Fuel cell power module for electric forklift with integrated metal hydride hydrogen storage system

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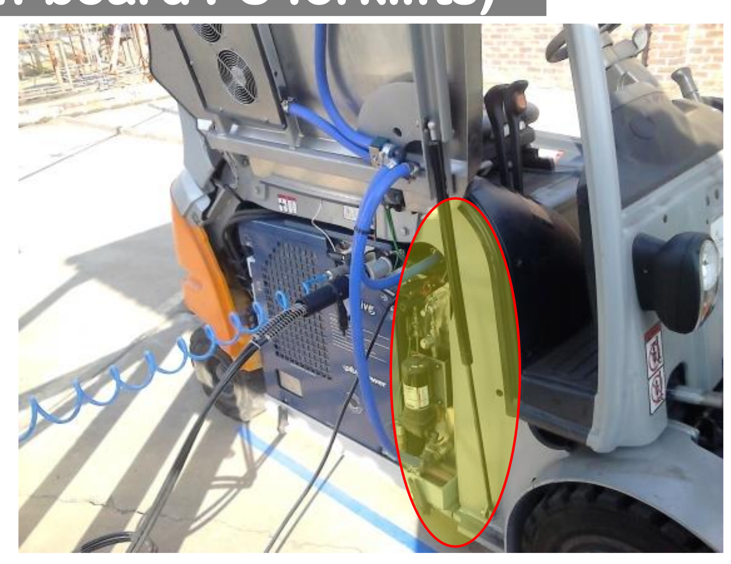
Almost all demonstrated FC powered forklifts use compressed H_2 stored in composite gas cylinders at pressures up to 350 bar. As a result, FC powered modules are too light, and additional ballast is required for proper vehicle counterbalancing. Use of metal hydrides (MH) for the on-board hydrogen storage is promising alternative to solve this problem [1].
In 2012-2015, HySA Systems integrated a metal hydride 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 [2]. This prototype is in operation at Impala Platinum refineries in Springs, South Africa, since September 2015, and the malfunctions identified were mainly related only to Lithium Nickel Manganese Cobalt Oxide (NMC) battery.
In this work, we present a prototype fuel cell power module with integrated MH hydrogen storage system for 3-tonne electric forklift developed by HySA Systems and integrated by Hot Platinum (Pty) Ltd, South Africa. The BoP was designed around Ballard 9SSL/75 Cell FC stack, and its main components included: air supply, H_2 storage and supply, the closed circuit liquid stack cooling / MH heating, and power conditioning and control subsystems. The MH tank has dimensions of 704 mm (W) x 970 mm (D) x 270 mm (H), weight ~1200 kg and combines functions of H_2 storage and vehicle ballast thus adding flexibility to the layout of the BoP components within strict space constrains of the application. Direct integration of the MH tank in the power module allowed to decrease minimum H_2 pressure on the high-pressure side of H_2 subsystem from 13.5 to 3-4 bar and to use more stable MH resulting in a lower refuelling pressure (100-150 against 185 bar) at the similar useable H_2 storage capacity and refuelling time as compared to the commercial FC power module with MH extension tank [2].
The tank is an assembly of several MH cassettes each comprising several MH containers made of stainless steel tube with embedded perforated copper fins and filled with a powder of a composite MH material, which contains AB_2- and AB_5-type hydride forming alloys and expanded natural graphite. The assembly of the MH containers staggered together with heating / cooling tubes in the cassette is encased in molten lead followed by the solidification of the latter. The tank can provide >2 hour long H_2 supply to the fuel cell 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) up to 150 bar) is less than 15 minutes. Preliminary results indicated a possibility of further lowering the refuelling pressure.

Background (H_2 storage on-board FC forklifts)



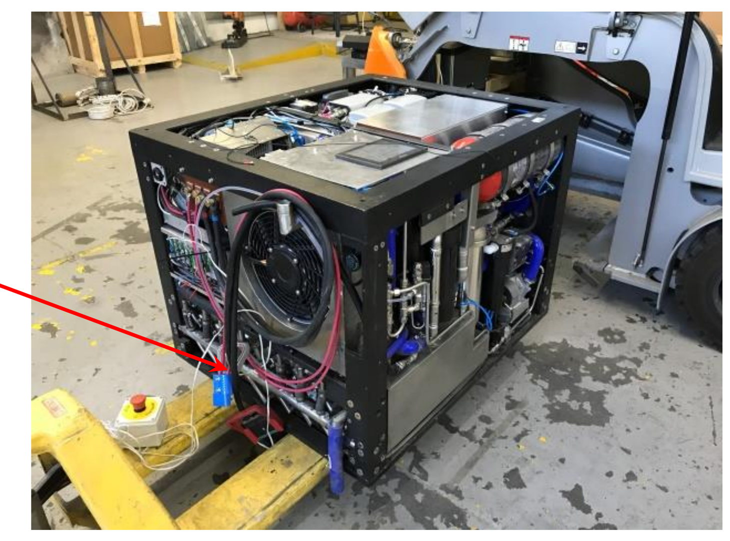
CGH2:

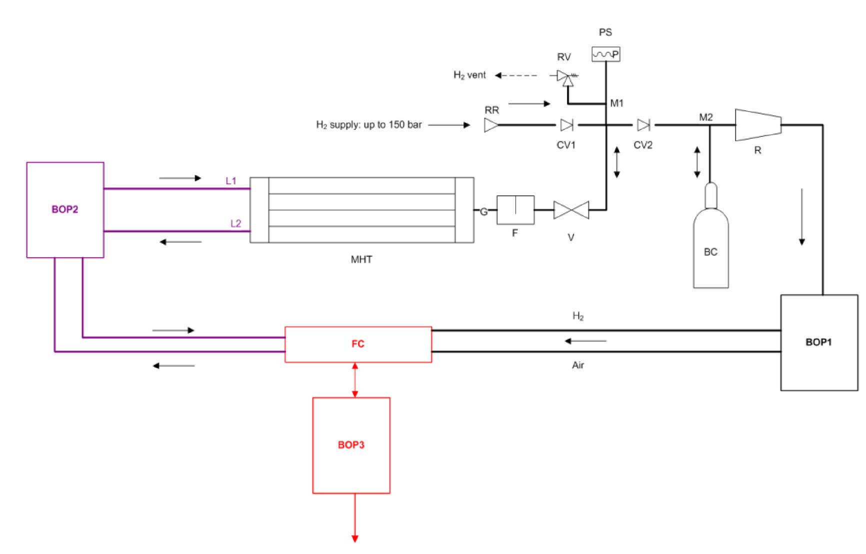
- •Approved technology, limited mass production;
- •Fast refuelling;
- •Safety and refuelling infrastructure (filling H_2 pressure ~350 bar);
- •Space constrains;
- •Additional counterbalance required (forklift operation safety).

MH:

- •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).

Integration of MH H_2 storage tank in FC power module on-board electric forklift

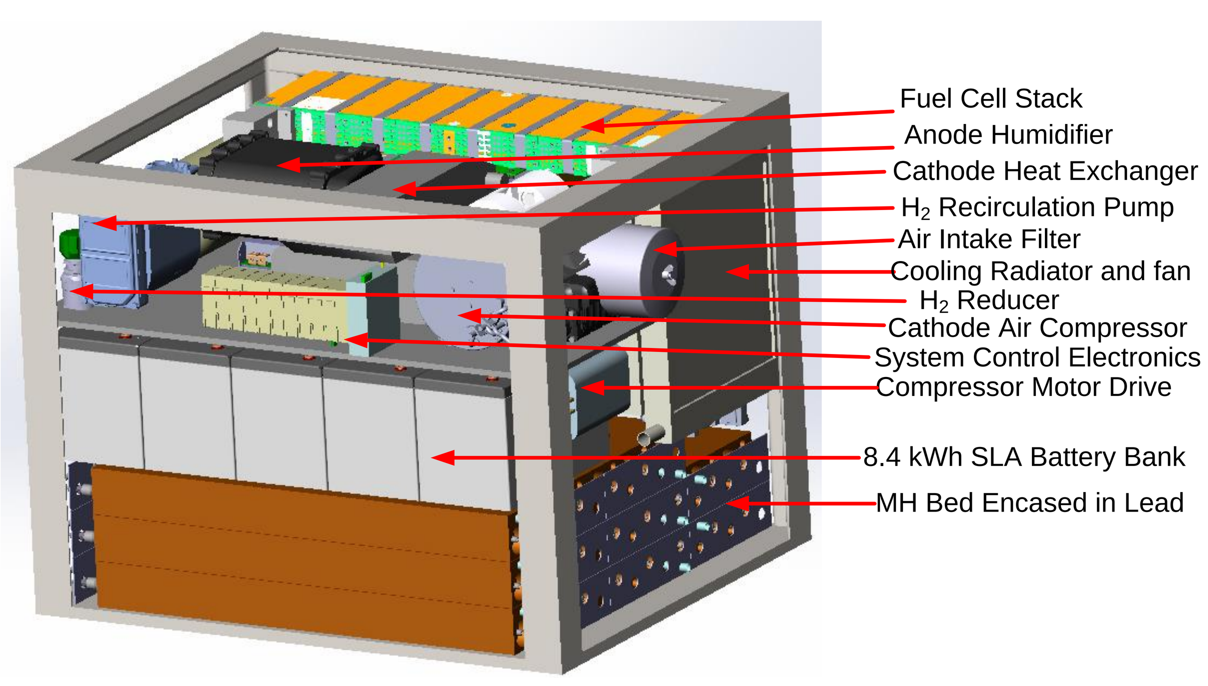




- ❖ The MH tank comprising of eight lead-encased MH cassettes;
- ❖ Both gas and heating / cooling liquid pipelines of the eight cassettes are connected in parallel,
- ❖ Introducing of a buffer cylinder allows to realise a concept of “distributed hybrid” hydrogen storage and supply system which significantly improves performance of H_2 supply from the MH.

Characteristic		CGH2 tank in the commercial FC power module	CGH2 tank in the commercial FC power module with MH extension tank	MH + CGH2 tank in locally developed FC power module
Maximum refuelling pressure [bar]		350	185	150
Minimum operating pressure [bar]		13.5	13.5	4
Number of MH containers		–	20	40
Total weight of power module and MH tank installed in the forklift		1600	1784	1830
System inner volume [L]	CGH2	74.2	74.2	9.0
	MH	–	7.4	14.8
	Total	74.2	81.6	23.8
Useable H_2 storage capacity [kg]	CGH2	1.7	0.9	0.1
	MH	–	0.9	1.7
	Total	1.7	1.8	1.8
Refuelling time [min]		3–5	6–15	9–15
Maximum H_2 supply flow rate [NL/min]		130	170	170

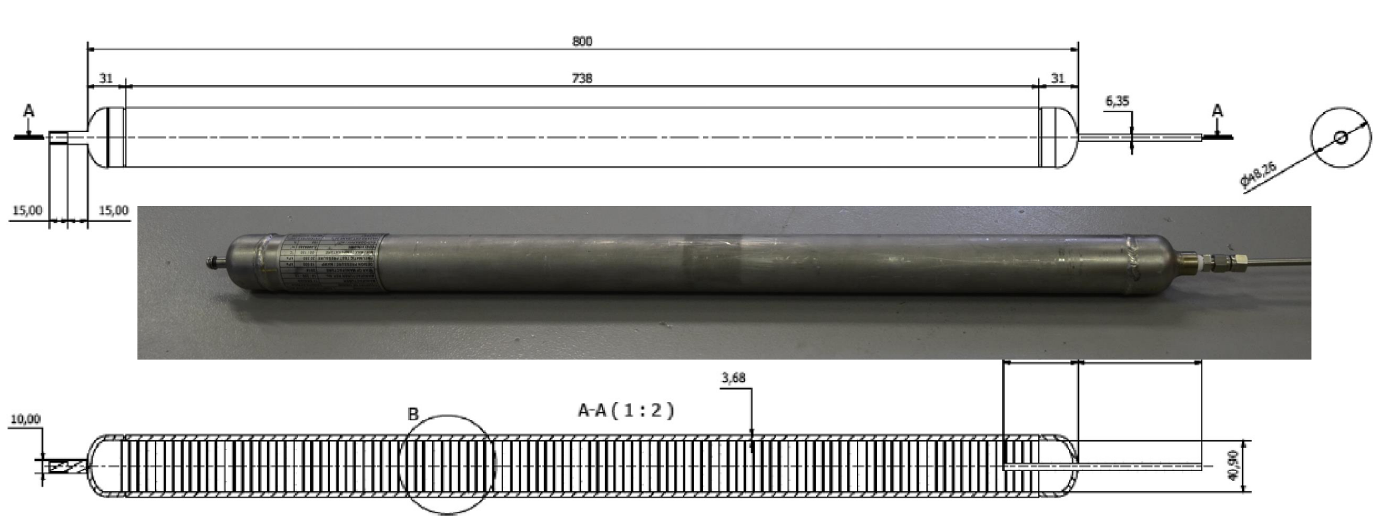
Specification and concept design



- 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

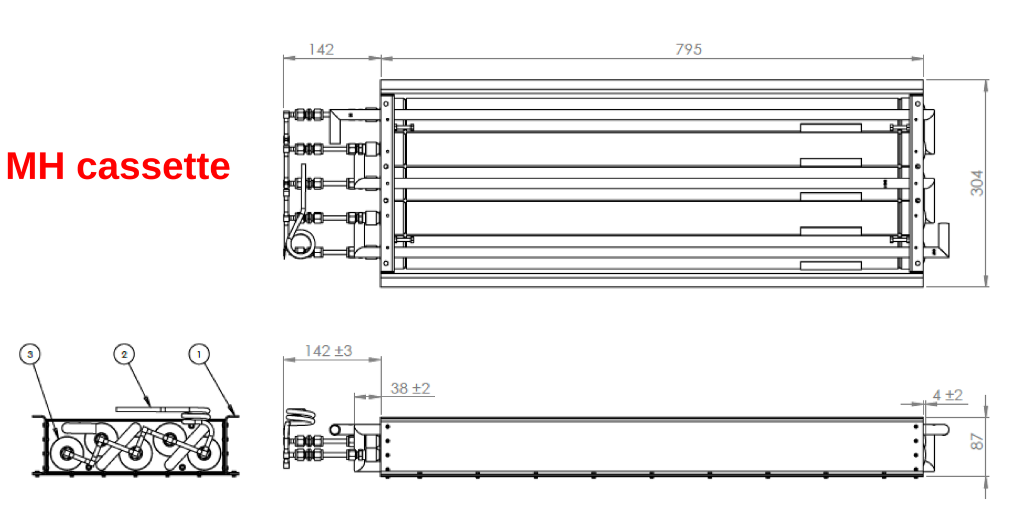
- ➢ Stack: closed cathode FC;
- ➢ H_2 storage: integrated MH storage unit, 20 Nm³;
- ➢ Battery bank: deep cycle lead-acid, 8…10 kWh.

Hydrogen storage system

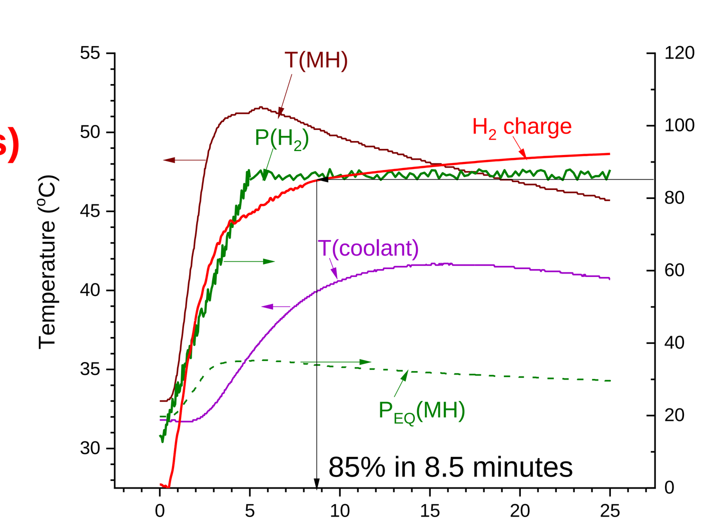


❖MH container

❖MH cassette



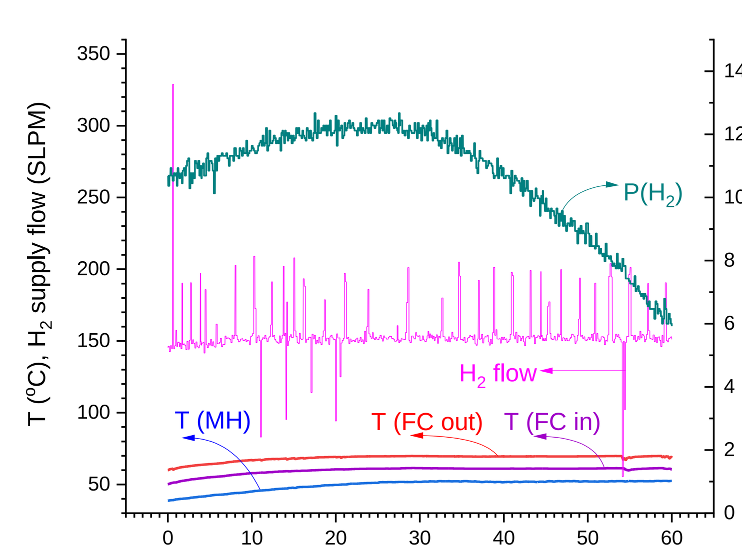
❖MH tank (8x cassettes)



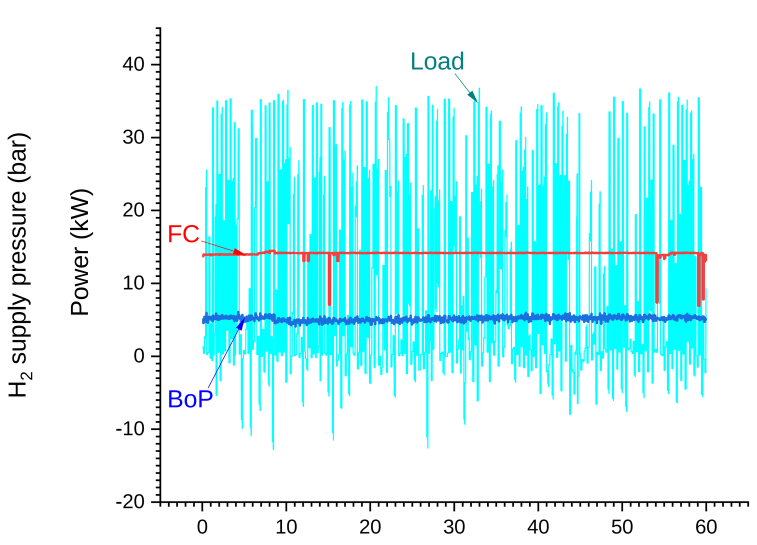
H_2 charge of the MH tank on-board power module

Fuel cell power module: VDI 60 test results

- ❖ Ambient air temperature during test was 26.5 ℃;
- ❖ Load energy consumption during 60 VDI combustion cycles/hour 9.564 kWh/h (7.5 kWh/h according to the manufacturer),
- ❖ BoP consumption during 60 VDI cycles 5.138 kWh/h,
- ❖ MH tank heating from the FC cooling system was sufficient to maintain required H_2 flow rate during the operation.



Characteristic temperatures in the power module and H_2 supply pressure and flow rate during VDI 60 tests



Electric power profiles during VDI 60 tests

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