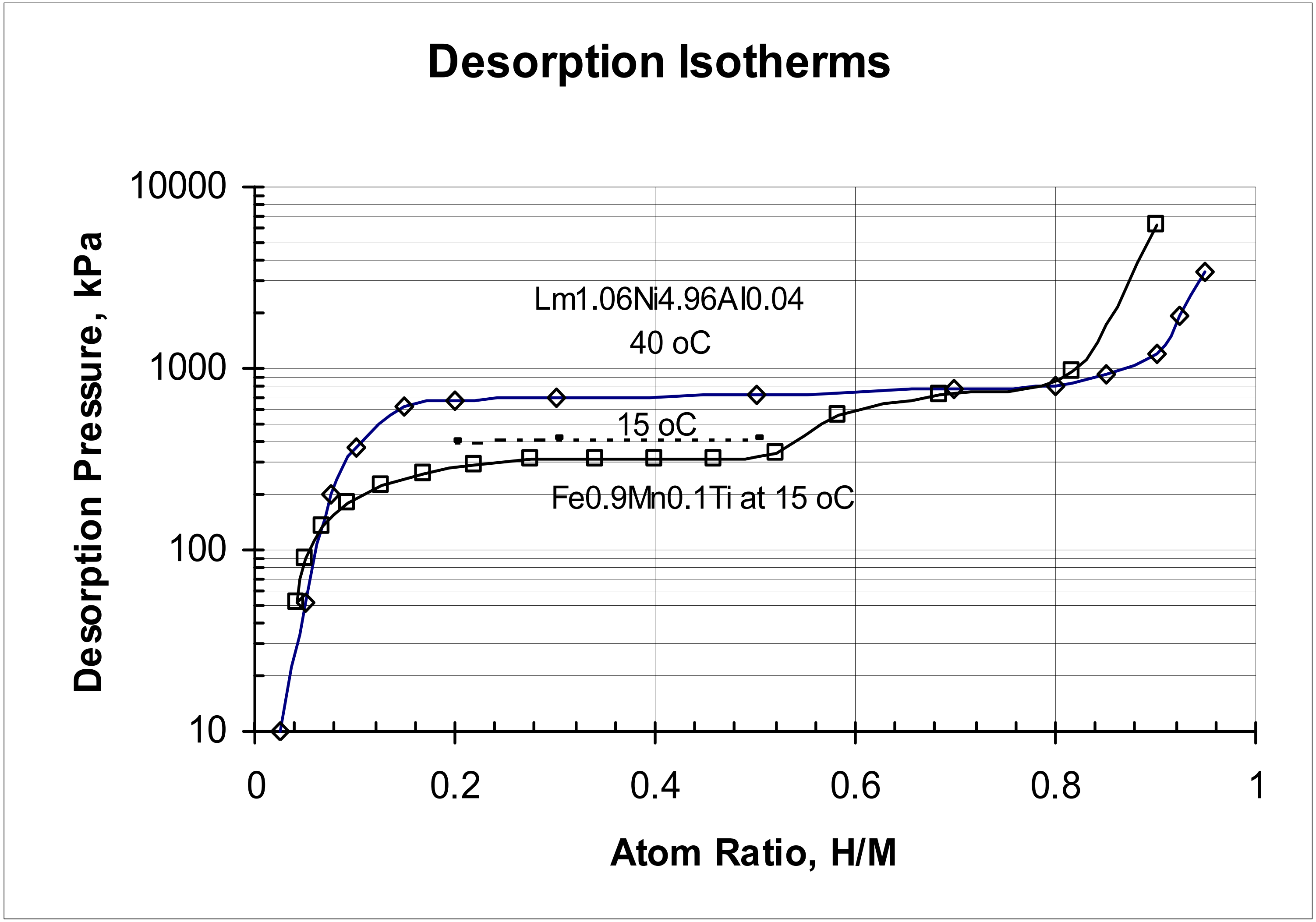


Figure 4. Typical desorption isotherms of $Lm_{1.06}Ni_{4.96}Al_{0.04}$ and $Fe_{0.9}Mn_{0.1}Ti$ (data from producers)

H_2 Fuel Cell Utility Vehicle

Metal Hydride H_2 Fuel Cell Power System

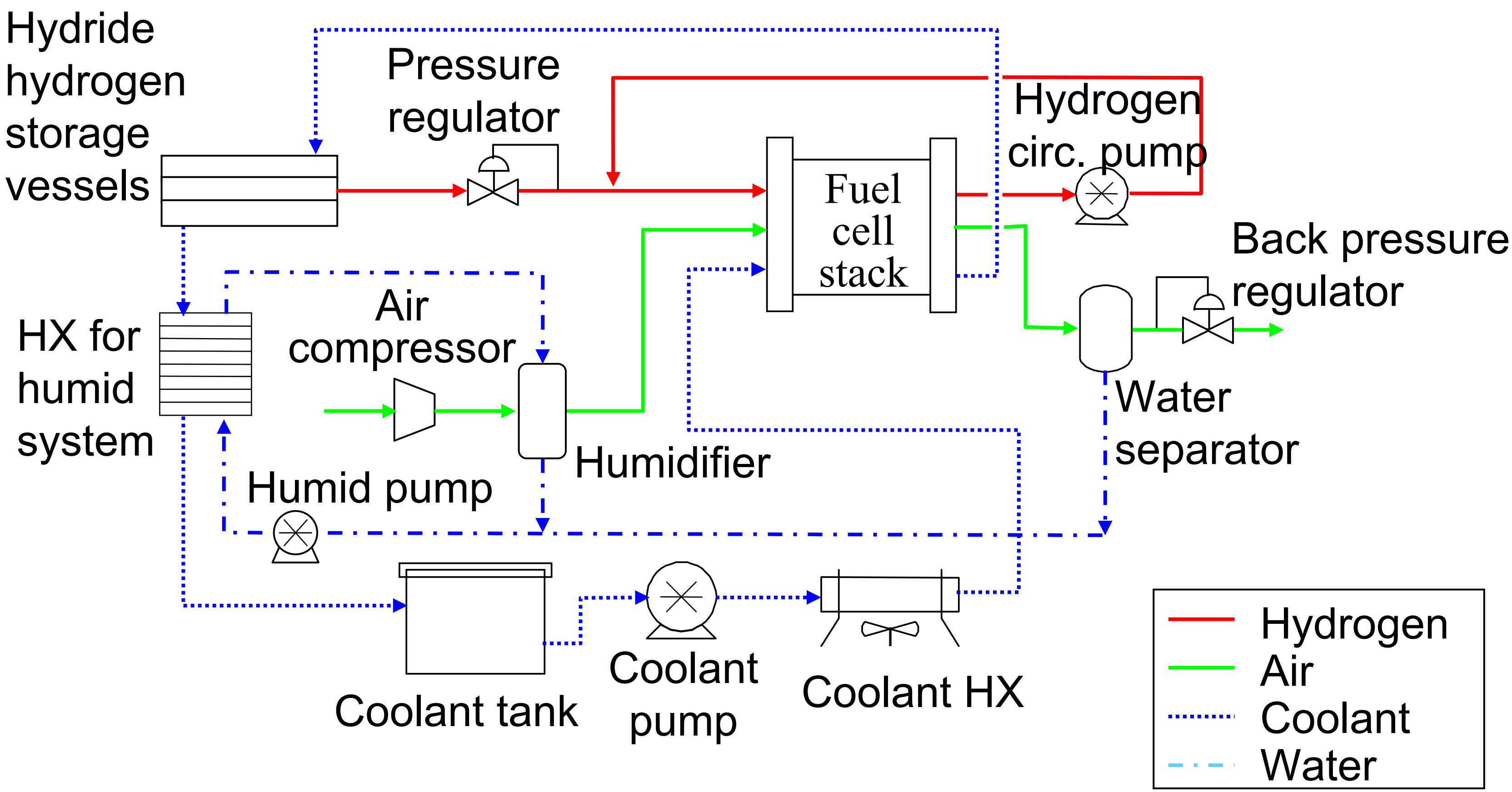


Figure 2. The power system of Gator 2.

H_2 Fuel Cell System Demonstrated

Table 2. Specifications of Hydrogen Fuel Cell Gator™ Utility Vehicle

Vehicle chassis mfr./type	Deere & Co. / Gator™ Utility Vehicle
Fuel cell type	NG2000™ 60 cells
Fuel cell operating pressure	150 kPa (122 to 308 kPa)
Fuel cell operation temperature	60 °C
Hydrogen / air flow rates	1.5x / 2.5x stoichiometric
Fuel cell power @ 163 kPa	8.3 kW at 38 V
Hydride material	$Fe_{0.9}Mn_{0.1}Ti$
Storage system weight	244 kg
Hydrogen storage capacity	2 kg
Hydrogen discharge temp./ pressure @ 50% loading	50 °C / 756 kPa
Refueling pressure / time	2170 kPa / 60 minutes
Vehicle weight	~ 900 kg
Operating range	7 hours, or 80 km @ 11.5 km/hr avg.
Maximum cruising speed	19 km/hr

Summery

- Present hydrogen storage methods are feasible but not practical for a hydrogen economy
- Metal hydrides though heavy do have advantages and may find niche applications
- Lighter metal hydrides (solid absorbents) are needed
- SRTC metal hydride vessel technology is applicable to both stationary and mobile applications
- Hydrogen economy requires a better storage method that is to be discovered.