Metal hydride hydrogen storage tank for fuel cell utility vehicles

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Fuel cell utility vehicles (incl. forklifts): Motivation

HyLIFT-DEMO Project Showcases Hydrogen Powered Fuel Cell Forklift Trucks at CeMAT logistics Fair May 2-6, Press release, Hannover, May 2, 2011

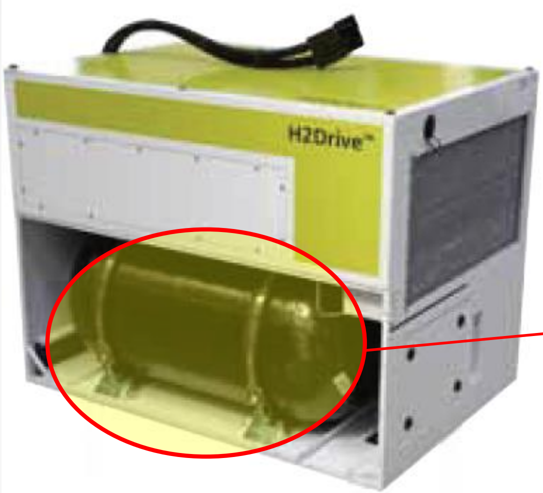
Hydrogen powered utility vehicles including material handling units with fuel cells combine the advantages of diesel / LPG and battery powered vehicles:

- Constant power during the entire shift;
- Short refuelling time;
- Zero emission electric propulsion.

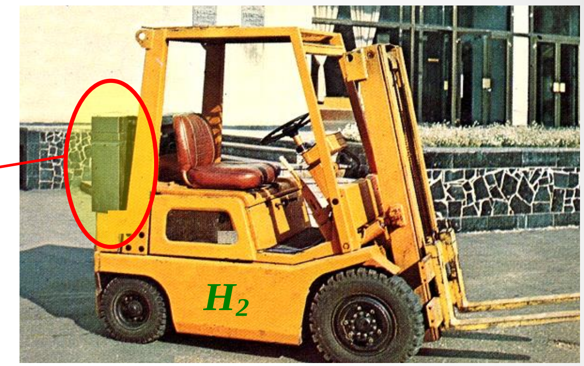
Lototskyy M. et al, Progress in Natural Science: Materials International 27 (2017) 3

Metal hydrides for heavy-duty FC powered utility vehicles incl. forklifts: Motivation

CGH2



MH

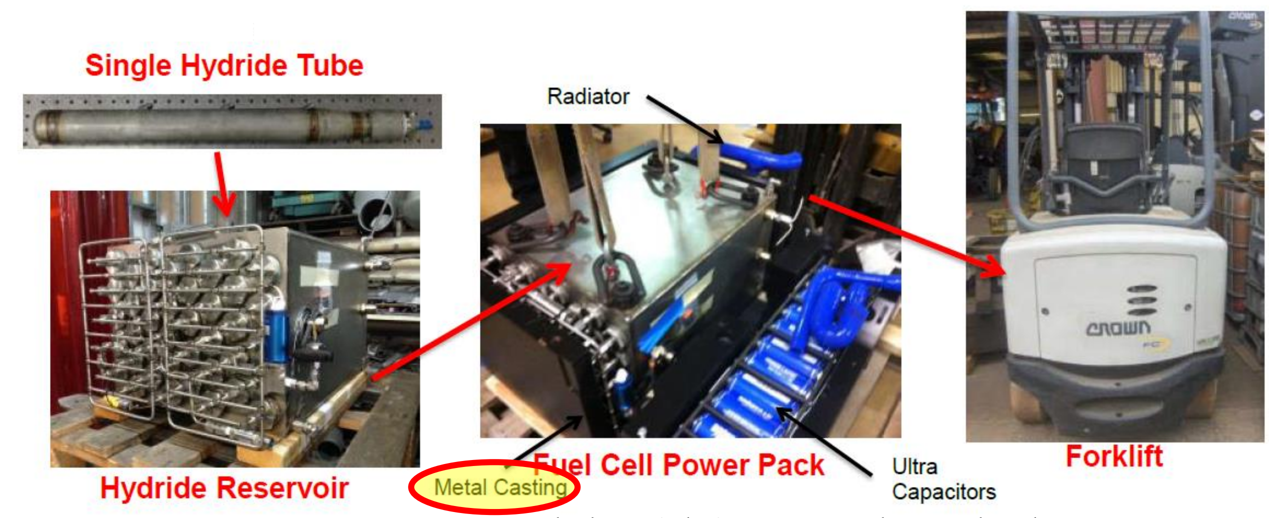


- Approved technology, prototypes available (Plug Power, H2Logics, Proton Motor, PearlHydrogen);
- Fast refuelling;
- Safety and refuelling infrastructure (filling H_2 pressure ~350 bar);
- Space constrains;
- Additional counterbalance required (forklift operation safety).

- Compact + heavy: intrinsic solution of the counterbalance problem;
- Safety (lower standby H_2 pressure);
- Simpler refuelling infrastructure (filling H_2 pressure <200 bar);
- Limitations of charge / discharge rates (heat transfer issues).

Lototskyy M. et al, J. Power Sources, 316 (2016)
Lototskyy M. et al, Progress in Natural Science: Materials International 27 (2017) 3

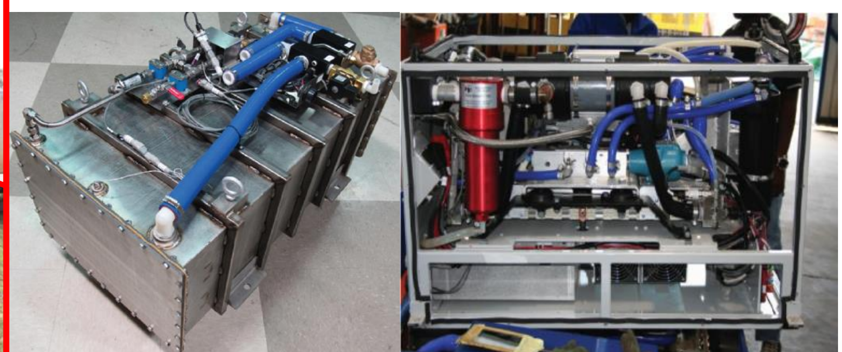
Background: MH hydrogen storage on-board fuel cell utility vehicles



- The MH tank (L=470 mm; W=700 mm; H=370 mm) stores ~2 kg (20 Nm^3) H_2 and has a weight ~500 kg when filled with water.
- For sufficient counter-balancing, all the components are assembled within rectangular metal casting body, and the most of its internal volume was occupied by the MH tank.

Prototype FC power module with integrated MH hydrogen storage (Hawaii Hydrogen Carriers)
A. Narvaez. Presentation at US DOE Annual Merit Review Meeting, June 18, 2014, Project ST 095

Mine locomotive

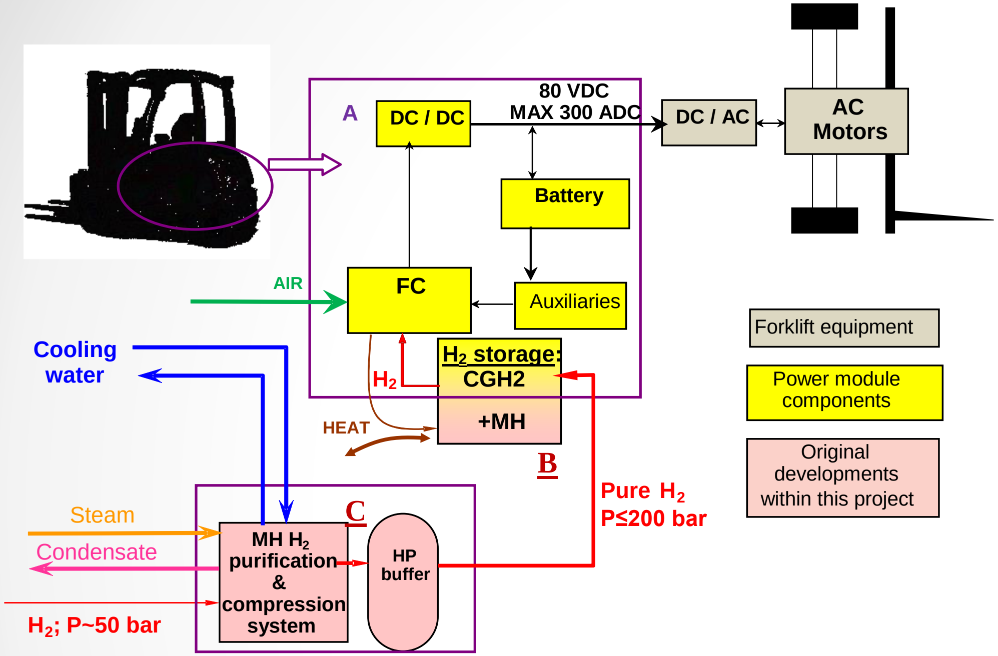


MH tank FC power module

FC powered mine locomotive with integrated MH hydrogen storage (Vehicle Projects, Inc. & Anglo American Platinum)
P. Valicek, F. Fourie, 6th Int. Platinum Conf, 'Platinum–Metal for the Future', The Southern African Institute of Mining and Metallurgy, 2014

- Low weight H_2 storage capacity in MH is not drawback but advantage for this application.
- **Main challenge of conventional solutions (MH containers in a water tank) is still insufficient system weight / too big size of the H_2 storage system.**

FC forklift with commercial FC power module and MH extension tank



- In 2012-2015, HySA Systems integrated a MH H_2 storage extension tank in a commercial GenDrive 1600-80CEA fuel cell power module (Plug Power Inc.) which was installed in a 3 tonne STILL electric forklift.
- Main performances (VDI-60):
  - Energy consumption 11.15 kWh/h.
  - H_2 fuel consumption 689 NL/kWh (CGH2 31%, MH 69%).
- The prototype is in operation at Impala Platinum refineries in Springs, South Africa, since September 2015.

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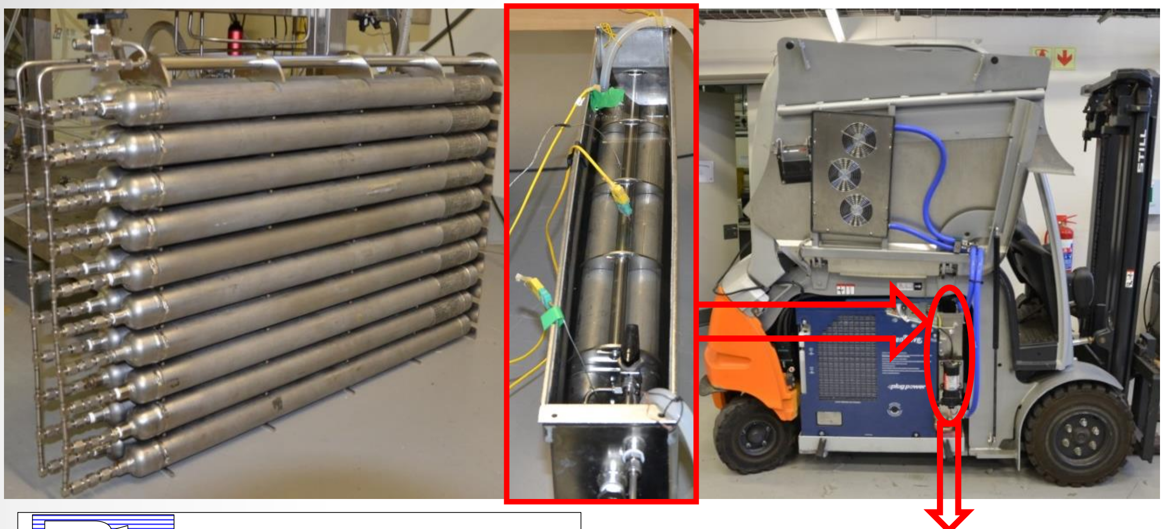
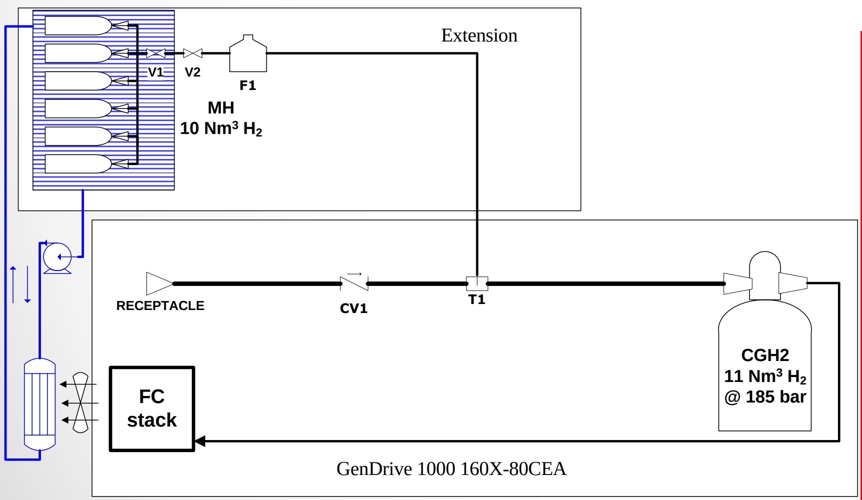
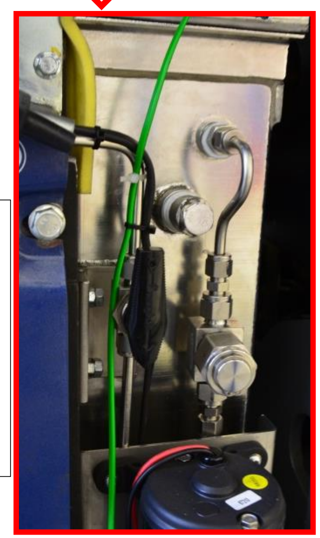
IMPALA Member of the Implats Group

Lototskyy M. et al, Int. J. Hydrogen Energy, 41 (2016) 13831
Lototskyy M. et al, J. Power Sources, 316 (2016)

MH extension tank: details







- Assembly of 20x MH containers connected in parallel to gas manifold.
- The assembly is submersed in external water / glycol tank providing thermal control during the charge (cooling with ambient air) and discharge (heating from the FC stack).
- Dimensions 950 (L) x 120 (W) x 700 (H) mm; weight ~200 kg.
- The tank is fitted in the forklift in the space remaining vacant after the installation of the GenDrive power module.
- The total weight of the power module and the extension tank is ~1800 kg that provides sufficient counter-balance for the safe forklift operation when lifting up to 3 tons.
- Only minor changes in high-pressure H_2 system of the GenDrive power module.
- 21 Nm^3 H_2 total capacity at charge pressure of 185 bar (for CGH2 only ~19 Nm^3 @ 350 bar).

- **Next step: full integration of the MH H_2 storage in fuel cell power module**

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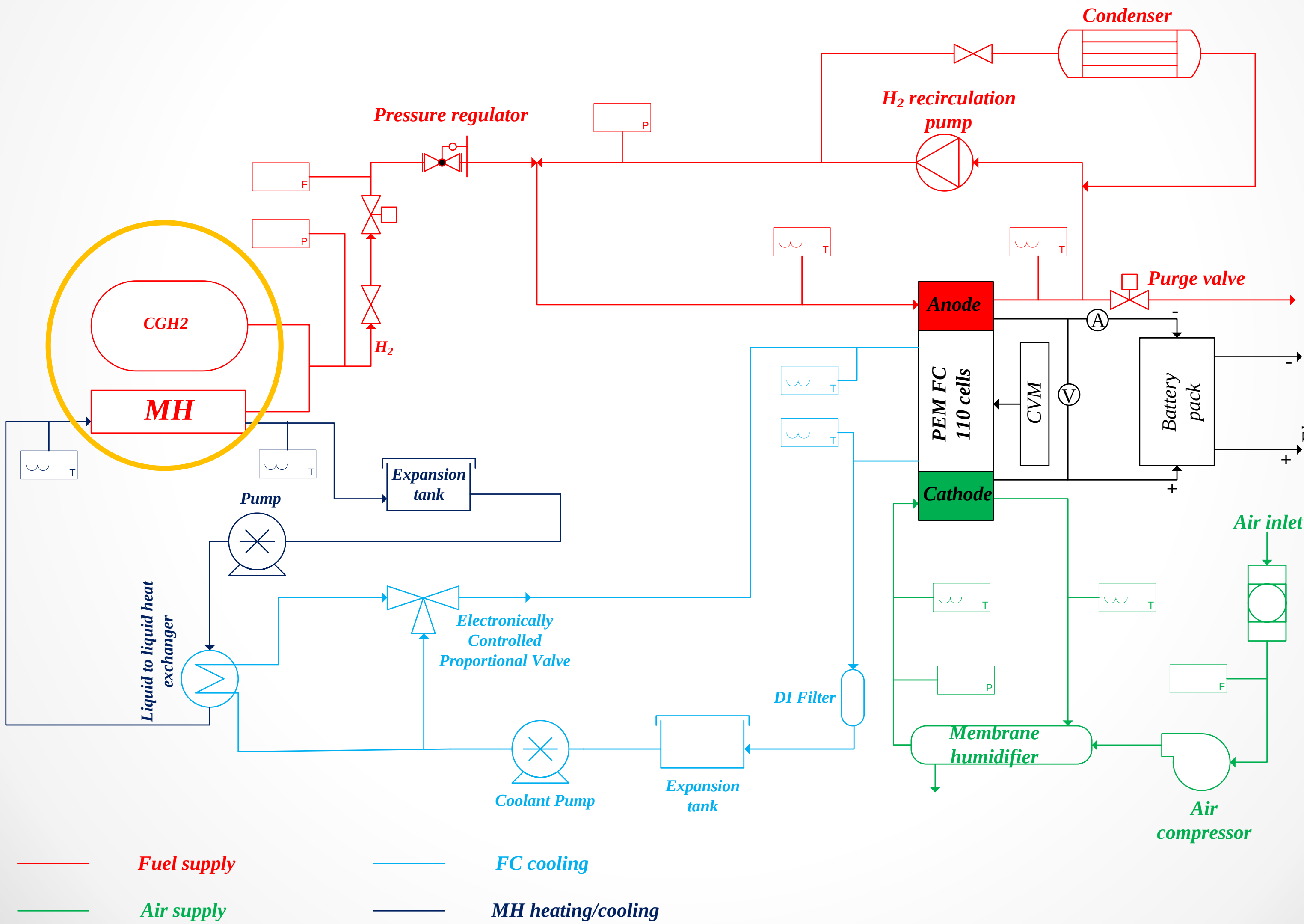
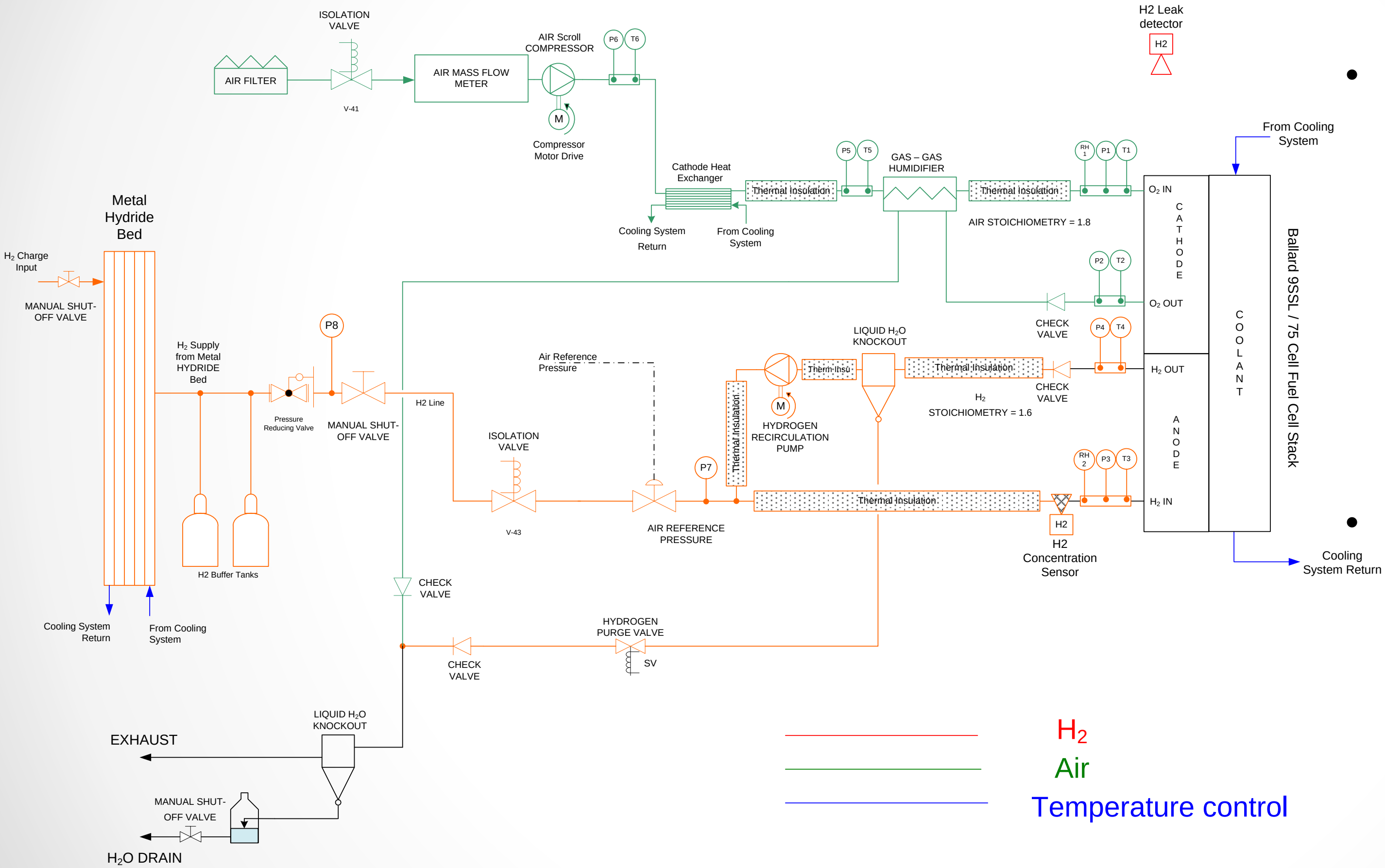
HySA Systems power module for forklift: concept



BoP design

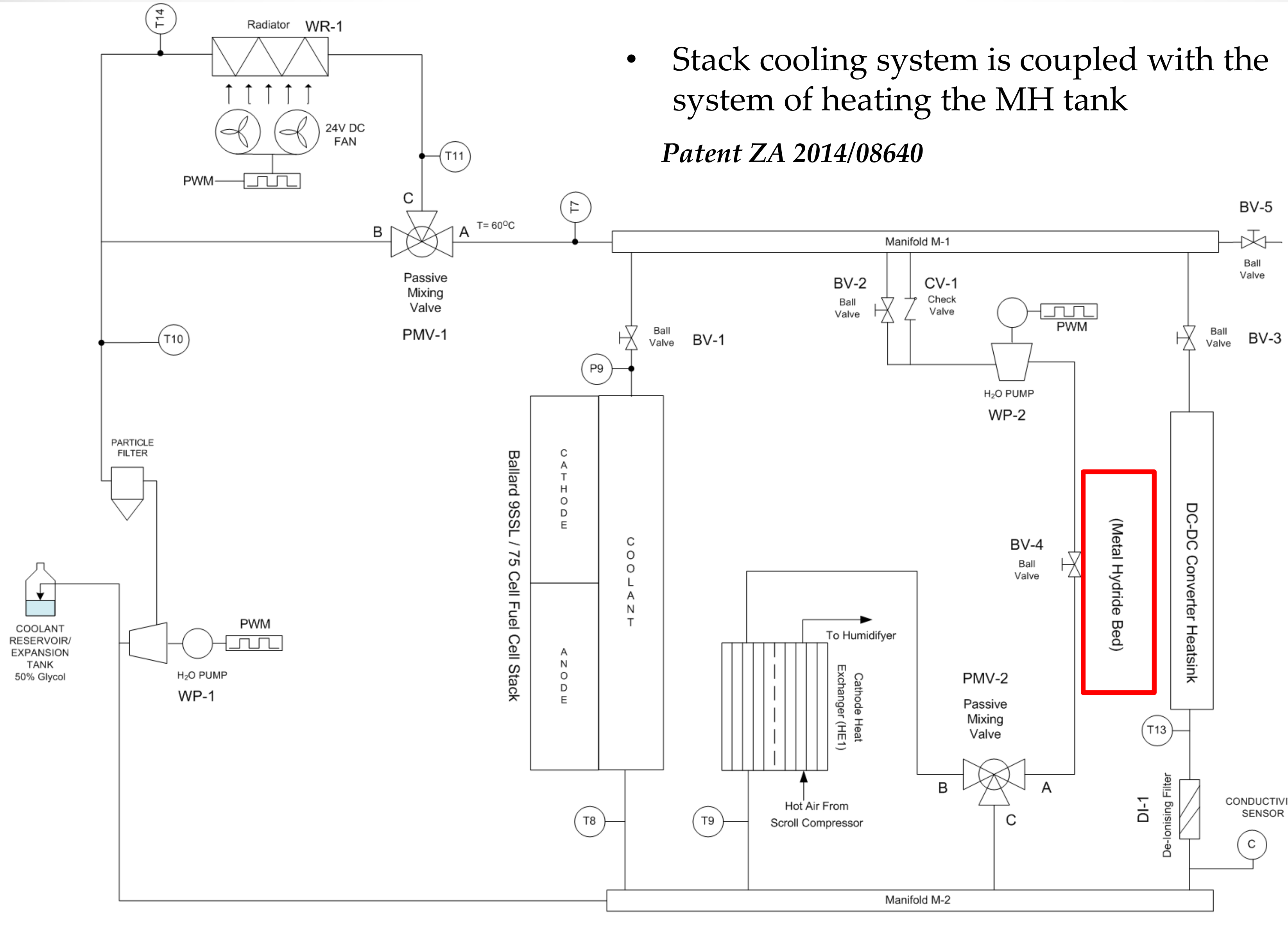


- The BoP designed around Ballard 9SSL / 75 Cell FC Stack.
- Main subsystems include:
  - The Cathode, Air Subsystem;
  - The Anode, H_2 Subsystem;
  - The Closed Circuit Water cooling (stack) / heating (MH) subsystem.
- Challenges:
  - Component selection constraints (availability, functionality & performance, size);
  - **Insufficient weight (ballast required);**
  - Alignment of the communication protocols

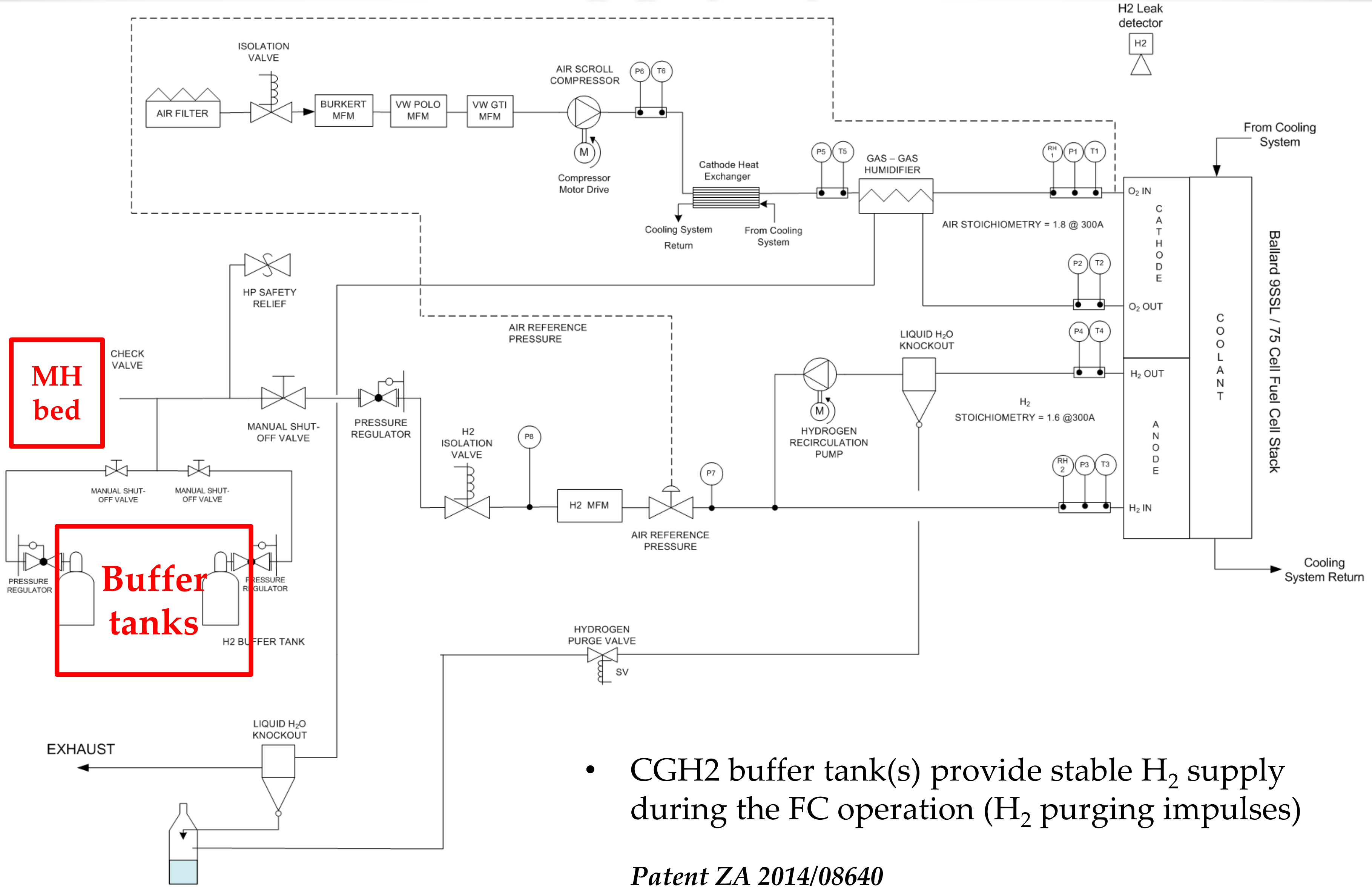
Stack cooling / MH heating system

- Stack cooling system is coupled with the system of heating the MH tank

Patent ZA 2014/08640



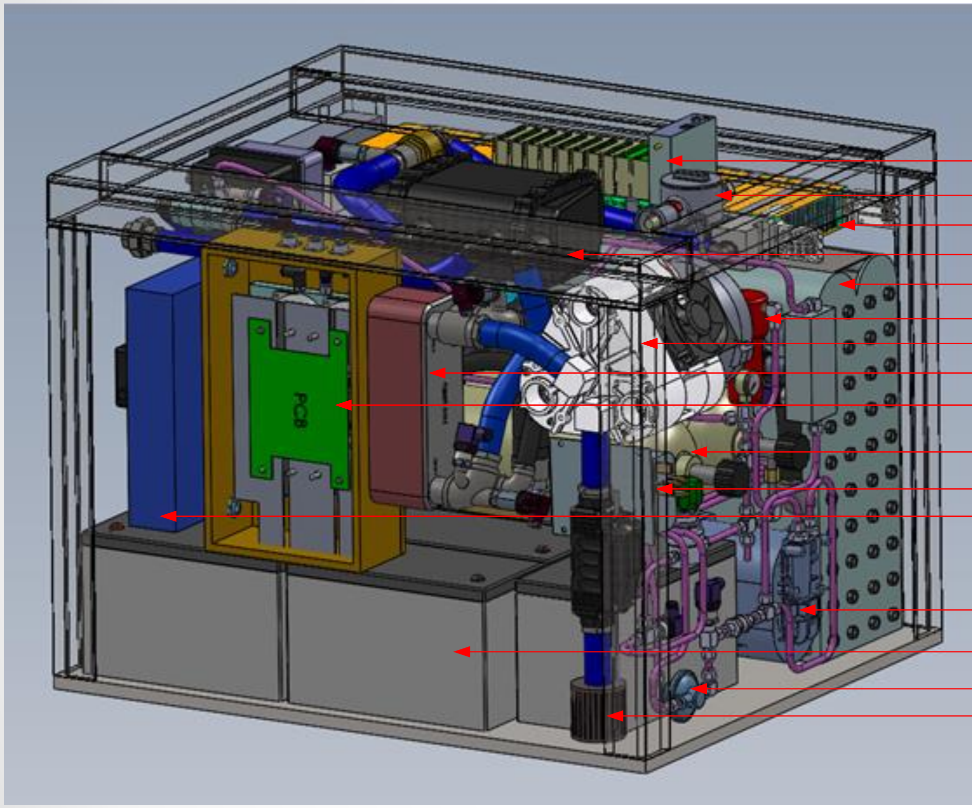
Gas supply system



- CGH2 buffer tank(s) provide stable H_2 supply during the FC operation (H_2 purging impulses)

Patent ZA 2014/08640

HySA Systems power module for forklift: Specification and preliminary design

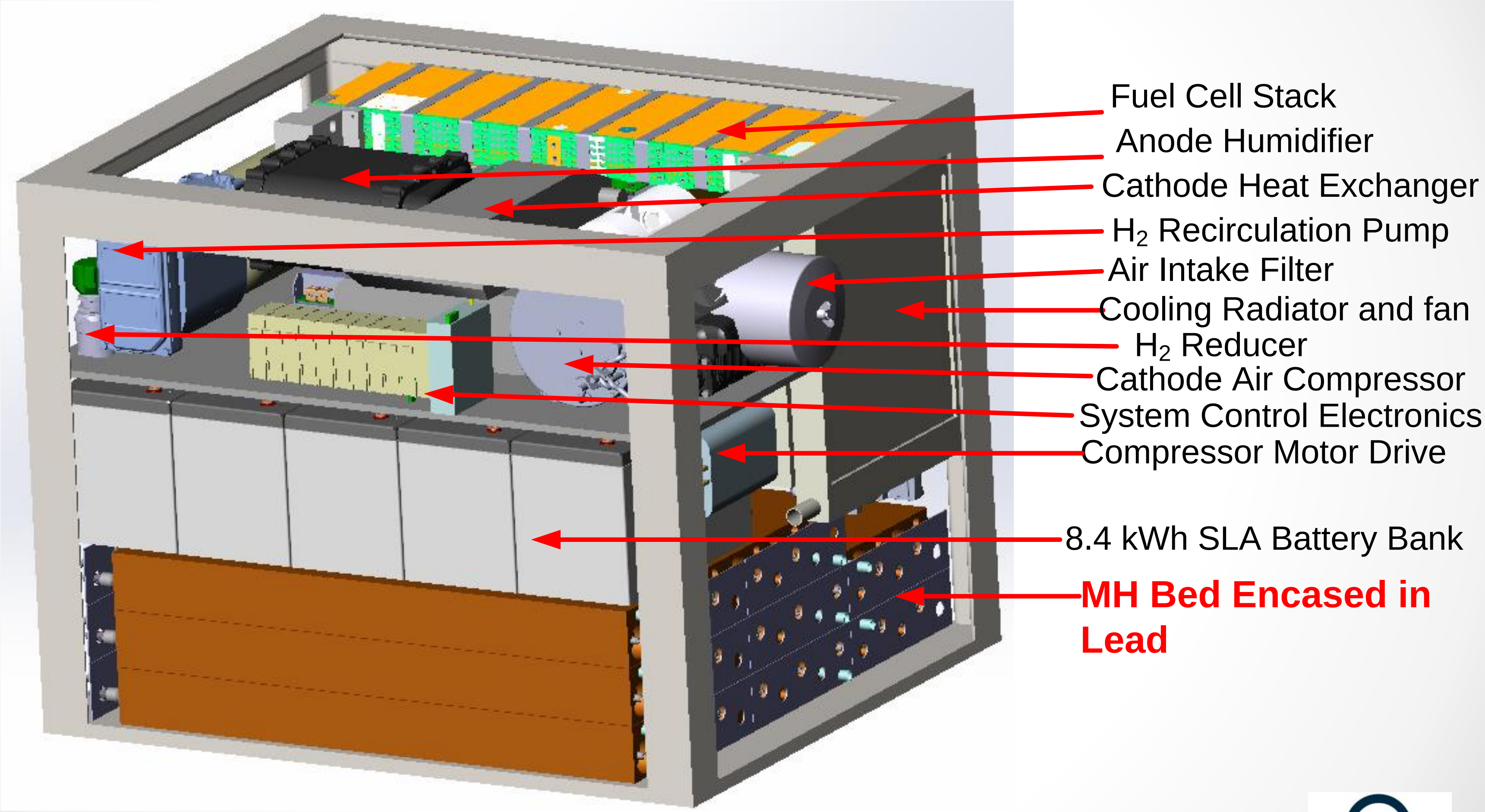


- Stack: closed cathode FC;
- H_2 storage: integrated MH storage unit, 20 Nm^3;
- Battery bank: deep cycle lead-acid, 8…10 kWh.

- Donor vehicle: STILL RX60-30L;
- Bus voltage (VDC): 80;
- Output power (kW): ~15 (average), up to 30 (peak);
- Dimensions (mm): 840 (L) x 1010 (W) x 777 (H);
- Weight (kg): 1800…1900

- **The total weight of the power module ~650kg. Addition of 1150 kg of a ballast is required to achieve the target weight.**
- **The size of the MH bed and water tank is almost 40% of the total space in the power module compartment. CGH2 buffer tanks do not fit in the available space**

HySA Systems power module for forklift: Updated design



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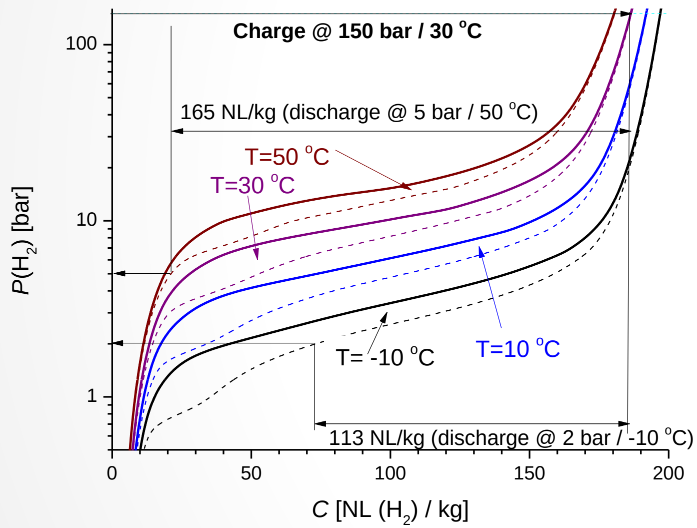
MH hydrogen storage: material

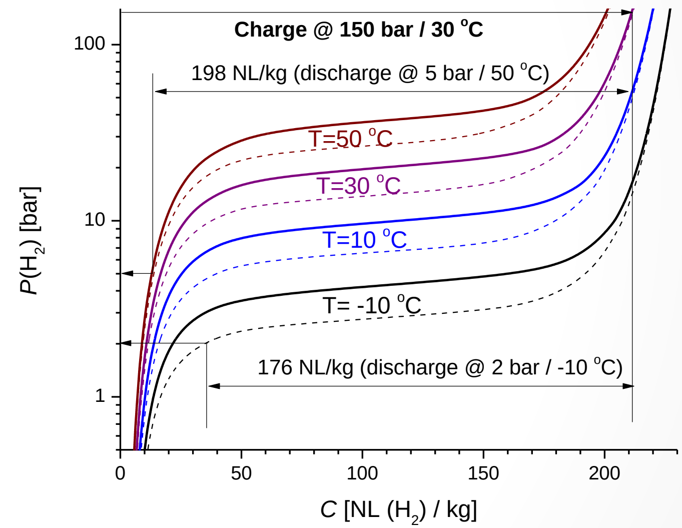
- *C-14 AB_2-type intermetallides; A=Ti+Zr, B=Mn+Cr+Ni+V+Fe*

Alloy 1: imported from CN (custom order)



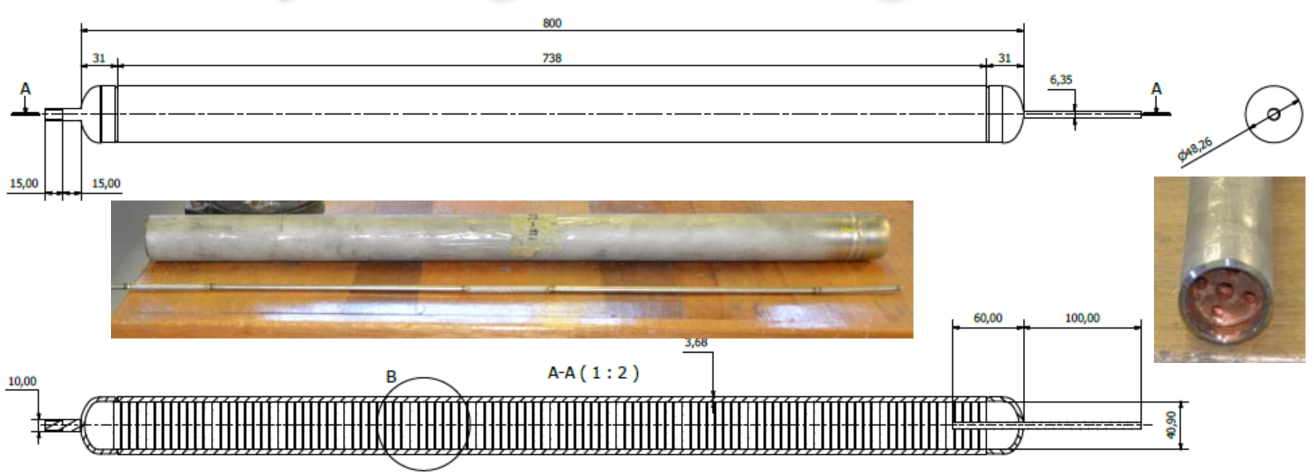
$Ti_{0.55}Zr_{0.45}(Cr,Mn,Fe,Ni)_2$ + 10 wt% $La_{0.8}Ce_{0.2}Ni_5$

Alloy 2: manufactured by HySA Systems



$Ti_{0.85}Zr_{0.15}(Mn,V,Ni,Cr,Fe)_2$

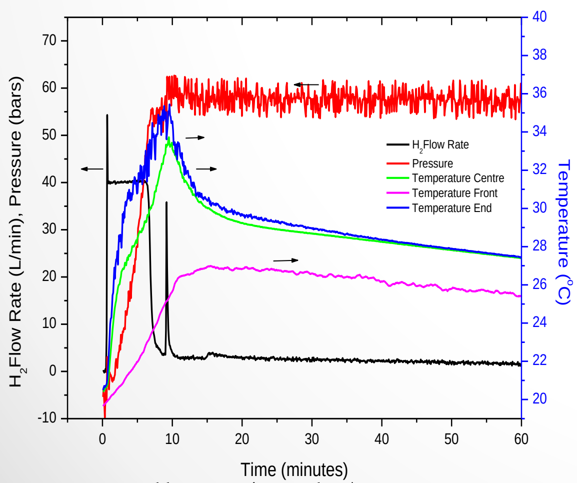
MH hydrogen storage: container



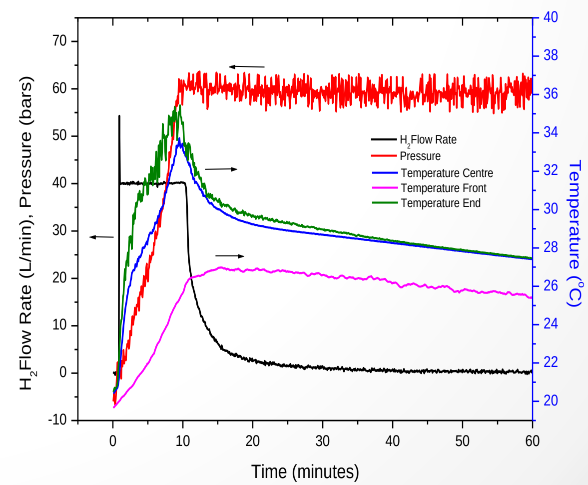
- *Standard SS pipe with pressed-in perforated copper fins*
- *Addition of expanded natural graphite to the MH powder*
- *Rated up to 190 bar / 100 °C*
- *External heating / cooling*

Patent application WO 2015 189758 A1; patent ZA 2016/08250

H_2 charge performance



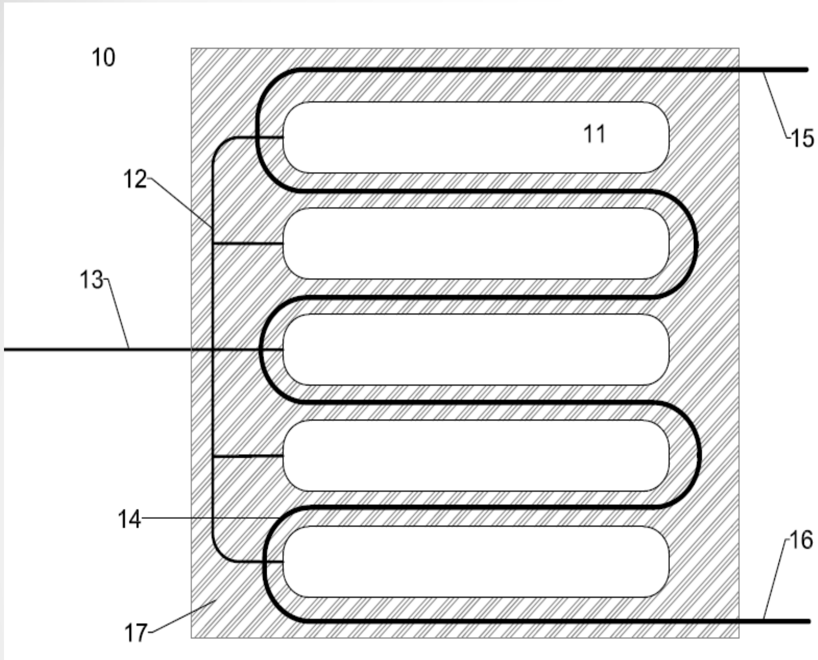
Alloy 1 (3.1 kg): ***503 NL H_2***



Alloy 2 (2.9 kg): ***624 NL H_2***

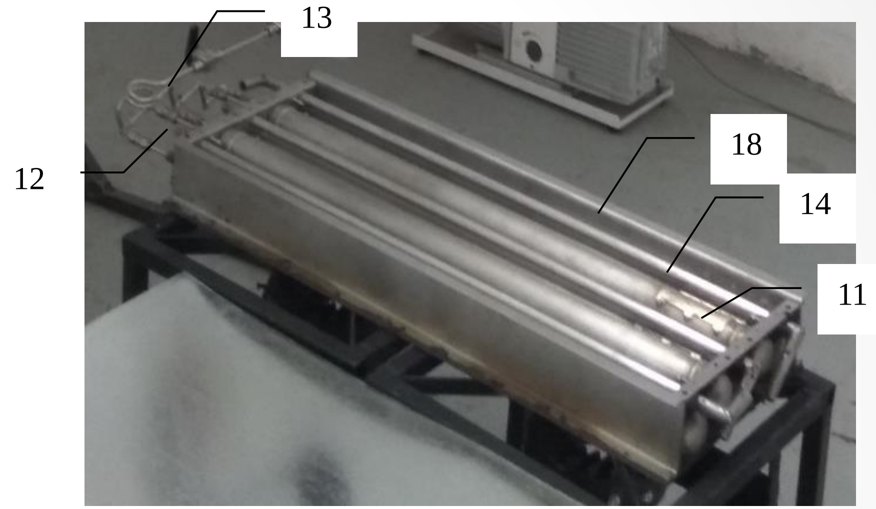
MH hydrogen storage: tank (general layout)

MH cassette



10 – metal hydride cassette:
- *11 – metal hydride container*
- *12 – gas manifold*
- *13 – external pipeline of the gas manifold*
- *14 – heating / cooling means*
- *15, 16 – external heating / cooling pipelines*
- *17 – filling body (lead alloy)*
- *18 – pre-assembly of the MH cassette*

MH cassette pre-assembly before lead encasing



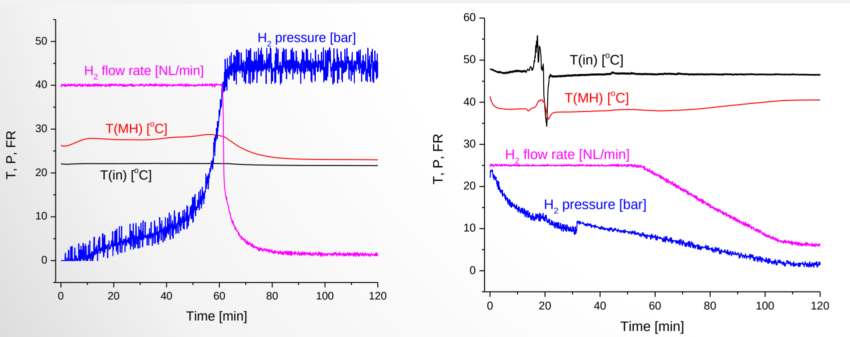
- Main challenge of conventional solutions (MH containers in a water tank) is insufficient system weight.
- **<u>Suggested approach</u>: assembly of cassettes each comprising several MH containers encased in lead.**

✓ ***Patent application UK1806840.3; 26.04.2018***

MH hydrogen storage: tank

Lead encasing

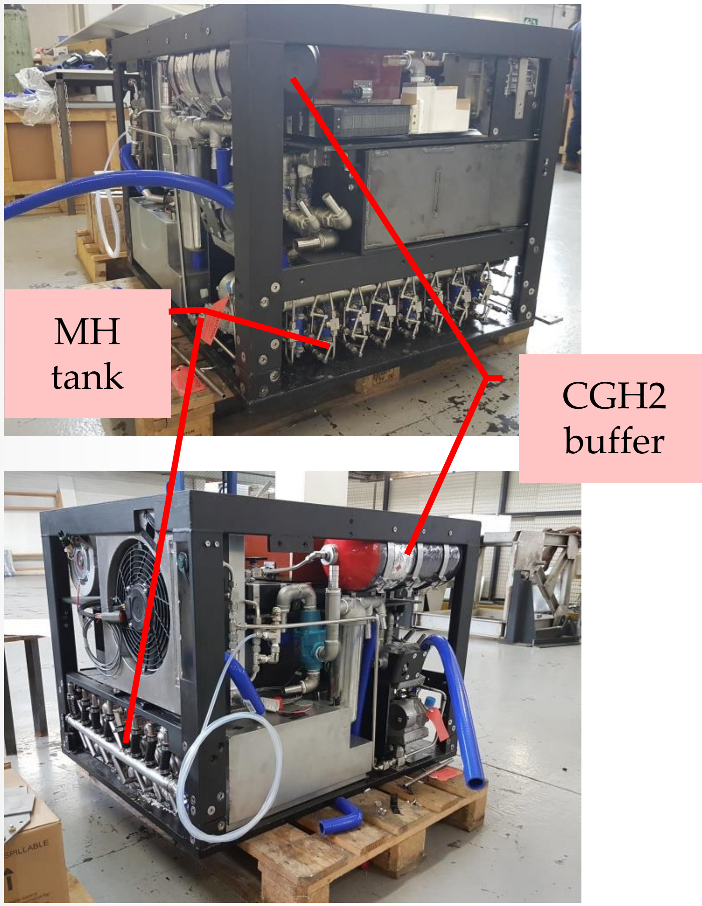
Left: two ready-to-use MH cassettes. Right: MH tank for forklift power module comprising 8 MH cassettes



H_2 charge (left) and discharge (right) performance of the MH cassette; water flow (T=T(in)) ~4 L/min

- Special procedure of lead encasing which allows to simultaneously activate the MH material in the MH cassette has been developed.
- When heated with running water to T=40–50 °C, the cassette releases more than 60% of its full capacity (~2.5 Nm^3) at the H_2 flow rate of 25 NL/min.
- 8 MH cassettes have been manufactured and installed in the frame of forklift power module to form, together with 9L buffer cylinder, a hydrogen storage tank.
- **The tank is characterised by H_2 storage capacity above 20 Nm^3 (1.8 kg) and has a weight ~1.2 tonnes that allows to provide counterbalancing weight (1850 kg for the whole power module within the space constrains) necessary for the safe operation of 3 tonne forklift.**
- The tank can provide >2 hour long H_2 supply to the FC stack operated at 11 kWe (H_2 flow rate of 120 NL/min).
- The refuelling time of the MH tank (T=15–20 °C, $P(H_2)$=150–180 bar) is about 15–20 minutes.

FC power module: Assembling on-board prototype



- Optimised BoP configuration (FC stack + SLA battery pack + supercapacitors) and control algorithms.
- Integration of the heating circuit of the MH tank with the stack cooling system.
- Optimisation of the fuel supply and purging strategy to reduce H_2 consumption and increase efficiency is in progress.

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Conclusions

- The use of fuel cells in heavy duty utility vehicles, including material handling units / forklifts or underground mining vehicles, has a number of advantages over similar diesel / LPG or battery-driven vehicles.
- Most of vehicular FC power systems have utilised compressed H_2 stored in gas cylinders at pressures up to 350 bar. This solution, however, results in too light weight of the FC power modules for the utility vehicles which require additional ballast for a proper counterbalancing to provide vehicle stability.
- Intermetallic hydrides with H storage capacities below 2 wt% can provide compact H_2 storage simultaneously serving as a ballast. However, further weight increase is necessary for the sufficient counterbalancing within strict space constrains.
- New engineering solution of a MH hydrogen storage tank for FC utility vehicles which combines compactness, adjustable high weight, as well as good dynamics of hydrogen charge / discharge has been developed.
- The developed MH tank comprises plurality of MH cassettes made as assemblies of externally heated / cooled MH containers staggered together with the heating / cooling tubes and encased in molten lead followed by the solidification of the latter.
- The MH tank has been successfully integrated in a prototype fuel cell power module for electric forklift.

Acknowledgements

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