

# Metal Hydride Technologies: *Existent and Prospective Niche Applications*

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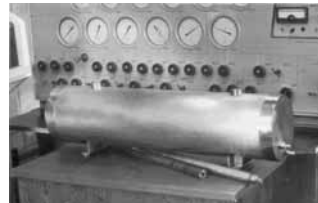
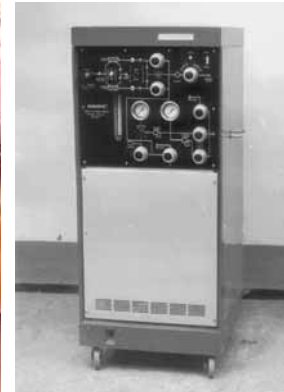


UNIVERSITY of the  
WESTERN CAPE

HYDROGEN STORAGE  
TECHNOLOGIES



I devote my presentation to the memory of late  
**Prof. Yuri F. Shmal'ko,**  
my elder colleague and friend

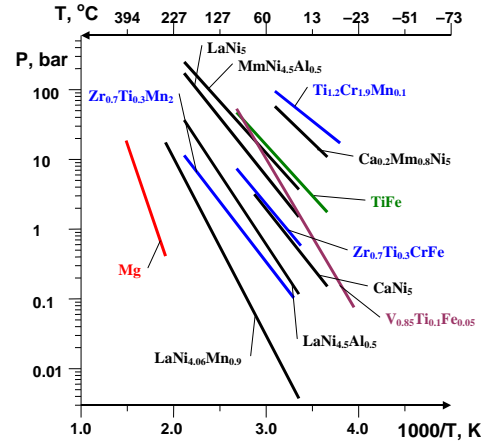
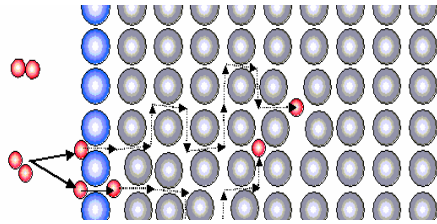


# OUTLINE

1. Applications of MH
  - a. General features
  - b. Gas-phase MH applications: advantages and bottlenecks
  - c. MH for H storage, compression, separation / purification
  - d. Promising market niches for MH applications
2. Development of MH technologies in South Africa
  - a. South African National HFCT Strategy: general features and contribution of HySA Systems
  - b. MH technologies: motivation
  - c. Overview of MH activities at SAIAMC / UWC and HySA Systems
3. Conclusions

## Metal Hydrides

Gas phase applications  
 $M (s) + x/2 H_2 (g) \leftrightarrow MH_x (s) + Q$



- ✓ Volume density of H in the metal lattice 1.5-2.0 times higher than for LH<sub>2</sub>
- ✓ Fast and reversible H<sub>2</sub> absorption / desorption
- ✓ Extremely wide T / P operation ranges
- ✓ Significant heat effects: H<sub>2</sub> sorption is accompanied by heating and H<sub>2</sub> desorption by cooling of the MH bed
- ✓ Selectivity: only H<sub>2</sub> interacts with MH
- ✓ H activation by MH

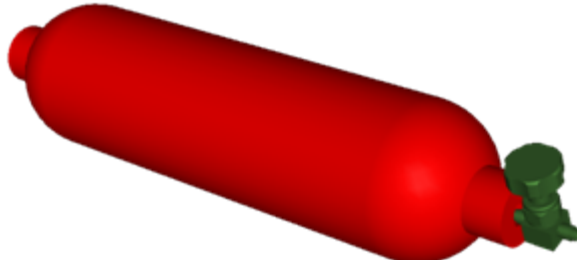


Hydrogen Storage

H Compression; Heat Management

H Separation and Purification

Processes Involving H transfer

# Hydrogen Storage Alternatives

	Volume (kg H <sub>2</sub> /m <sup>3</sup> )	Mass (wt.%)	Energy loss	Safety
 CGH <sub>2</sub>	max. <b>33</b>	<b>10-13</b>	<b>15-20 %</b>	-
 LH <sub>2</sub>	<b>71</b>	<b>&lt;85</b>	<b>30 %</b>	-
 MH	max. <b>150</b>	<b>2-3</b>	<b>5-10 %</b>	+

**Feasibility strongly depends on consumer's requirements**

# On-Board Hydrogen Storage (utility vehicles)

H<sub>2</sub>-fuelled ICE forklift

*(IPMach NAS Ukraine, mid 1980-th)*



2.4 kg H<sub>2</sub> MH storage unit

*M=490 kg (incl. ~200 kg of AB<sub>5</sub>+AB alloys)*

*Installed instead of counterbalance*

H<sub>2</sub>-fuelled FC mine locomotive

*(Consortium initiated by the Fuelcell Propulsion Institute and led by Vehicle Projects LLC, USA, 2002)*



3 kg H<sub>2</sub> MH storage unit

*M=430 kg (incl. ~ 200 kg of AB<sub>2</sub> alloy)*

*Partially replaces 1100 kg counterbalance*

**FEASIBLE (no weight penalty)**

# Stationary Hydrogen Storage for LT PEMFC Power Systems

## Focus: UPS for telecommunication facilities



## MH units for LT PEMFC power systems : (Texaco Ovonic Hydrogen Systems, USA)

**85G250 / 0.9 m<sup>3</sup> H<sub>2</sub>**  
storage unit (M=6.5 kg; op.  
temperature 25 to 60 °C)  
and rack-mount H storage  
system on its basis  
providing operation of 1  
kW FC (2 hrs permanent  
@ 1.2 kW).



Prototype stand-alone  
**112 m<sup>3</sup> H<sub>2</sub> bulk  
storage system** (10  
containers Ø 152x1575  
mm) + heating /  
cooling:  
• charge @ 7-10 bar  
(electrolyser / fuel  
processor)  
• discharge up to 35 bar  
• op. temp. -20..100 °C  
• **slow dynamics (full  
charge in ~ 13 hours)**

- Typical power requirement 1 to 10 kW
- Operation 200 hrs/year (1-2 to 24 hrs permanent)
- Estimated H storage capacity 2 to 20 m<sup>3</sup>  
(15 to 150 kg of "LT" MH)
- H<sub>2</sub> output 0.6 to 6 m<sup>3</sup> H<sub>2</sub> / hr
- Ambient heat or waste heat from FC can be used

# Laboratory MH H Storage Units

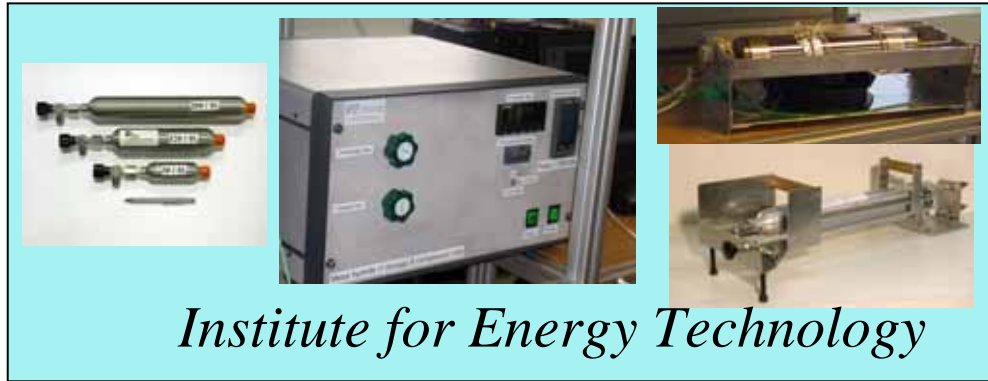
- Capacity from 30–40 litres to few m<sup>3</sup>
- Supply pressure 1–10 bar (options – controlled up to 200 bar)
- AB<sub>5</sub> or AB<sub>2</sub> H storage alloys; (option – Mg alloy)



*IPMach NAS Ukraine*



*Japan Metals & Chemicals Co., Ltd.*



*Institute for Energy Technology*



*HERA Hydrogen Storage Systems*

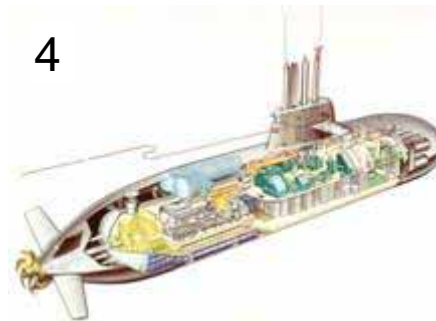


*The Japan Steel Works, Ltd.*

## Promising niche applications:

- Stationary and portable:
  - ✓ H storage units for PEM FC applications (backup power);
  - ✓ H storage & supply systems for laboratories and special technological processes
- Special mobile (H-fuelled utility vehicles)

- ✓ Safe and easy operation
- ✓ The highest H volume density
- ✓ Low “quality” of consumed energy
- ✓ Low H weight capacity (“LT-MH”)
- ✓ High temperature / power consumption (“HT-MH”)
- ✓ Scale effect: poor dynamics because of heat transfer limitations

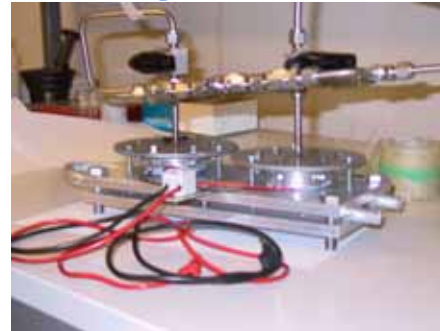


- 1 – 10...500 L H<sub>2</sub>
- 2 – 1...10 m<sup>3</sup> H<sub>2</sub>
- 3 – 50...100 m<sup>3</sup> H<sub>2</sub>
- 4 – ~15000 m<sup>3</sup> H<sub>2</sub>

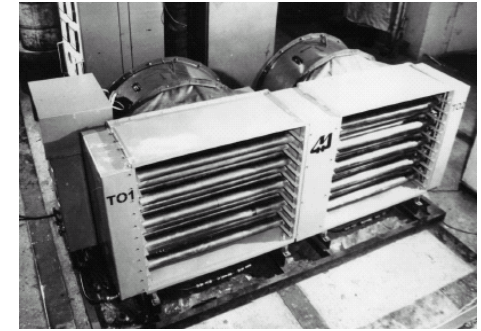
# MH Hydrogen Compressors

## Promising niche applications:

- Laboratory facilities
- Space
- H<sub>2</sub> filling stations
- Utilisation of low-potential heat
- Temperature sensors & actuators
- Special technological processes (e.g., powder metallurgy)



1 stage laboratory-scale (10-50 bar, 60 L/h H<sub>2</sub>) MH compressor (*IFE, Norway*)

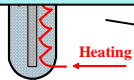


2 stage industrial-scale (5-150 bar, 10 m<sup>3</sup>/h H<sub>2</sub>) MH compressor for H<sub>2</sub> filling station (*IPMach, Ukraine*)



MH H<sub>2</sub> compression element for the Plank Engineering Bread Board cryocooler (6x, 0.6–50 bar, 240 L/h H<sub>2</sub>; *NASA – JPL, USA*)

- ✓ **Safe and easy operation (no moving parts)**
- ✓ **Modular design: good scaleability, easy reparation / maintenance**
- ✓ **Waste heat (T~150°C) can be utilised to achieve hundreds bar H<sub>2</sub> output pressure (proper layout incl. selection of MH materials is required)**
- ✓ **Low efficiency**
- ✓ **Limited cycle life of MH material (ca 10<sup>4</sup> ABS/DES cycles)**



Seat lifting wheel chair: MH actuator (40 g of H storage alloy); max. load 80 kg; max. stroke 400 mm (*The Japan Steel Works, Ltd.*)



## Promising niche applications:

### ➤ Energy saving MH technologies:

- ✓ CHP
- ✓ Utilisation of low-potential industrial heat
- ✓ Residential energy systems

### ➤ “Cold start” and similar systems



Micro turbine system



28 kW cogeneration system is a combination of micro gas turbine power generation and metal hydride refrigeration (*The Japan Steel Works, Ltd.*)

Experimental system for transportation of industrial waste heat (80 – 150 °C) (*The Japan Steel Works, Ltd.*)



MH heat pump; 2 MH alloy beds, 70 kg each



Hydrogen pipeline, distance 1 km



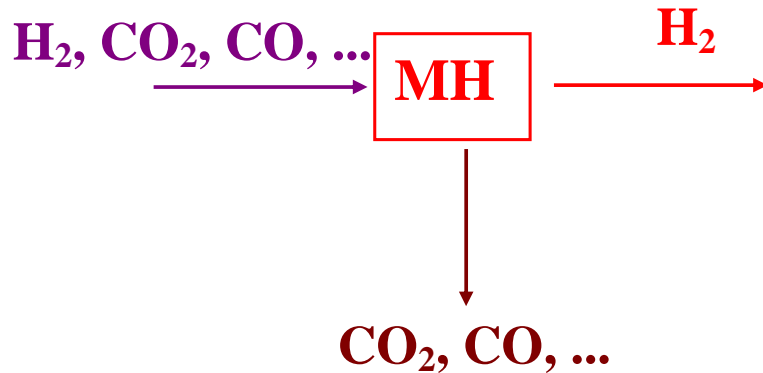
HT MH

LT MH

Cold start engine system on the basis of MH heat transformer (up to 400 °C in less than 5 s) (*Ergenics, USA*)

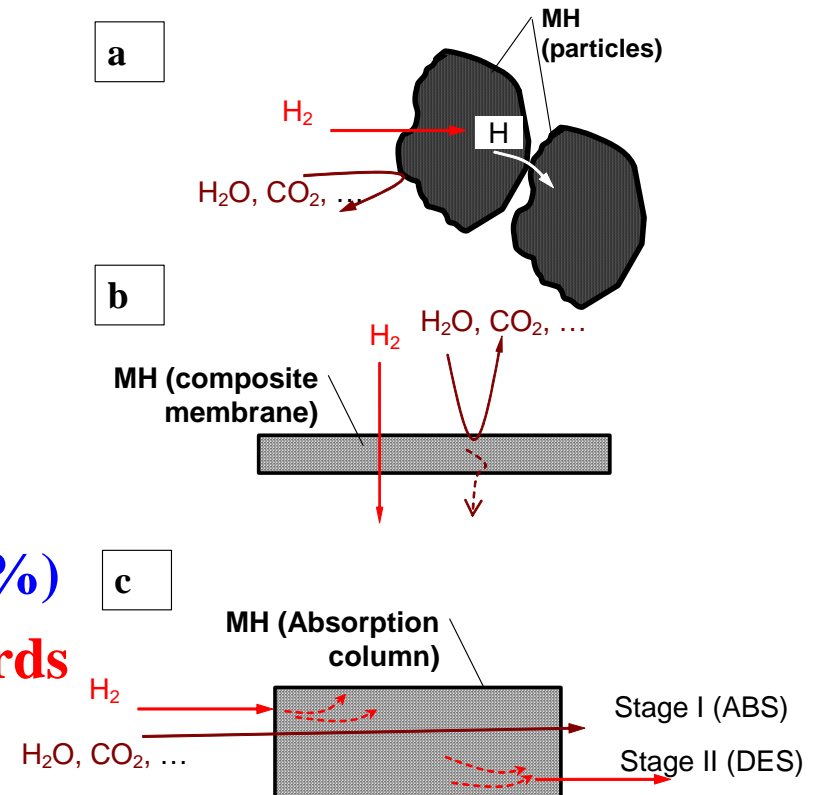
- ✓ **Safe and easy operation (no moving parts)**
- ✓ **Waste heat (T~150°C) can be utilised (proper layout incl. selection of MH materials is required)**
- ✓ **Low efficiency**

# MH for H<sub>2</sub> separation & purification



- ✓ Easy (1-2 stages) operation
- ✓ Low power consumption
- ✓ High purity of the output H<sub>2</sub> (99.99+%)
- ✓ Sensitivity of the MH materials towards poisoning with gas impurities

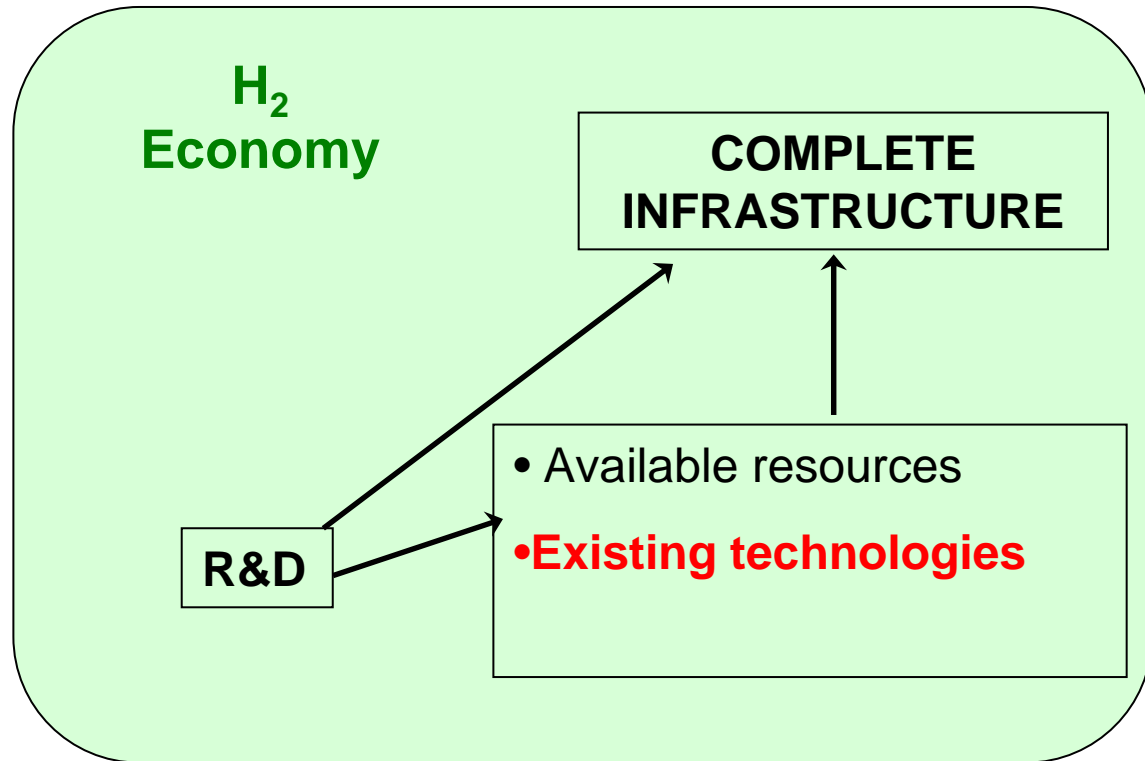
**Poisoning-tolerant MH materials must be developed**



# Implementation Strategy

✓ Straightforward?

➤ ~~Step by step?~~



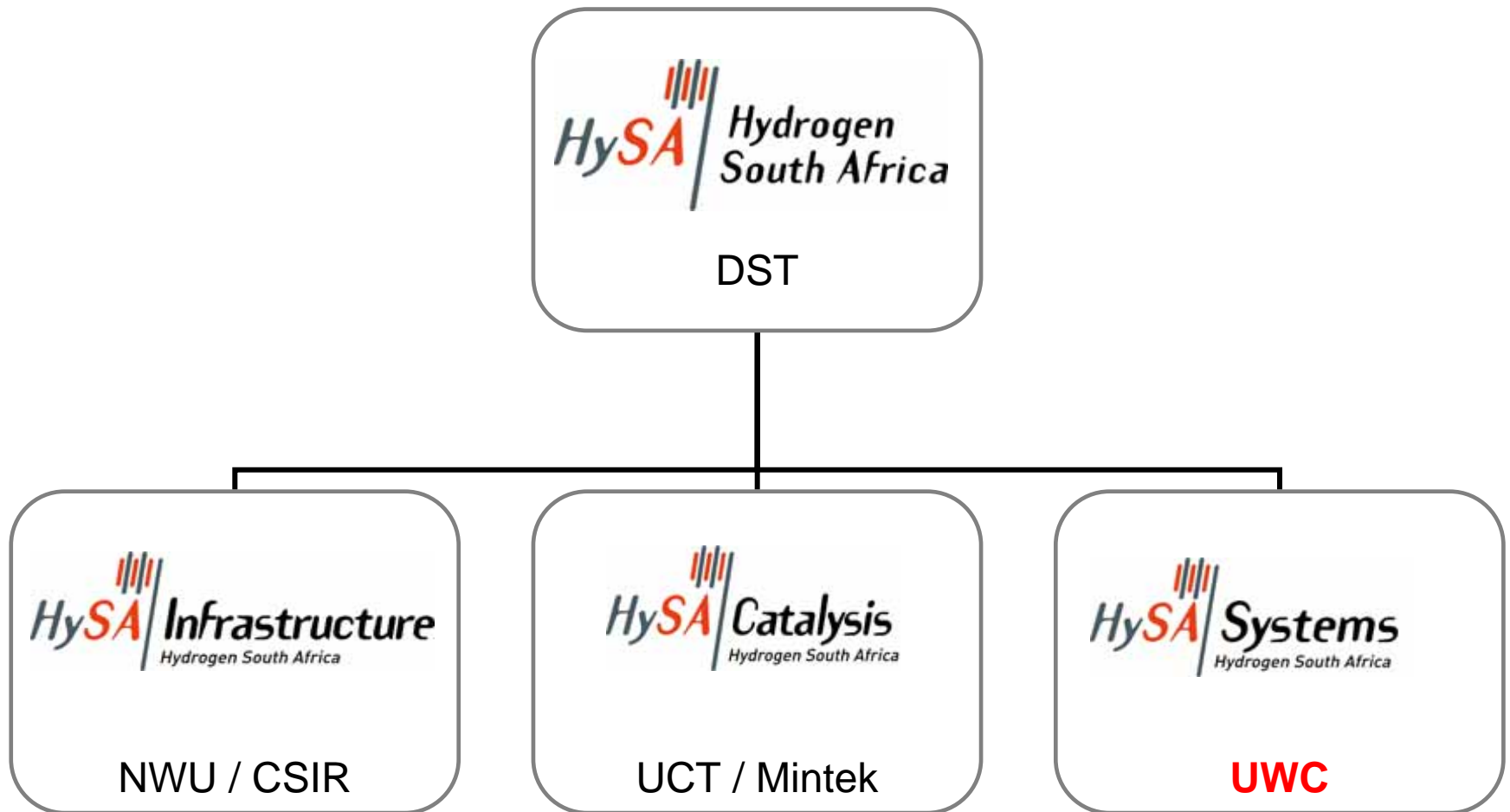
# SA Hydrogen Programme: Overall Objectives

- Move South Africa towards knowledge based economy



- Extract more value from natural resources

# HySA Organization



# System Integration and Technology Validation CC (HySA Systems)

## Key Technologies

1. Hydrogen Purifiers (Pd Membranes)
2. Fuel Cell Catalysts (all electrocatalysts)
3. Direct Photo-Catalysis
4. Membrane Electrode Assemblies (<120°C)
5. Membrane Electrode Assemblies (>120°C)
6. Stacks
7. Fuel Cells
8. Fuel Processors (H<sub>2</sub> and Hydrocarbon fuels)
9. H Storage (Solid State)
10. H<sub>2</sub> Purification & Compression – MH
11. Batteries and other Electrical Devices
12. Electrolyser Systems (Wind)
13. Hydrogen from Solar
14. Hydrogen from Nuclear
15. Hydrogen Storage (other)
16. Hydrogen Reticulation/Delivery)
17. Systems integration (End-use)
18. Systems Integration (Production and Delivery)

**HySA  
Systems CC**

- 9 researchers;
- 4 post-doctoral fellows;
- 4 PhD students
- 2 MSc students

## Key Programmes

### KP1: Combined Heat and Power

- KP1-S01 – FC catalysts and MEAs (>120°C)
- KP1-S02 – Power Management & Batteries for CHP
- KP1-S03 – Tech. Validation & System integration

### KP2: Portable Power

- KP2-S01 – Metal Hydride Storage for LT PEMFC**
- KP2-S02 – Pd-Nanocomposite Membrane Reactors
- KP2-S03 – Tech. Validation & System integration
- KP2-S04 – Power Management System

### KP3: Hydrogen Fuelled Vehicles

- KP3-S01 – Combined Li-ion Batteries & Supercaps
- KP3-S02 – Metal Hydrides for Utility Vehicles**
- KP3-S03 – Tech. Validation & System integration
- KP3-S04 – Onboard Hydrogen Storage**
- KP3-S05 – High temperature MEA for FCVs

### KP7: Human Capital Development

- KP7-S01 – Education in the Hydrogen Economy

### KP8: Special Projects

- KP8-S02 – MH Integrated Energy Systems**

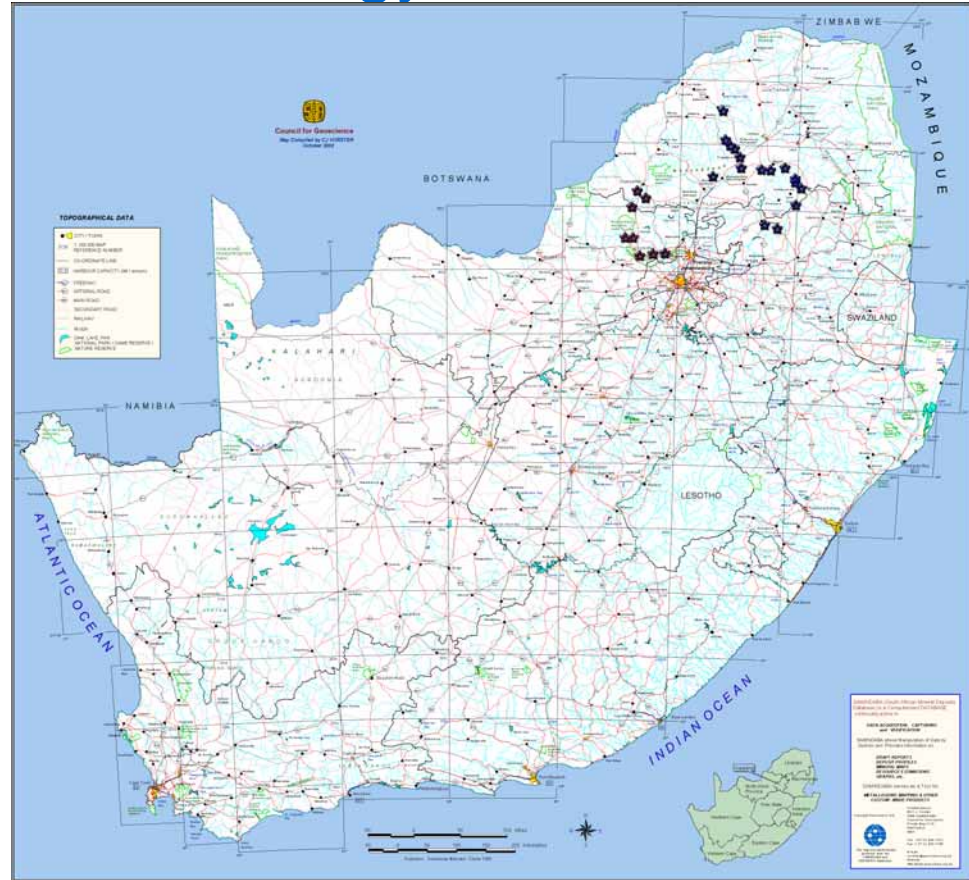
# MH: Motivation within SA National strategy

- ★ Dominating position in PGM production

Pt – world's #1

Pd – world's #2

The overall vision of the South African HFCT RDI strategy is to bring about wealth creation through the initiation of new high tech industries based on minerals found on South African soil, especially platinum group metals (PGMs). **A major goal of the strategy is to capture 25% of the global demand for PGM in hydrogen energy technologies.**



# MH: Motivation within SA National strategy

- ★ Dominating position in PGM production
- ✓ Well-developed mining & production of important components for H storage alloys :

● REM

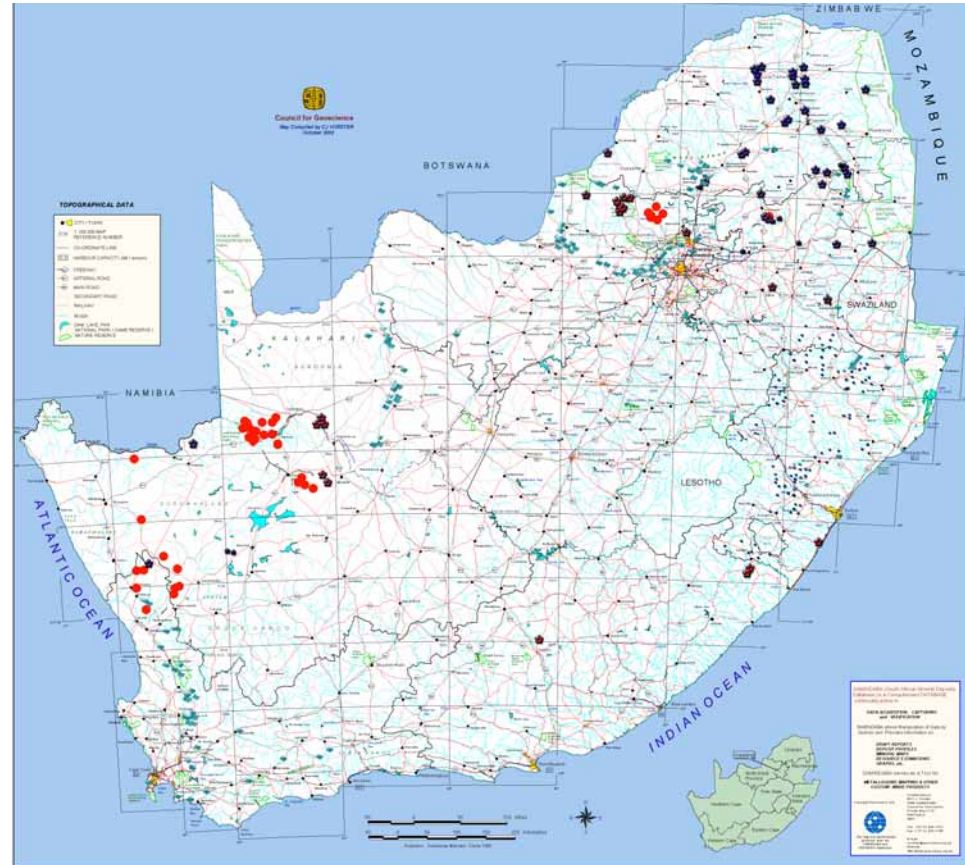
★ Ni

★ Co

■ Mn (world's #1)

■ Al

➔ **AB<sub>5</sub>**



# MH: Motivation within SA National strategy

- ★ Dominating position in PGM production
- ✓ Well-developed mining & production of important components for H storage alloys :

● Ti (world's #2)

● Zr (world's #2)

■ Mn (world's #1)

★ V (world's #3)

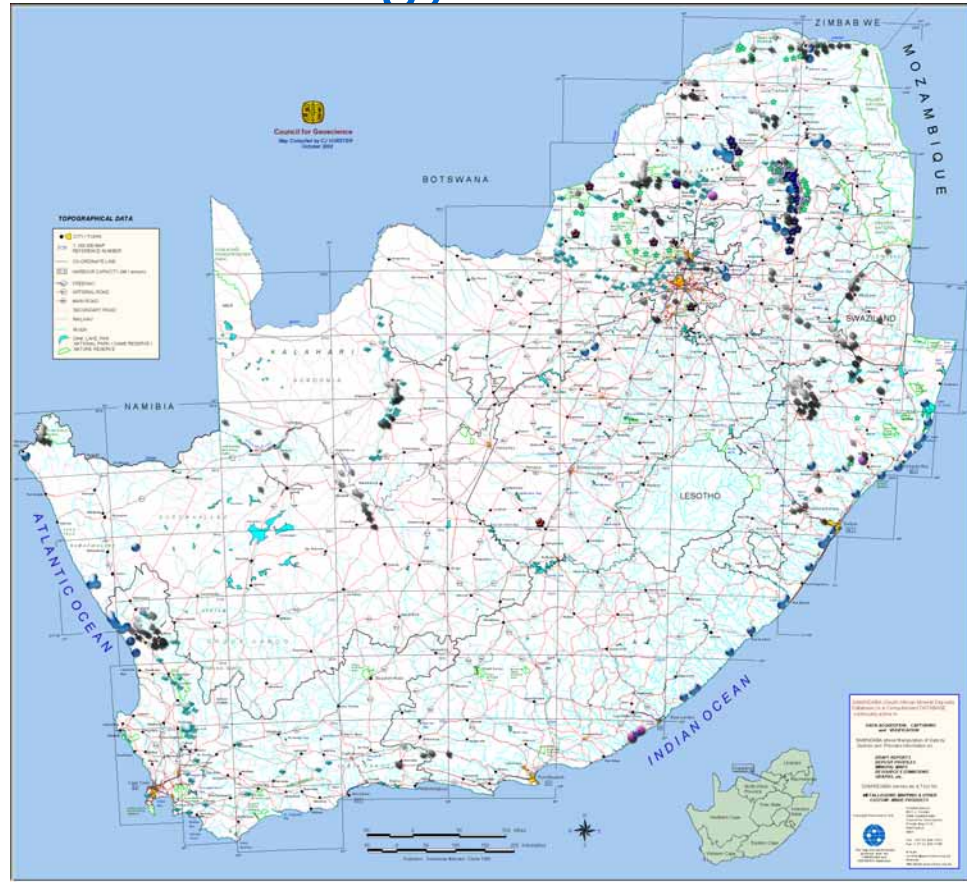
★ Cr

■ Fe



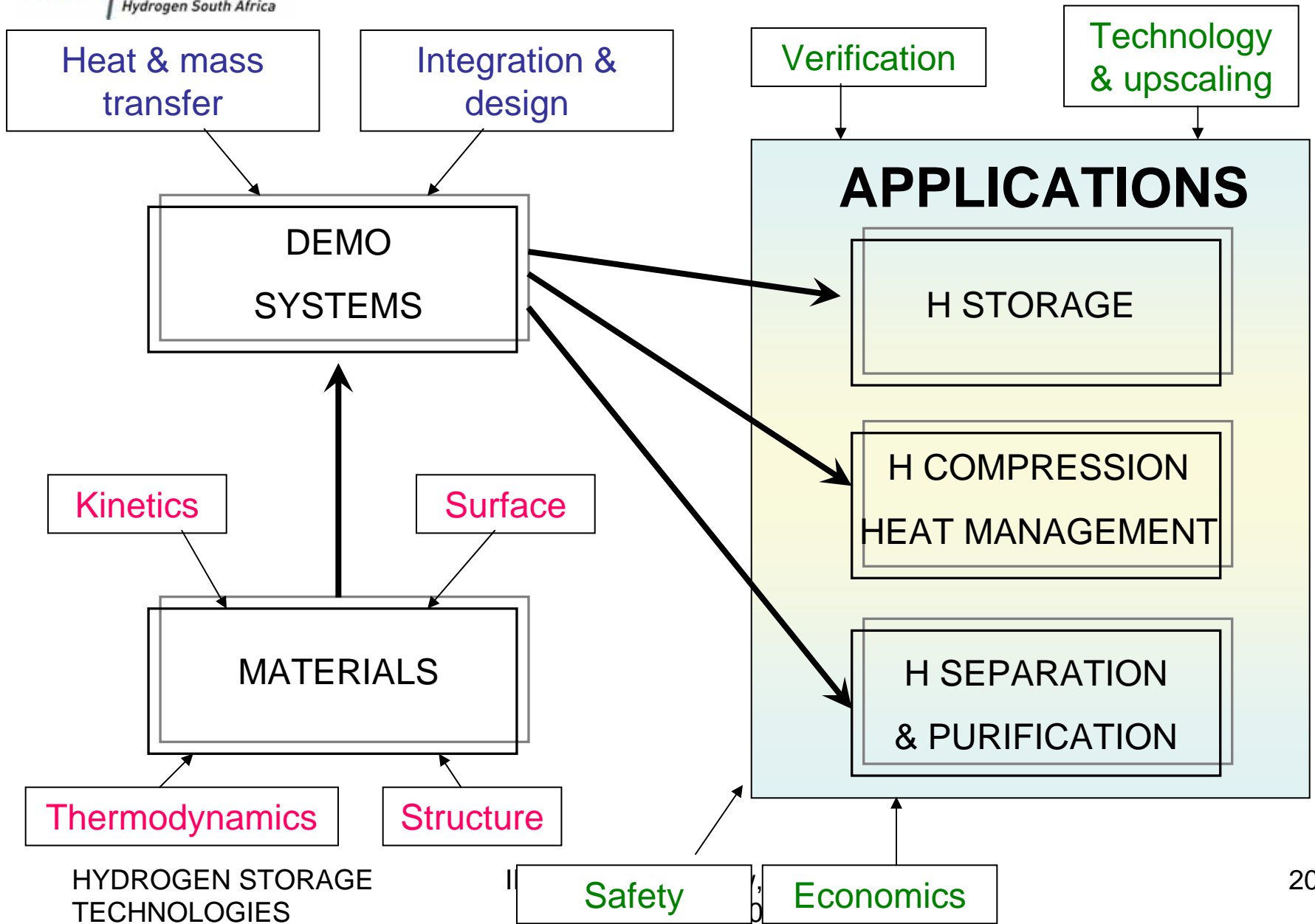
**AB**

**AB<sub>2</sub>**



➤ **Focus : Solid state (Metal Hydride) H storage solutions; related technologies**

# R&D strategy



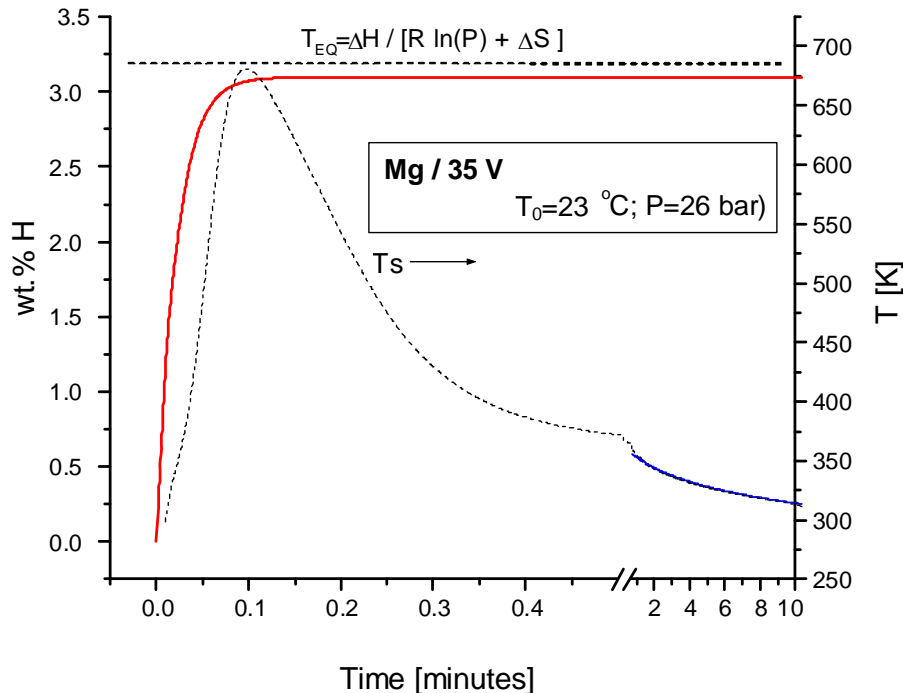
- Materials development:
  - New H storage materials:
    - **New MH materials, their structural & morphological characterisation (international collaboration)**
    - Study of H sorption performances (incl. PCT measuring and modelling)
  - Improvement of performances of MH by their modification / development of composites:
    - **Surface modification / PGM**
    - Composites with nanoscale carbon (e.g., CNT, TEG)
    - Reactive Ball Milling
  
- System integration of the advanced MH materials into different applications:
  - **H storage**
    - Stationary
    - Special mobile
  - **Heat-driven H<sub>2</sub> compression**
  - Heat management using MH
  - **H<sub>2</sub> separation & purification**



# New MH materials: collaboration with IFE & NTNU / NO

“Industrial Applications of Metal Hydrides for Hydrogen Extraction, Storage and Compression”; funded by the NRF and Research Council of Norway, under the framework of the South Africa – Norway Programme of Research Co-operation (project #180344).

## Mg- based H storage nanocomposites



- Hydrogenation completes in 5–60 seconds and is accompanied by a significant heat release
- Sample temperature,  $T_s$ , approaches equilibrium value ( $\text{Mg} \leftrightarrow \text{MgH}_2$ ) for the operating  $\text{H}_2$  pressure
- Lototsky M.V., Denys R.V., Yartys V.A. (2009), *Int. J. Energy Research*, DOI: 10.1002/er.1604

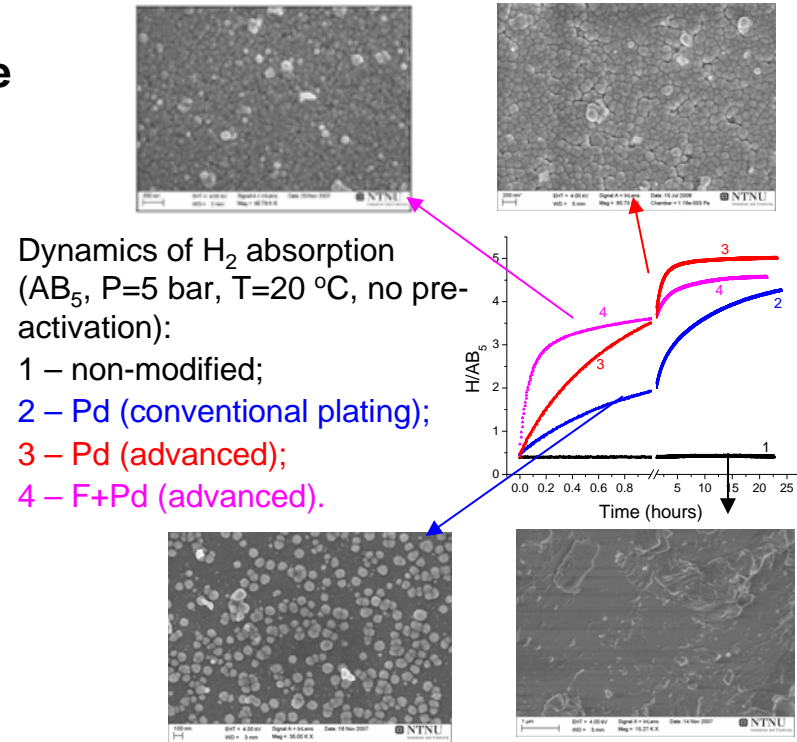
# Advanced MH materials: collaboration with IFE & NTNU / NO

“Industrial Applications of Metal Hydrides for Hydrogen Extraction, Storage and Compression”; funded by the NRF and Research Council of Norway, under the framework of the South Africa – Norway Programme of Research Co-operation (project #180344).

➤ **New surface engineering technologies for modification of powdered H storage alloys have been developed at SAIAMC (*one SA patent granted and one international pending*) :**

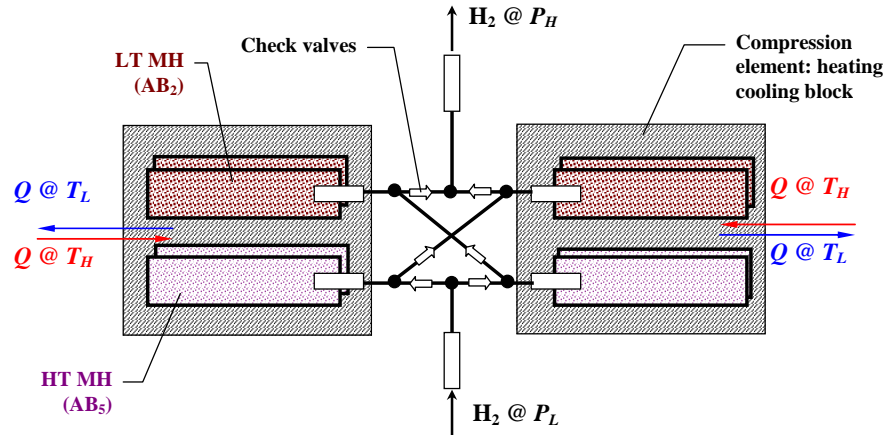
- ✓ Surface functionalization with aminosilanes + electroless deposition of Pd (Pt)
- ✓ Fluorination + surface functionalization with aminosilanes + electroless deposition of Pd

- Advanced characterisation: IFE, NTNU
- Total introduction of 0.5–1 wt.% Pd results in an increase of the H absorption rate by ~2 orders of magnitude
- The surface-modified materials (developed within ESKOM-funded project) may be applied in highly-selective H<sub>2</sub> extraction and purification processes



- Williams M, Lototsky M.V, Nechaev A.N, Linkov V.M, Yartys V.A, Li Q, Proc. NATO Adv. Research Workshop on Using Carbon Nanomaterials in Clean-Energy Hydrogen Systems, Sudak, Crimea, Ukraine, September 22-28, 2007, Springer, 2008, pp. 625-636
- Williams M, Nechaev A.N, Lototsky M.V, Yartys V.A, Solberg J.K, Denys R.V, Pineda C, Li Q, Linkov V.M (2009), Materials Chemistry and Physics, 115 (1): 136-141.
- Williams M., Lototsky M.V., Linkov V.M., Nechaev A.N., Solberg J.K., Yartys V.A. (2009), Int. J. Energy Research, DOI: 10.1002/er.1609

# Prototype 60 L H<sub>2</sub> / h MH micro-compressor



- Developed within ESKOM-funded project
- 2 stages (I – AB<sub>5</sub>; II – AB<sub>2</sub>)
- P<sub>L</sub> ~ 5–10 bar; P<sub>H</sub>=200 bar
- T<sub>L</sub> ~ 15–25 °C; T<sub>H</sub>~120 °C
- Permanent operation
- Water cooling
- Electric (option - steam) heating
- Assembled & tested (March 2009)
- Original solutions as to the layout are being verified

*Two SA patents pending*

# Conclusions

- MH systems have features of low- to high pressure operation, compactness, safety, tailorable delivery pressure, excellent absorption / desorption kinetics, modular design for easy scalability.
- In addition to hydrogen storage, some extra options, including H<sub>2</sub> compression, separation & purification, etc., should be considered in the development of MH technologies.
- The main activities in realising this approach are in the detailed adjustment of properties of MH material, system design and consumer's specification.
- Several promising niche applications for MH systems have been identified as:
  - H storage units for PEM Fuel Cell applications, incl. UPS systems for telecommunication facilities;
  - H storage units for utility vehicles (e.g. forklift trucks, mine locomotives) ;
  - Heat recovery and / or energy saving systems on the basis of MH compressors and heat pumps;
  - H<sub>2</sub> separation and purification technologies.
- SAIAMC / UWC has a strong background in the MH materials & systems and is the leading SA team in the field.
- H storage in MH and related applications is a key technology that is to be developed by HySA Systems within several projects undertaken in the framework of HySA.

# Acknowledgements

- **Department of Science & Technology (DST), South Africa**
  - **Eskom Holdings, Ltd.**
  - **National Research Foundation (NRF), South Africa**
- and
- Institute for Mechanical Engineering Problems (IPMach), National Academy of Sciences of Ukraine and, personally, **Prof. Yu. Shmal'ko** and *Prof. V. Solovey*;
  - Institute for Energy Technology (IFE), Norway and, personally, *Prof. V. Yartys*;
  - Joint Institute for High Temperatures, Russian Academy of Sciences and, personally, *Prof. S. Malysenko*.

# Contact Details

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Extra slides

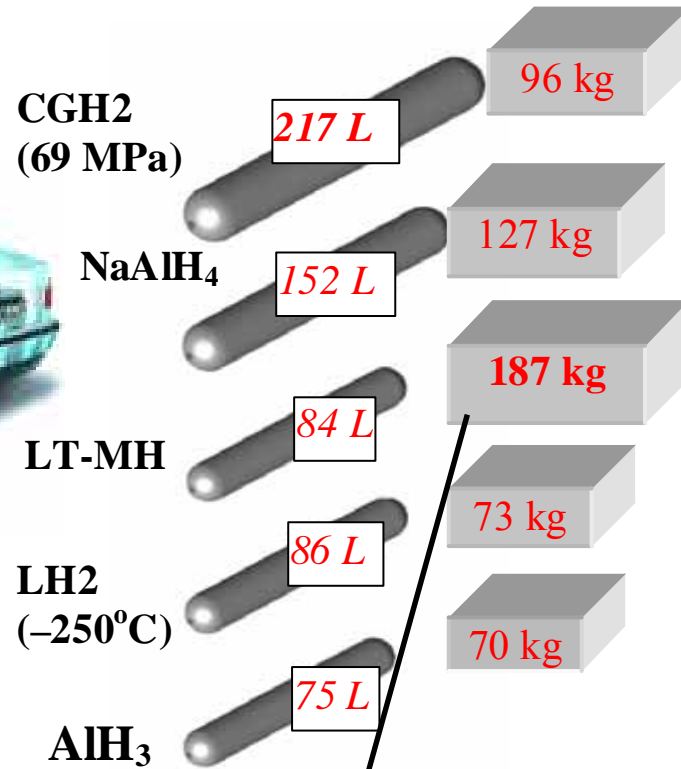
# Summary

Application	Features used	MH materials	Advantages	Problems
Solid state H storage	<ul style="list-style-type: none"> <li>• high volume H density;</li> <li>• reversible H<sub>2</sub> charge / discharge;</li> <li>• tuneability as to required P / T conditions;</li> <li>• heat effects accompanying H<sub>2</sub> absorption / desorption.</li> </ul>	LT: IMC (AB <sub>5</sub> , AB, AB <sub>2</sub> ); solid solution alloys (V, Ti–Cr)	<ul style="list-style-type: none"> <li>• safety: moderate P / T conditions;</li> <li>• compactness;</li> <li>• <b>technological versatility</b> (e.g., possibility to control the output H<sub>2</sub> pressure);</li> <li>• easy operation.</li> </ul>	<ul style="list-style-type: none"> <li>• low weight H capacity;</li> <li>• scale effects: heat transfer limitations;</li> <li>• high material cost.</li> </ul>
		HT: Mg-based		<ul style="list-style-type: none"> <li>• high operation temperatures;</li> <li>• sensitivity to overheat;</li> <li>• insufficient weight H capacity on system level;</li> <li>• scale effects: heat transfer limitations.</li> </ul>
H <sub>2</sub> compression; heat management		LT: IMC (AB <sub>5</sub> , AB <sub>2</sub> , AB)  HT: Mg-based (heat management at T > 300 °C)	<ul style="list-style-type: none"> <li>• thermally driven (no moving parts);</li> <li>• low-potential heat (T &lt; 150 °C) can be utilised;</li> <li>• safety &amp; reliability;</li> <li>• compactness;</li> <li>• easy operation.</li> </ul>	<ul style="list-style-type: none"> <li>• low efficiency;</li> <li>• adjustment of required pressure and available temperature ranges;</li> <li>• heat transfer limitations;</li> <li>• cycle life (material degradation / “hydrogenolysis”).</li> </ul>
H <sub>2</sub> separation / purification	<ul style="list-style-type: none"> <li>• selectivity of H<sub>2</sub> absorption.</li> </ul>	LT: IMC (AB <sub>5</sub> )	<ul style="list-style-type: none"> <li>• simplicity, easy operation (1-2 stages) ;</li> <li>• low energy consumption;</li> <li>• high purity of output H<sub>2</sub>;</li> <li>• compactness.</li> </ul>	<ul style="list-style-type: none"> <li>• sensitivity of the MH materials towards poisoning with gas impurities</li> </ul>

# On-Board Hydrogen Storage (passenger car)



**5 kg H<sub>2</sub> = 600 MJ**  
Target for 2015: 61.7 L / 55.6 kg  
(US DOE)

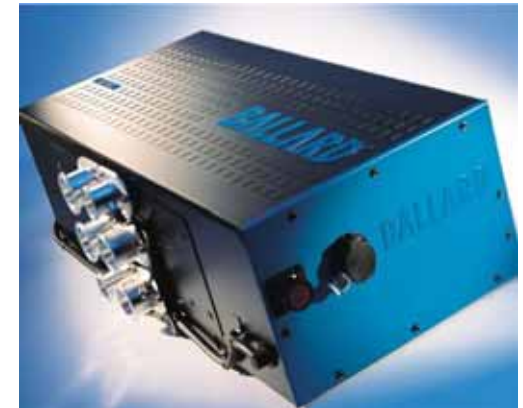
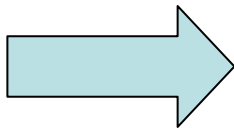


**NOT FEASIBLE (weight penalty)**

# Specific Goal

- To promote equity and inclusion in benefits from South Africa's resources by
  - Creating new downstream industries from natural resources

**Pt**



# HySA Strategy

- Funding of ~ R400 million (~ USD 49 mill.) over three years;
- 80% towards technology and expertise development + 20% to leverage private sector funding;
- **Market-driven approach**: the HySA projects are aimed at product development within the Hydrogen Economy;
- Focus on developing competency on Key Technologies and implementation of Key Programmes & projects.