"Innovative Metal Hydride Compressor (MHC) for Hydrogen Compression to Pressure of more than 300bar"

by

Prof. Chris Christodoulou

International Conference on Deregulated Electricity Market Issues in South-Eastern Europe (DEMSEE2018), 20-21 September 2018, Nicosia, Cyprus

Scientific Contributors

FREDERICK UNIVERSITY

Dr. Chris Christodoulou, Dr. George Karagiorgis

Hystore Technologies Ltd.

Demetrios Hadjipetrou, Marios Odysseos
Constantinos Deligiannis

NCSR "Demokritos"

Vasilis Analytis, George Tzamalis, Filippo Peru

Deutsches Zentrum für Luft-und Raumfahrt , DLR

Marion Senholdt

Acknowledgements to:

"ATLAS-MHC" FP7-PEOPLE-2013-IAPP/612292 (2014-2018)
"ALTAS-H2" FP7-PEOPLE-2009-IAPP/251562 (2010-2014)

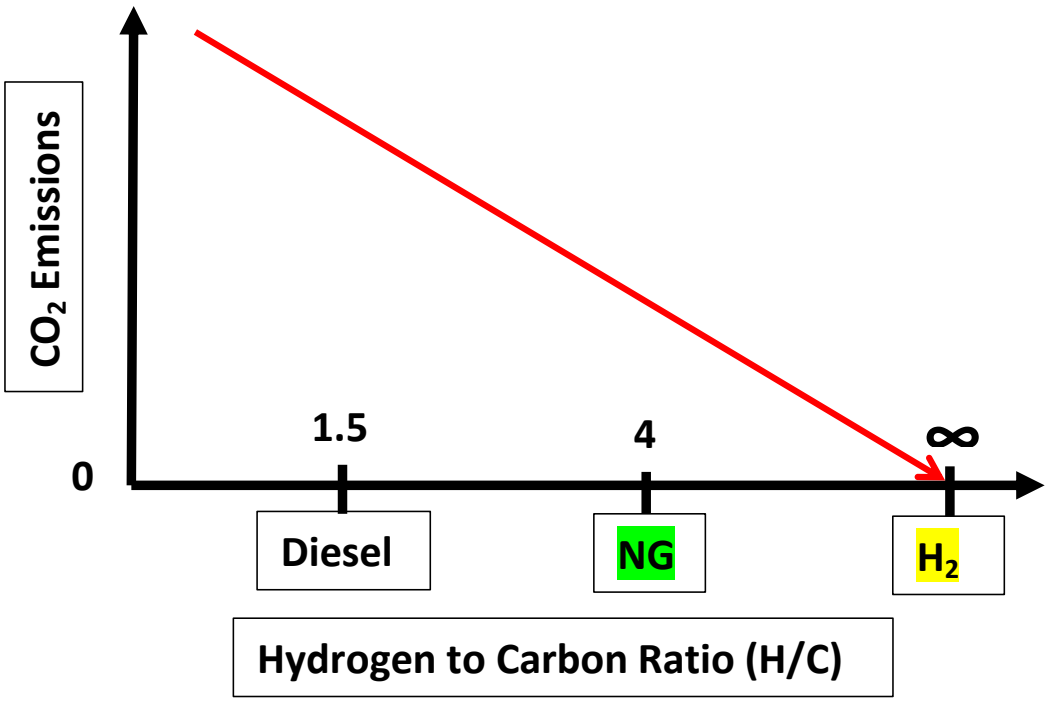
OVERVIEW

1. **Global Warnings**
2. **RES & Hydrogen**
   - Why Renewable Energy Sources (RES)?
   - Why to use Hydrogen (H_2)?
3. **Hydrogen Applications**
   - H_2/Fuel Cell Electricity generation
   - Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)
4. **Our vision for Cyprus**
   - RES&H2 in conjunction with Public Transportation
5. **Hydrogen Storage Technologies**
   - Liquefied Hydrogen
   - Metal Hydrides
   - **Compressed Hydrogen Gas (CHG)**
6. **Conclusions**

1. Global Warnings

Did everybody hear about:

- Extreme Climatic Changes
- Global Temperature increase
- Global Warming
- Melting of ice in the poles
- Low-Carbon footprint
- Low-Carbon energy



- Natural Gas (NG) use for electricity generation
- Moving form the "Oil Economy" towards the "Hydrogen Economy"

2. RES & Hydrogen (H_2)

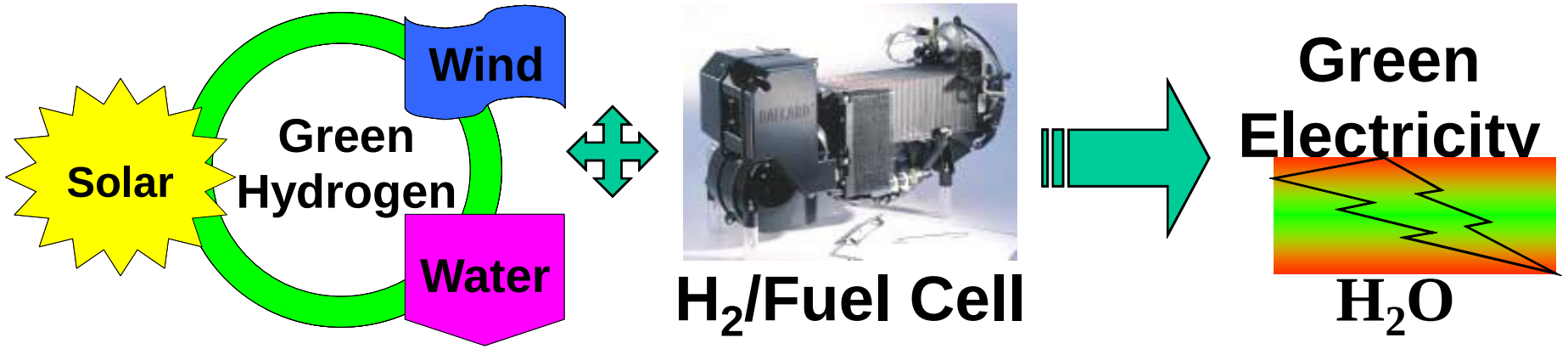
Why Renewable Energy Sources (RES)

- We are running out of fossil fuels
- For a cleaner environment
- For sustainability

Why to use Hydrogen (H_2)?

- It can be produced by RES anywhere by water-electrolysis ($H_2O \rightarrow H_2 + \frac{1}{2}O_2$)
- It can be used as a fuel in Transportation and Electricity generation (Gas Turbines, H_2/Fuel Cells)
- It is the cleanest and only carbon-less fuel producing only harmless water $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$
- It can be stored!!!!

3. Hydrogen Applications
H_2/Fuel Cell Electricity generation



H_2/ICE
Gas Turbine

Distributed electricity generation with the use of H_2/Fuel Cells, with zero CO_2 emissions (TEXNO/0603/03)

1 kW H_2/Fuel Cell

Grid-Connected 10kW H_2/Fuel Cell

"ATLAS-MHC" FP7-PEOPLE-2013-IAPP/612292 (2014-2018)

3. RES & H_2 Applications

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

Hydrogen Fuel Cell Electric Vehicles (Cars and Buses)

Comparison between Conventional and Hydrogen Fuel Cell Electric Buses

For a 100 km distance						
	Fuel Consumption		Fuel Price (€)		Total Fuel Cost (€)	Fuel Cost per km (€/km)
Conventional Diesel Bus	50.5	liters Diesel	1.37	€/liter Diesel	69	**0.69**
H_2/FC Electric Bus	11.3	kgH_2	3.28	€/kgH_2	37	**0.37**
	Electricity Cost		0.06	€/kWh		
	H_2 Production		4.5	kWh/Nm^3H_2		

4. Our vision for Cyprus

- Installation of >30% RES (PV, Wind, Solar Thermal)
- Controlling Electricity Supply & Demand by:
  - Electricity consumption by on-demand Hydrogen Production through Water-Electrolysis (Power to Gas) and Storage (Compressed Hydrogen Gas, CHG) in Hydrogen Filling Stations, or Pump-Hydro
  - H_2 Storage (CHG) in NG Pipelines (more renewable NG, Hythane)
  - Consumption of CHG as a fuel for H_2/FC Buses of Public Transportation
  - Electricity generation using H_2/Fuel Cells or Gas Turbines (more renewable NG)

The Envisioned System in Cyprus for the Contribution of RES in "Green" Transportation, towards "Hydrogen Economy"

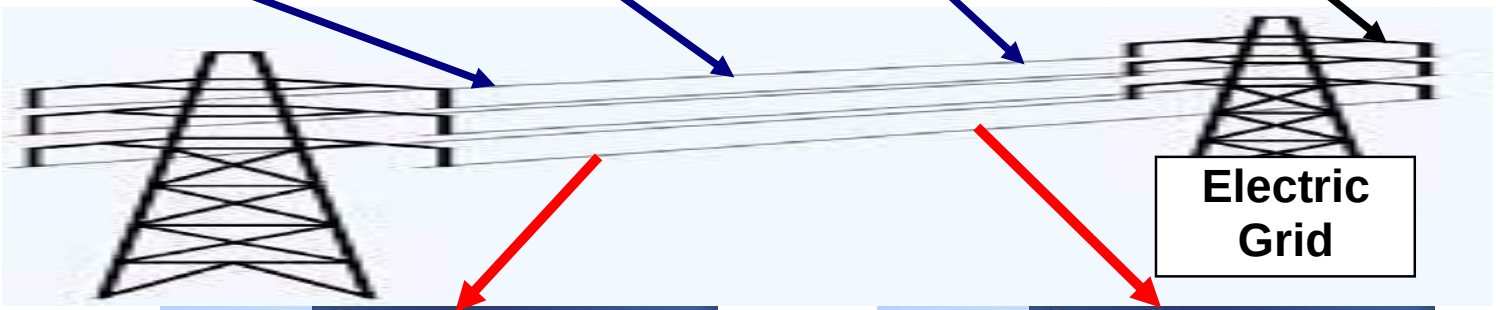
Renewable Energy Sources (RES)

Solar Thermal

PV Parks

Wind Parks

Power Station



Electric Grid

"Green" Hydrogen Production form RES and Hydrogen Filling Stations for H_2/FC, H_2ICE Buses

Therefore, Electricity can be stored in the form of Hydrogen which can be used for Power generation (Gas Turbines, H_2/Fuel Cells, Hythane etc)

5. Hydrogen Storage Technologies

- Liquefied Hydrogen
- Metal Hydrides
- Compressed Hydrogen Gas (CHG)

5. Hydrogen Storage Technologies

➢ Compressed Hydrogen Gas (CHG)

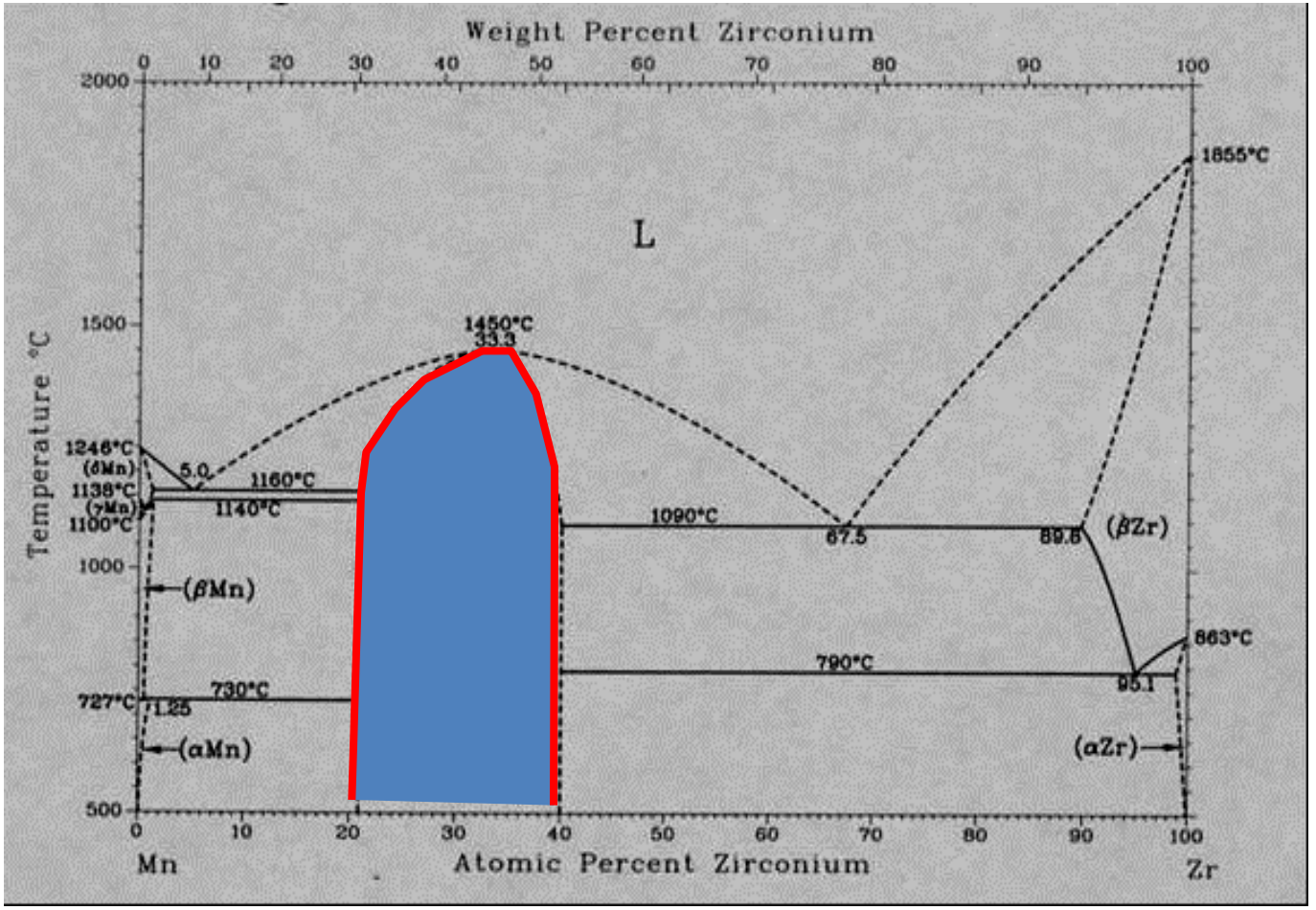
5. Hydrogen Storage Technologies

Compressed Hydrogen Gas (CHG) for **Hydrogen Filling Stations**

- Conventional Compressors
- Metal Hydride Compressors (MHC)
  - Metal Hydrides inside Metal Tanks

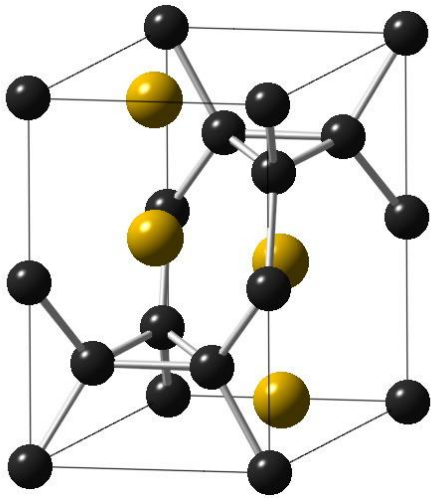
Hydrogen Storage Materials
Metal Hydrides
using
AB_5H_6-type
AB_2H_3-type
Crystal structures containing Hydrogen atoms in their Interstices

$ZrMn_2$-Phase Diagram

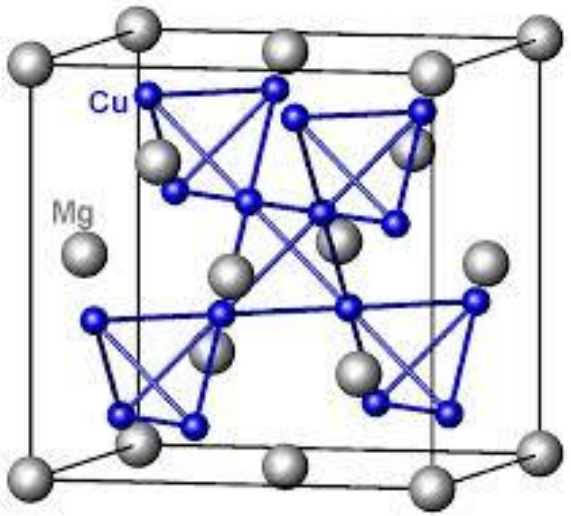


AB_2-based Metal Hydrides
A=Ti, Zr, Hf, B=Fe, Mn, Cr, Ni, V

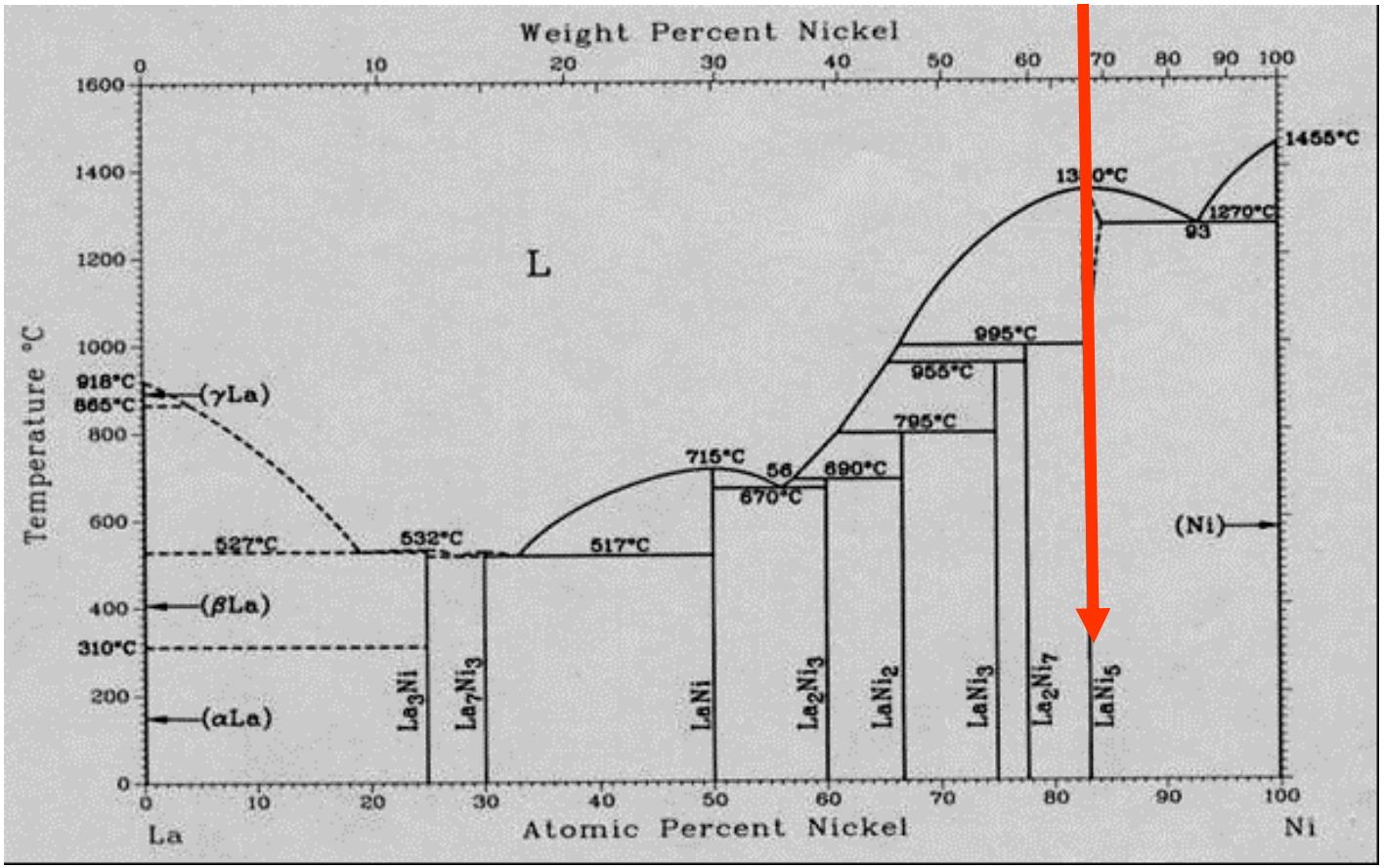
$MgZn_2$-type
C14
$P6_3mmc$



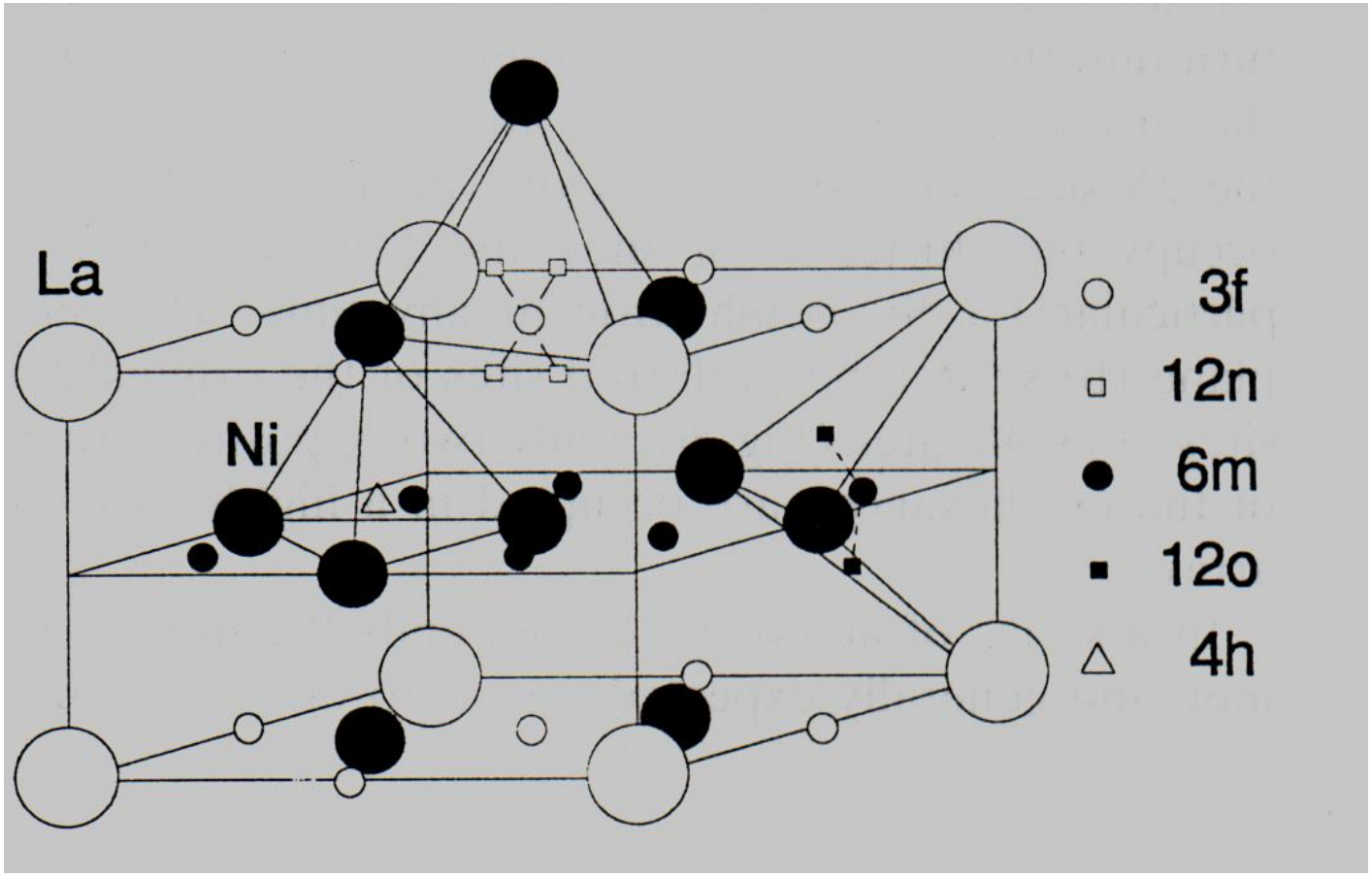
$MgCu_2$-type
C15
Fd3m



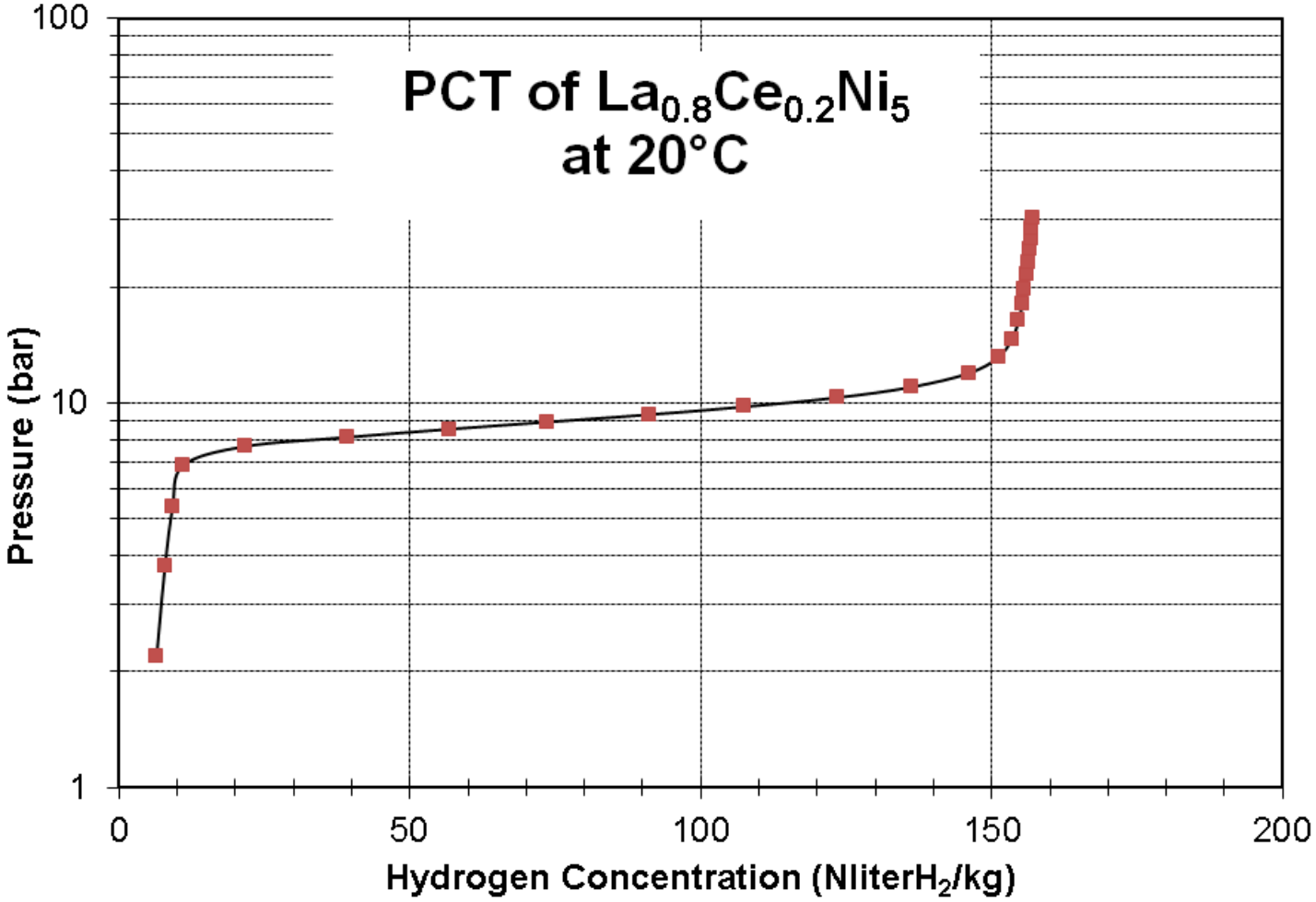
$LaNi_5$-Phase Diagram



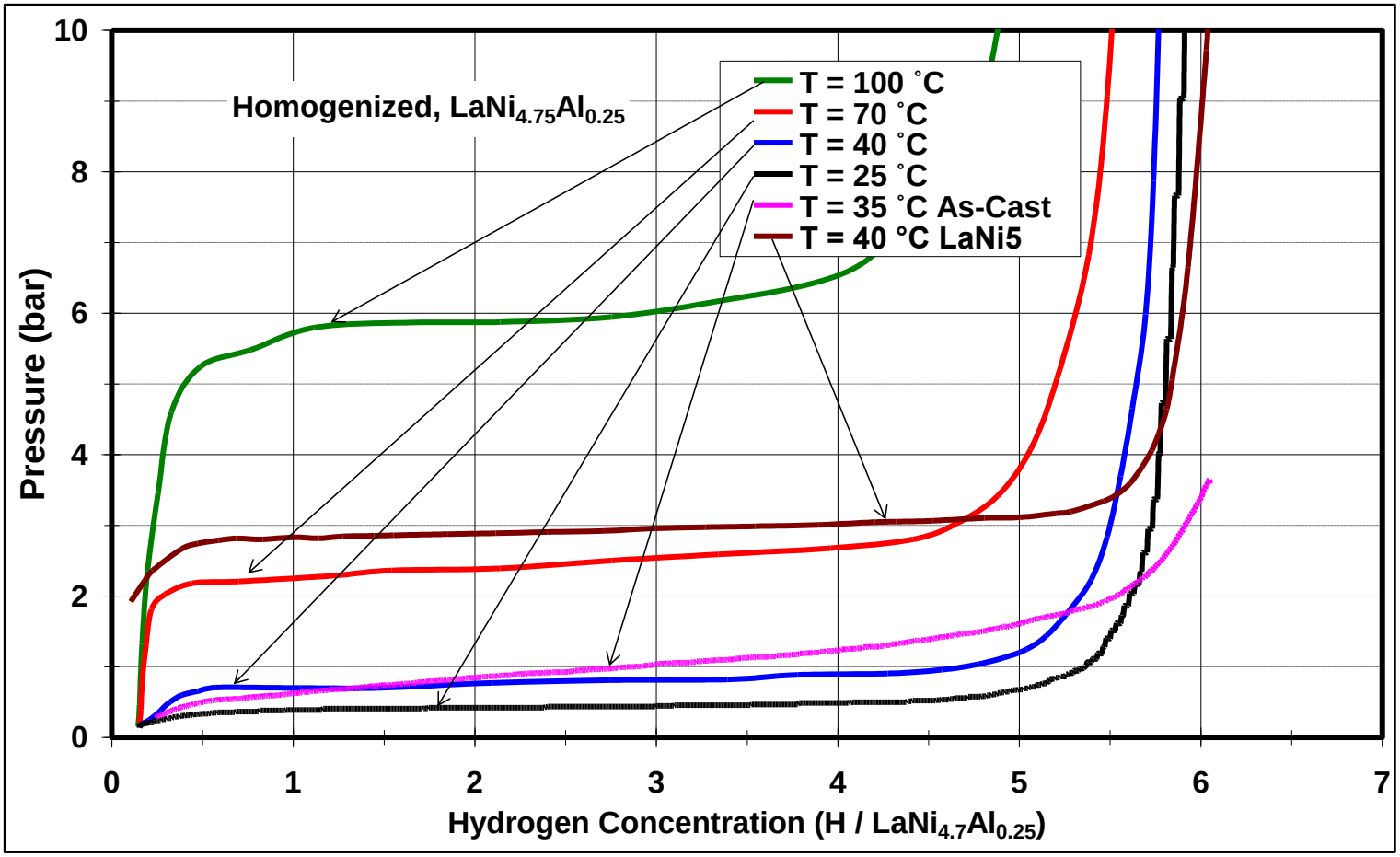
$LaNi_5$-based Metal Hydrides
$CaCu_5$-structure



Metal Hydride Materials: H_2 Storage



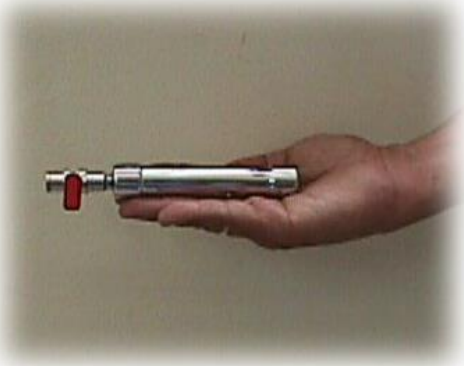
$LaNi_{4.7}Al_{0.3}$


Homogenized, LaNi4.75Al0.25
T = 100 ˚C
T = 70 ˚C
T = 40 ˚C
T = 25 ˚C
T = 35 ˚C As-Cast
T = 40 °C LaNi5
Pressure (bar)
Hydrogen Concentration (H / LaNi4.7Al0.25)
0
2
4
6
8
10
0
1
2
3
4
5
6
7

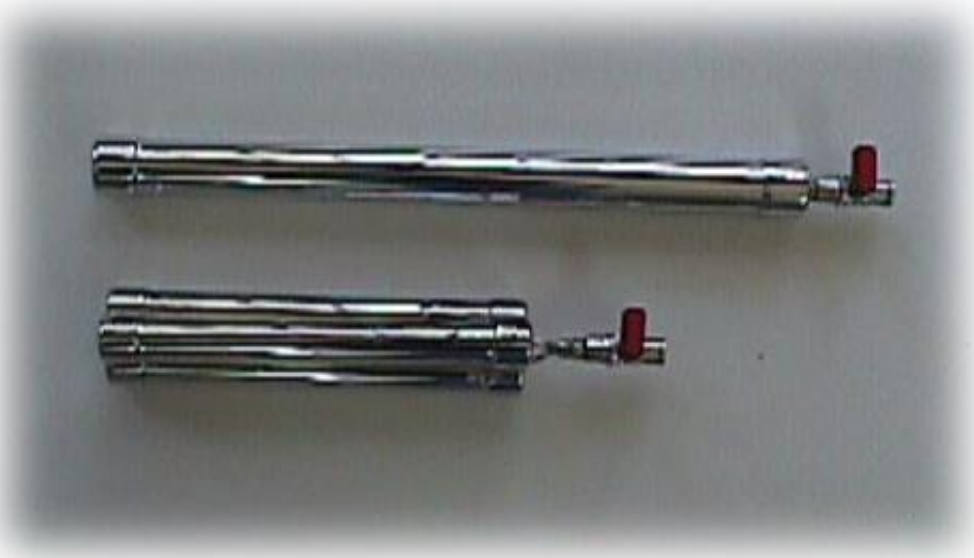
Metal Hydride Tanks (MHT) Designs/Products

Air-cooled MHT

20 NlitersH_2



Air-cooled MHT



100 NlitersH_2

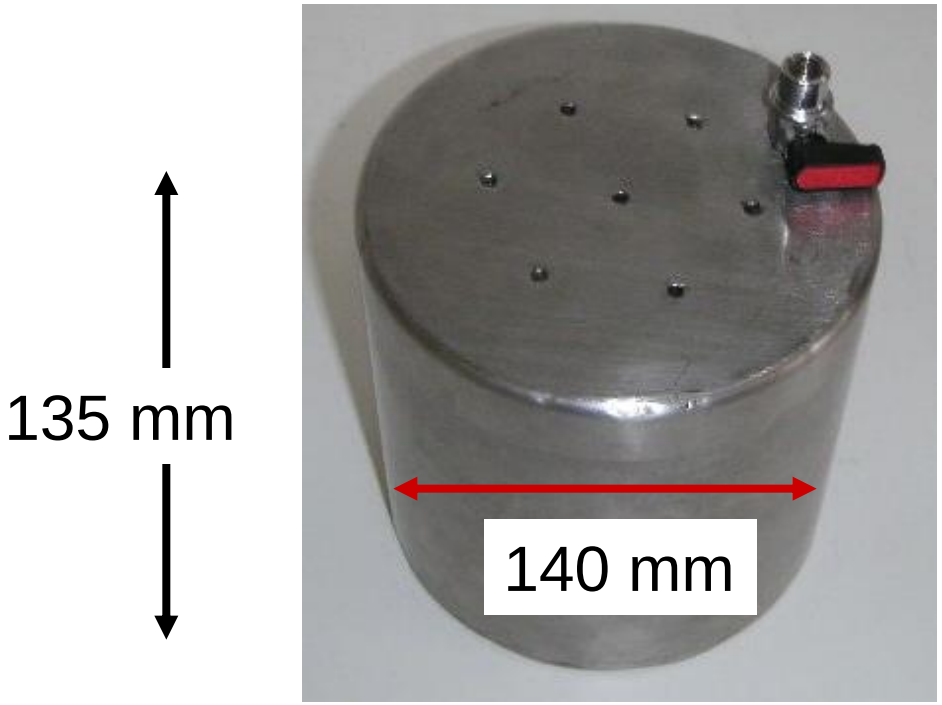
Air-cooled MHT

15 cm

100, 50 NlitersH_2

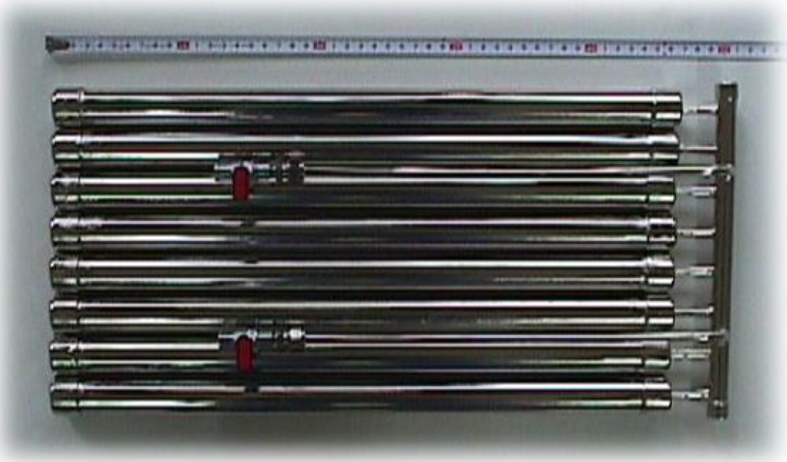
150 NlitersH_2

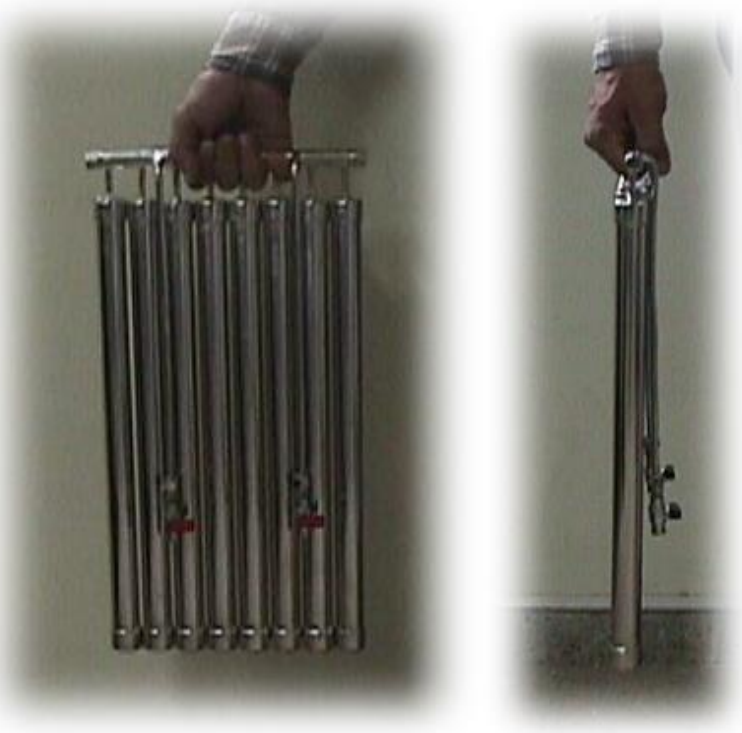
Air-cooled MHT



1110 NlitersH_2

Air-cooled MHT



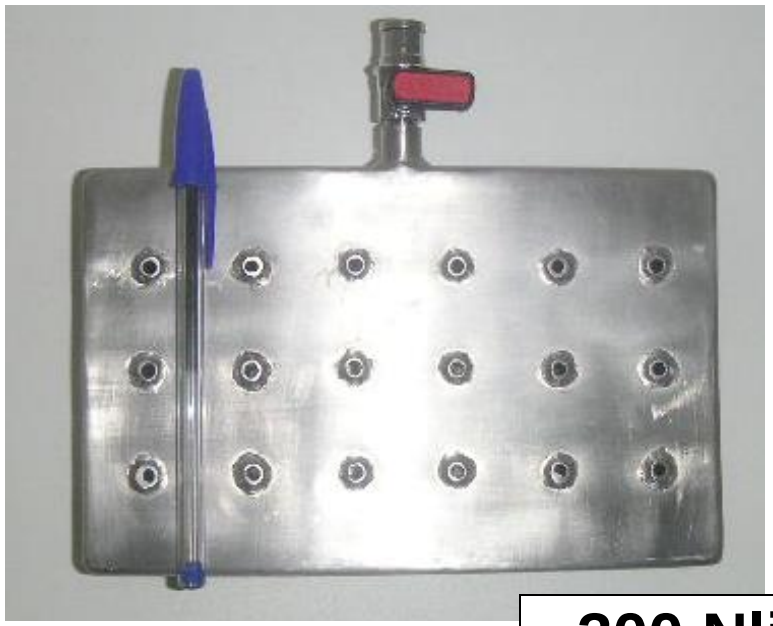


1000 NlitersH_2

Air-cooled MHT

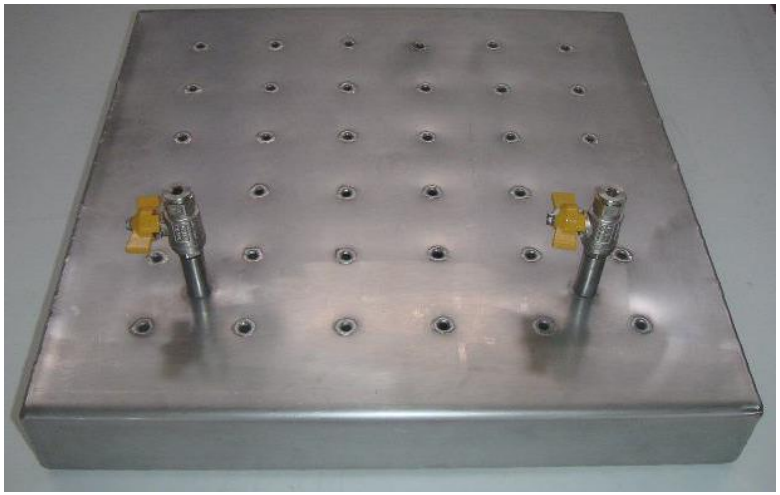
50-75-100 NlitersH_2

Air-cooled MHT



300 NlitersH_2

Air-cooled MHT



6000 NlitersH_2, 120NlitersH_2/kgMHT (1.2wt%H_2)

450 NlitersH_2/literMHT

Air-cooled MHT, Aluminum Canisters

500-1500 NlitersH_2

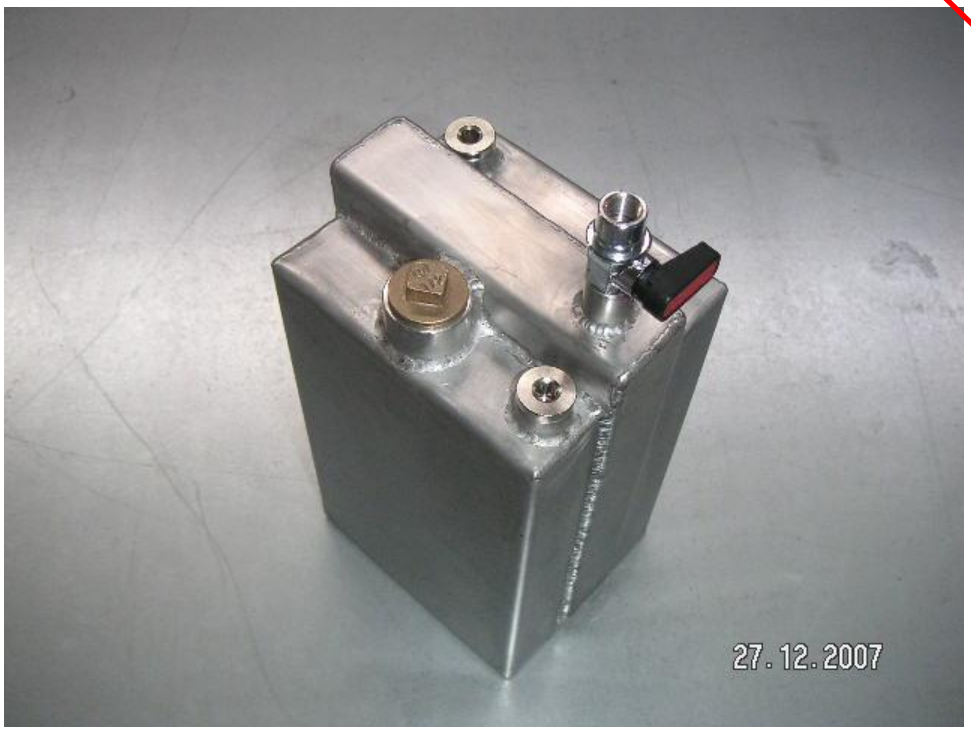
80000 NlitersH_2

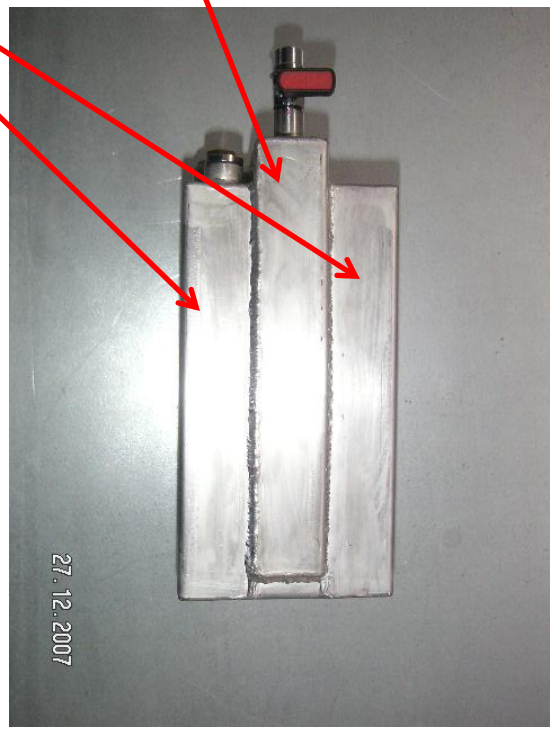
Water-cooled MHT

Water-cooled MHT

35000 NlitersH_2

Hybrid CHEM-HY / MHT

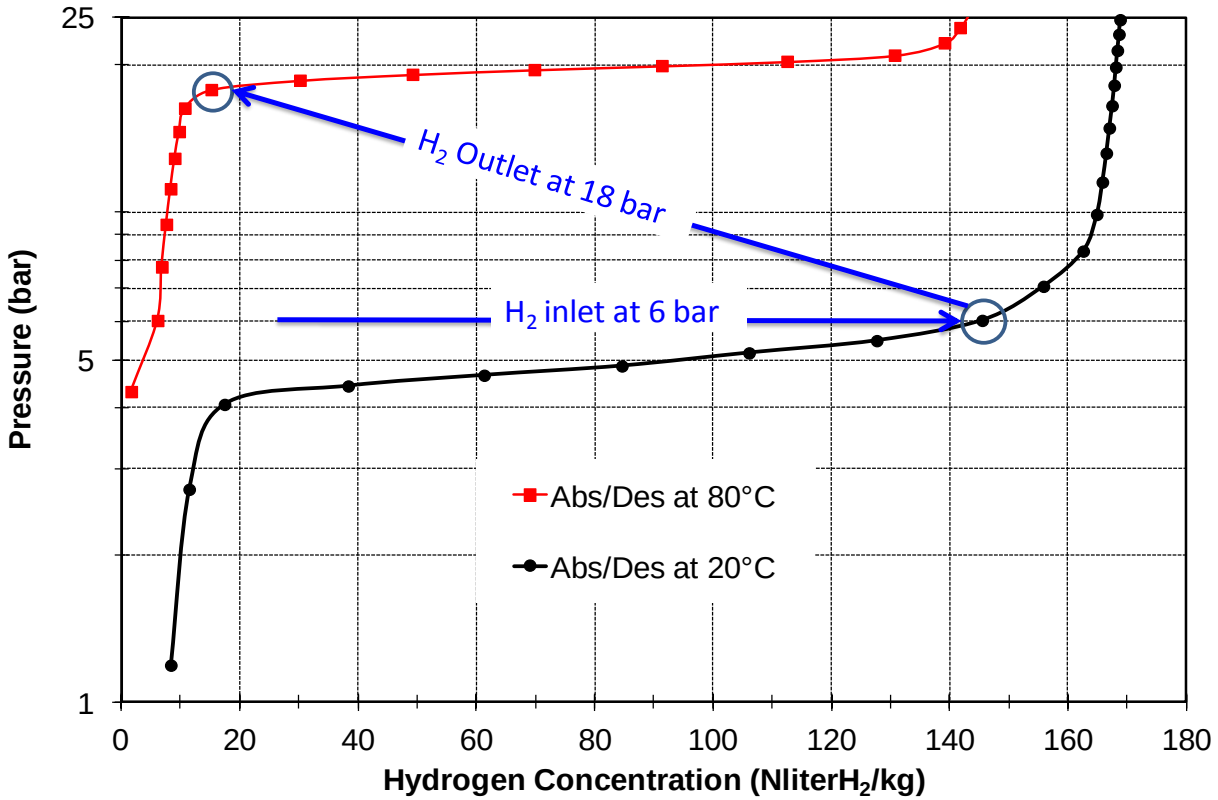




Exothermic CHEM-HY transfers heat to **Endothermic** MHT

5. Hydrogen Storage as Compressed Gas (CHG) at P>200bar): Metal Hydride Compressors (MHC)

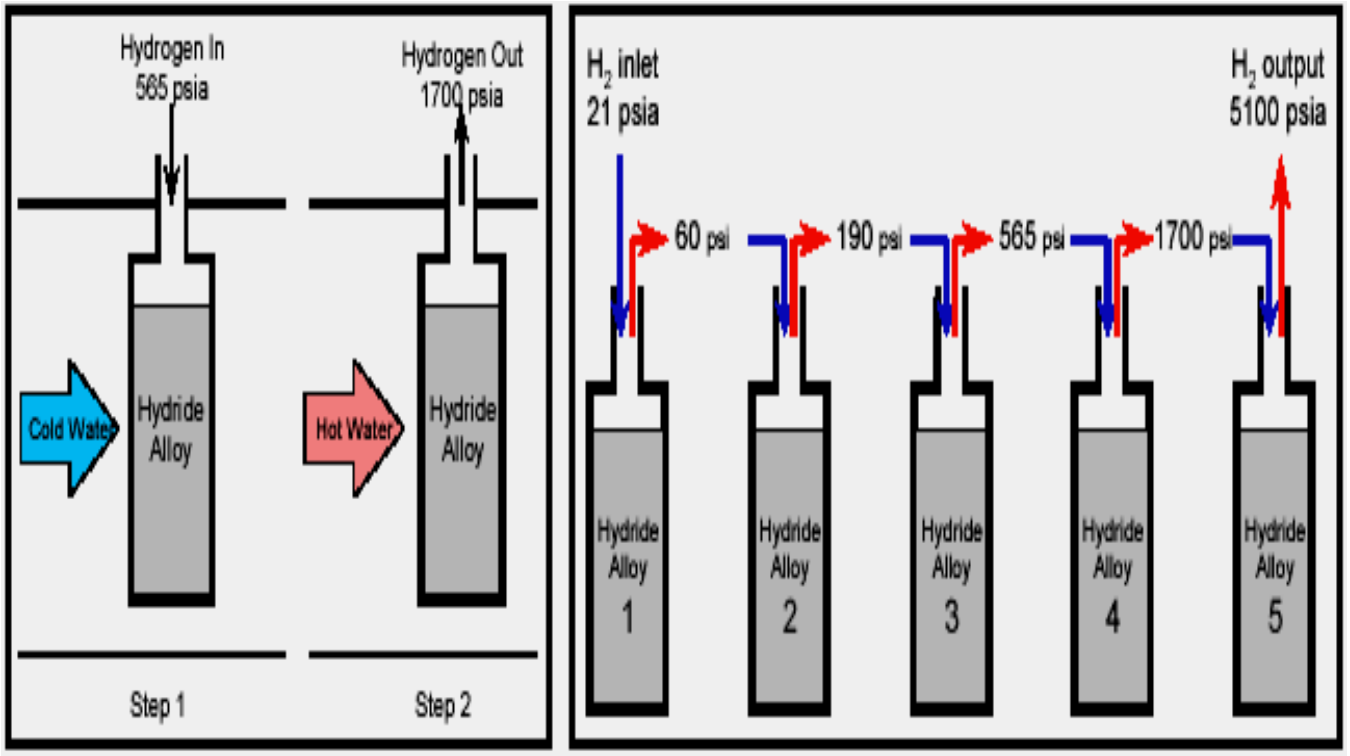
The principle



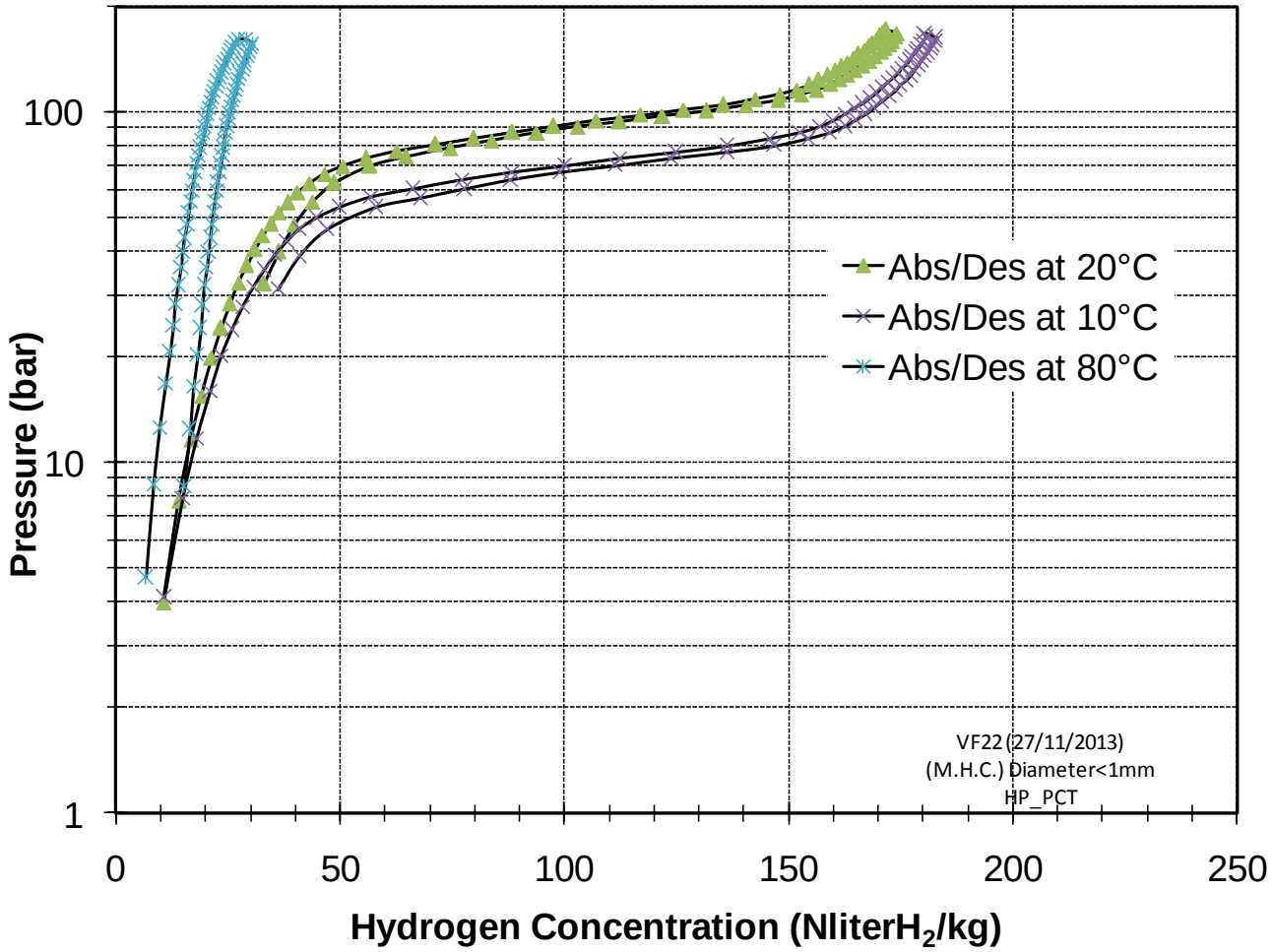
5. Metal Hydride Applications

Metal Hydride Compressors (MHC) (Metal Hydride materials in a metallic container)

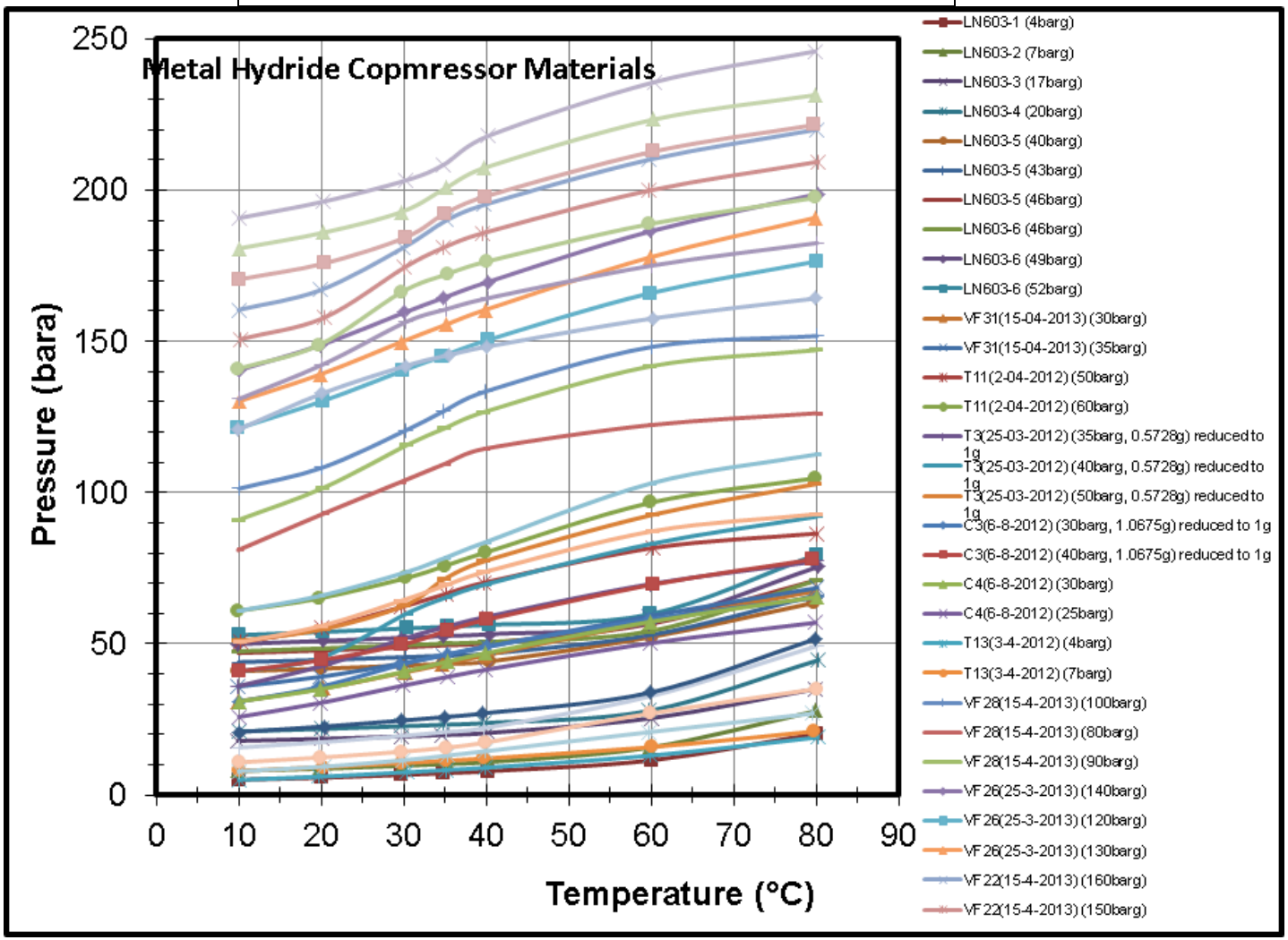
The principle (By cooling and Heating)



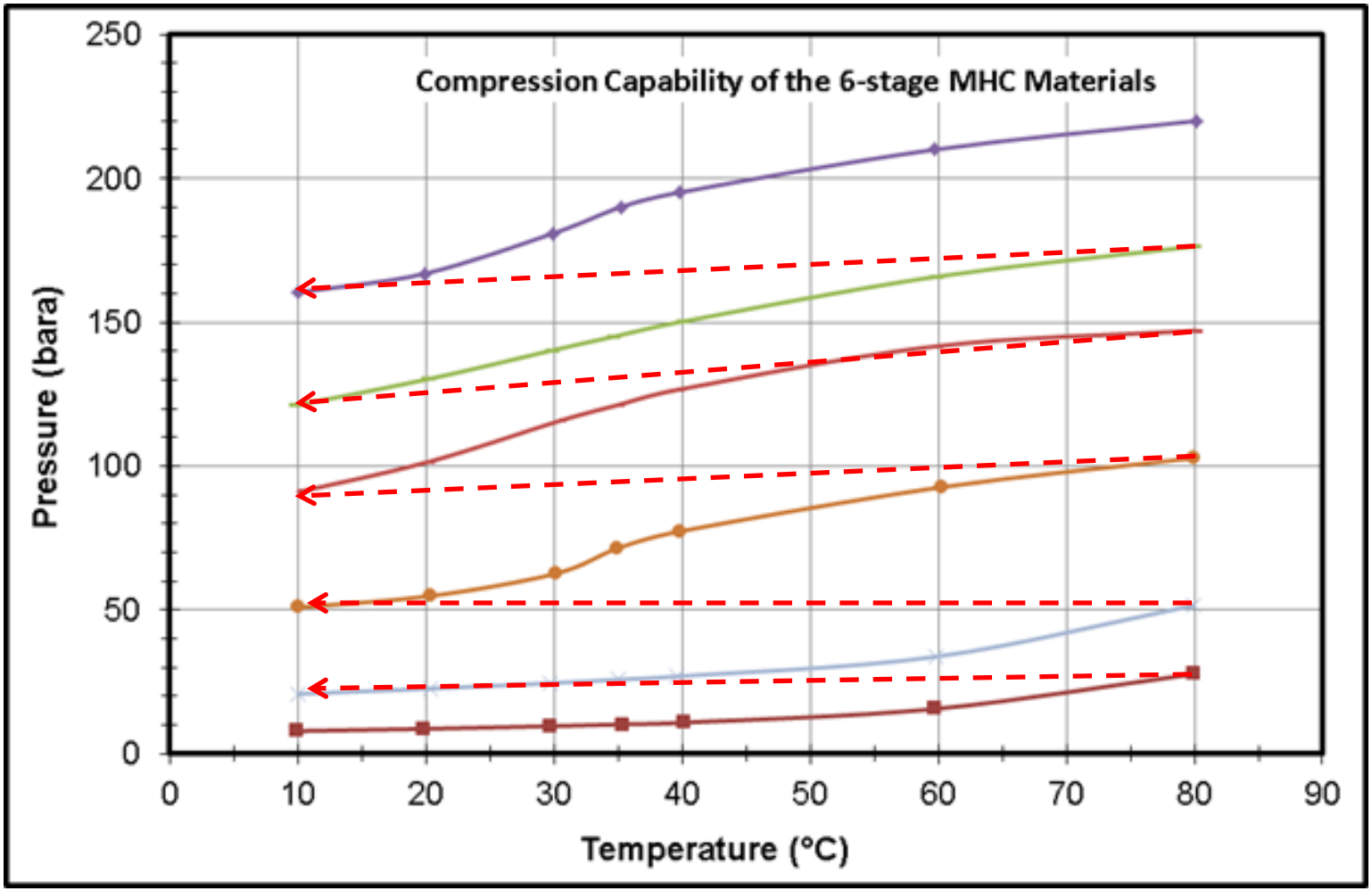
PCT of a High Pressure AB_2 Alloy used



MH materials tested



6-Stage MH materials used



Design and construction of Tubular 300bar MHT









Design and construction of Tubular 300bar MHT






Design and construction of Tubular 300bar MHT

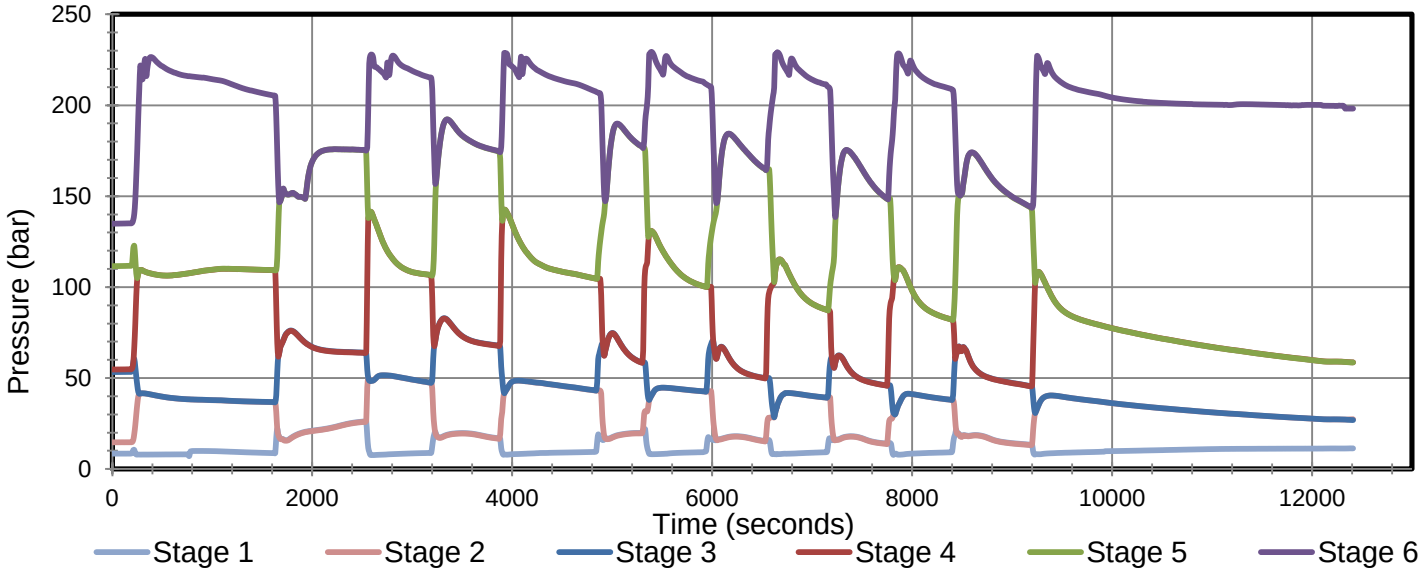
Cold/Hot Water Management for the MHC

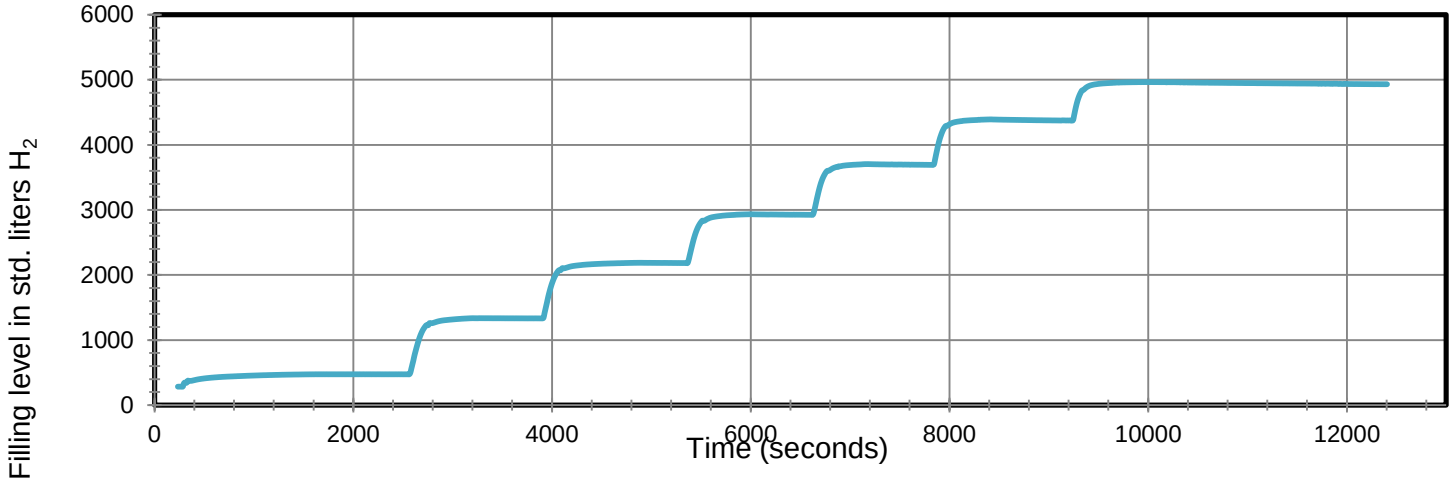
6-Stage MHC Operation, (10-80°C) 2.5m³H_2/h, >220bar

6-Stage MHC Operation, (10-80°C) 2.5m³H_2/h, >220bar

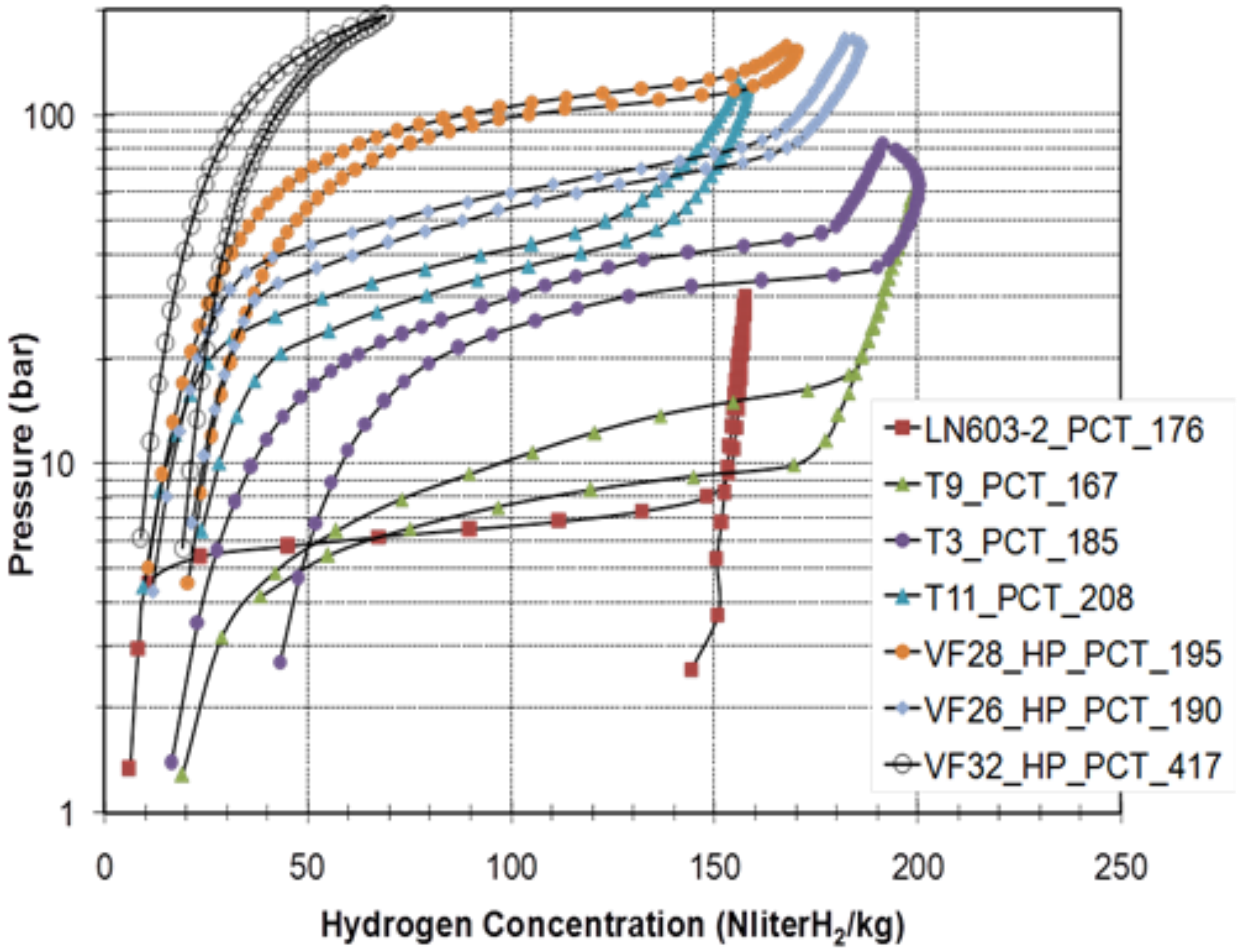
6-Stage MHC Operation, (10-80°C) 2.5m³H_2/h, >220bar

6-Stage MHC Operation, (10-80°C) 2.5m³H_2/h, >220bar





New Materials for a 5-Stage MHC (PCT at 10°C) towards >300bar



Currently under construction at Hystore Technologies Ltd
5-Stage MHC, (10-80°C) 10m³H_2/h, >300bar

Currently under construction at Hystore Technologies Ltd
5-Stage MHC, (10-80°C) 10m³H_2/h, >300bar

CONCLUSIONS

1. RES & H_2 Technologies is the name of the game for moving from the "Oil Economy" to the "Hydrogen Economy"
2. New Innovative Metal Hydride Compressors (MHC) will provide high pressure (>300bar) hydrogen and contribute to the penetration of Hydrogen into the energy mix, especially in transportation. The compressor is using only cold (10-20°C) and hot (70-80°C)water, no electricity
3. For higher efficiencies and fuel savings
4. For fossil fuel independence
5. For less CO_2 emissions, slowing-down global warming, combating extreme climatic changes, less pollution, a clean Environment and sustainability

I Thank You Very Much

And Always

Think H_2