INNOVATIVE H2 COMPRESSION

Project No.: 736122
Project acronym: COSMHYC

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COmbined hybrid Solution of Metal Hydride and mechanical Compressors for decentralised energy storage and refuelling stations

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Summary report on test results for the compressors

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RE	Restricted to a group specified by the consortium (including FCH2 JU Services)	
CO	Confidential, only for members of the consortium (including FCH2 JU Services)	

Document History

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Introduction

The COSMHYC project aims at developing a hybrid compression concept coupling a metal hydride compressor (MHC) with a mechanical compressor (MC), enabling to combine the advantages of both technologies to supply hydrogen at very high pressure with an optimized design and energy consumption.

Following the design and fabrication of components of both compressors (incl. metal hydrides and reactors, new membranes and components for the mechanical compressor, etc. performed in WP3 and WP5, as well as the construction and commissioning of the MHC in WP4 and MC in WP5), both compressors were installed, commissioned and tested on 2 different sites, in Denmark and Germany. 12 months of operation for the MC and 4 months for the MHC took place and enabled to assess the performances of both technologies as well as the pertinence of their combination. This deliverable presents the main results of the test campaign.

This report has been documented and validated at EIFER under the reference: HN-43/21/016.

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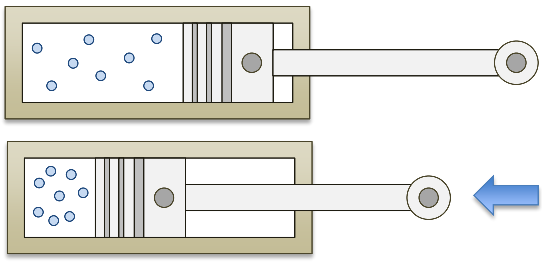
1. Principle of the technology

The COSMHYC project aims at developing a hybrid compression concept based on metal hydrides combined with a mechanical compressor, combining advantages of both technologies to supply hydrogen at very high pressure with an optimized design and performance.

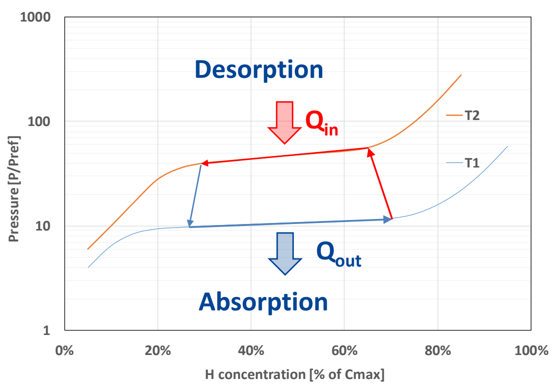
The mechanical compression consists of decreasing the volume of a gas by applying a mechanical force on a piston, as illustrated below, directly or indirectly driven by electricity.



$$W_t = C \cdot T_1 \cdot \left[\left(\frac{P_2}{P_1} \right)^d - 1 \right]$$

The work needed for the compression is directly related to the ratio between the outlet / inlet pressure. Therefore, the mechanical compression is inefficient to compress hydrogen from very low to very high pressure. In addition several practical issues are encountered in the operation of current compressors (hydrogen contamination if lubricants are used, noise disturbance, high maintenance costs). On the other hand, mechanical compression is very efficient to boost hydrogen for the last compression step, (e.g. from 450 bar to 950 bar), enabling very high flow rates with limited CAPEX and size, making it well adapted to adapt to meet the flexibility requirements of the refueling of fuel cell electric vehicles (FCEVs).

The metal hydride compression consists of using an thermally driven absorption/desorption effect in metal alloys. By controlling the temperature of the absorption and desorption, it is possible to desorb at higher pressure than the absorption, resulting in a compression effect, as illustrated below.

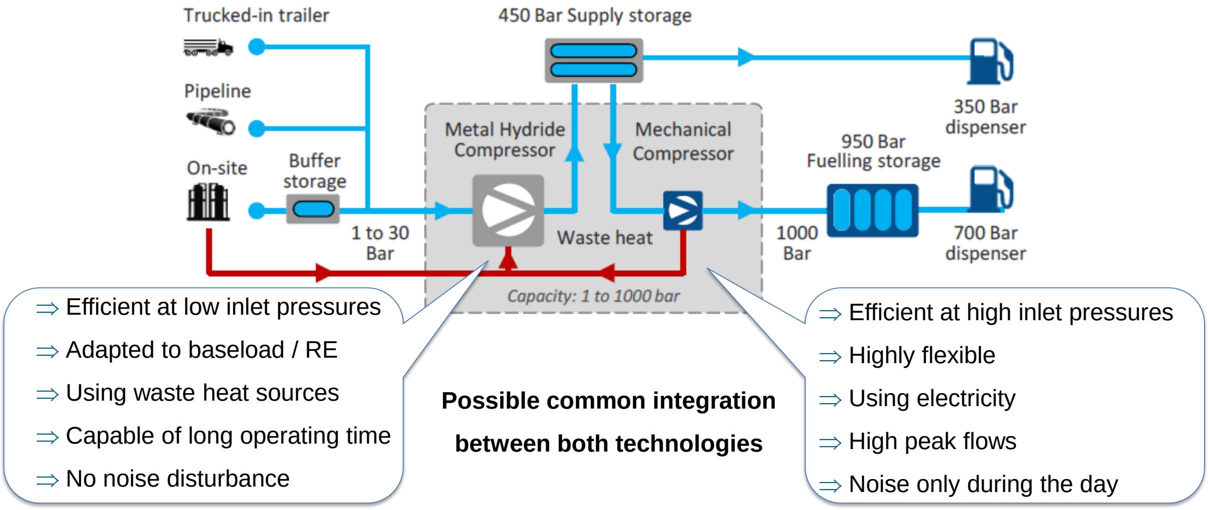


$$M(s) + x/2\ H_2 \underset{desorption}{\overset{absorption}{\rightleftarrows}} MH_x(s) + Heat$$

Van't Hoff equation: $\ln P_{eq} = \frac{\Delta H}{RT} - \frac{\Delta S}{R}$

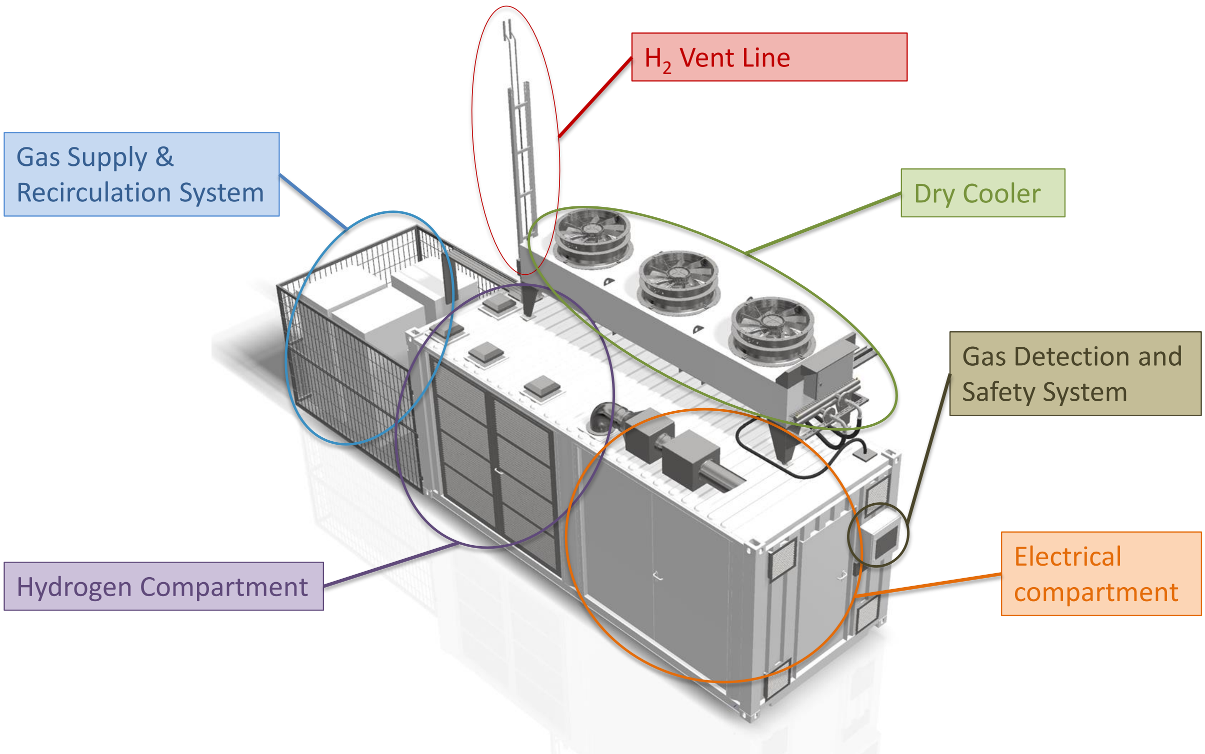
In this case, the energy consumption is no longer directly related to the pressure ratio but to the reaction enthalpy of the absorption/desorption process. The achievable pressure ratio is related to the temperature difference between the absorption and desorption, the kinetics of the cycle playing a major role in the achievable flow rates. No noise disturbance nor H2 contamination is expected as there is no more moving part in the hydrogen system. On the other hand, the temperature and number of stages must be carefully selected: the technology is of particular interest if a waste heat source can be employed, and the availability of waste heat decreases if higher temperatures are required.

As a whole, it was decided to combine both the mechanical and metal hydride technologies in order to take advantage of the strengths of both technologies, as illustrated below.



2. Results of the tests of the metal hydride compressor

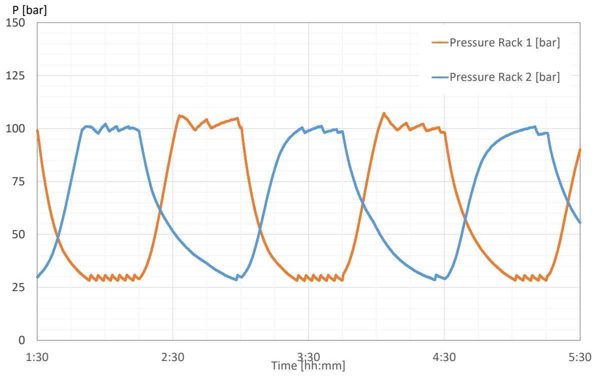
After a commissioning phase that took place until November 2020, the metal hydride compressor was tested between December 2020 and April 2021.

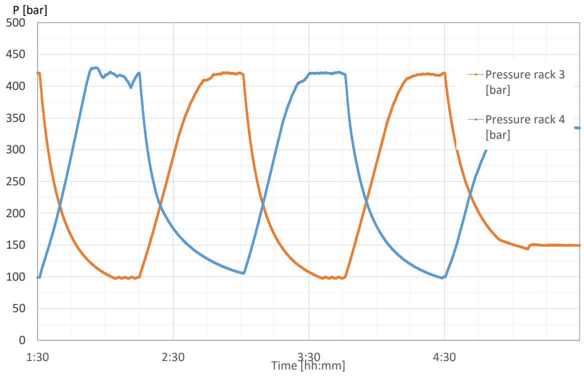




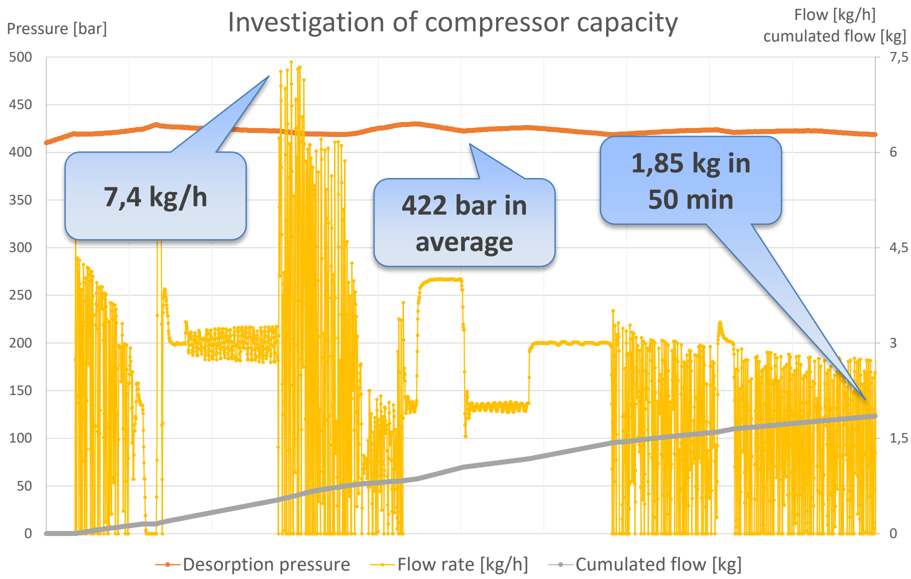
The main results of the testing phase can be summarised as described below.

- The MHC includes 2 compression stages. Pressure tests were performed on each stage and on the combination of both. An overall compression **from 28 bar to 429 bar** was measured in the field and **the possibility to compress far above 450 bar was demonstrated[1], enabling the MHC to be used as a stand-alone compression solution for a wide range of mobility applications (trains, busses, forklifts, etc.).**



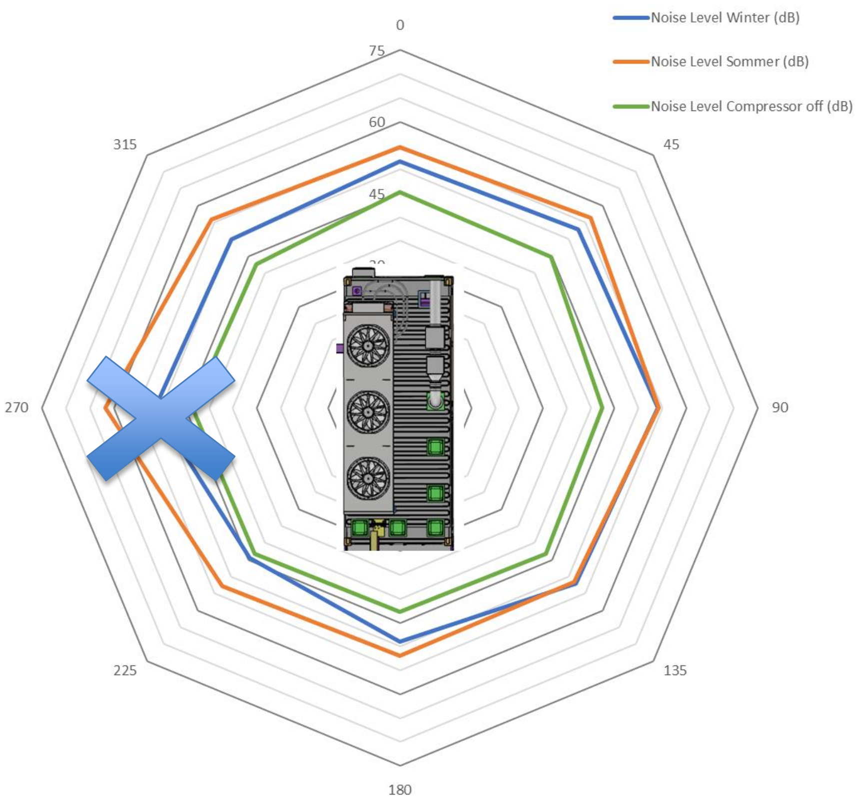


- **Peak flows up to 7 kg/h were measured.** Average flow rates over longer periods strongly depend on testing conditions & range from a few 100 g/h to a few kg/h. As a whole, **the capacity achieved in COSMHYC is >10 x higher than the state-of-art.**



[1] It was not tested during the test campaign due to the limitations of some BoP e.g. safety valves, but the measured data show that the hydrides would easily reach this pressure level if wanted.

- **Noise measurements** were performed during the tests. It turned out that most of the noise is supressed compared to a mechanical compressor. the main remaining noise source is the roof ventilation (which would be mutualised anyway with the overall ventilation concept of the station in a commercial HRS). This noise is quantitatively lower than the typical values of a compressor and qualitatively less disturbing as it is a regular noise. **A maximal noise at 5 m distance of 53.9 dB in the day mode was measured and only 50.6 dB in the night mode, far below the state-of-art (85 dB)!**

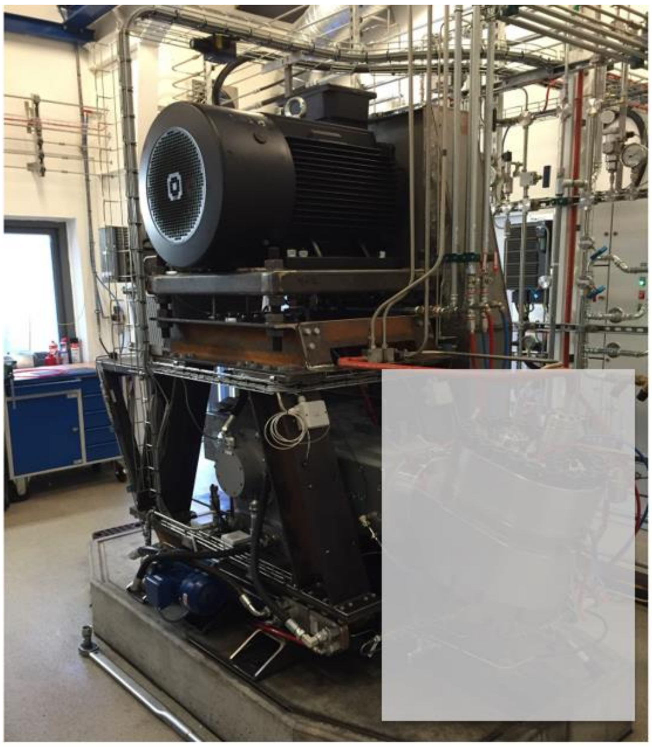


- The feasibility of using an **external heat source** instead of electricity was tested thanks to an integrated heat exchanger. The tests proved that this operation mode could be successfully implemented with satisfactory compression ratios. Therefore, **the possibility of an energy consumption close to 0 kWh/kg was demonstrated in the case of the availability of a waste heat source onsite.**

- Further improvement potential was identified. In particular, some BoP components proved to be unreliable, partly due to the components themselves, and partly due to the integration strategy in the prototype. In addition, the thermal insulation of the thermal circuits as well as the compression reactors themselves are not well insulated, resulting in significant thermal losses. Finally, fine tuning of the hydrides composition could enable to further optimise the flow rate of both compression stages.

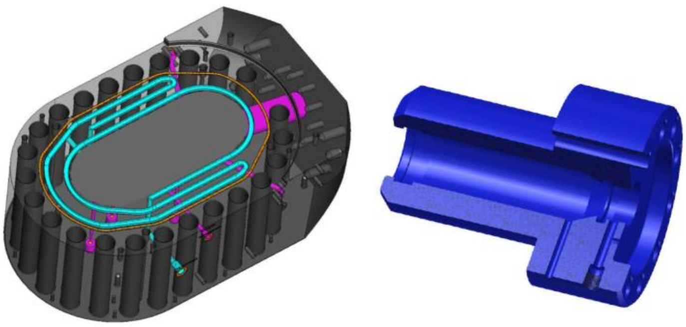
3. Results of the tests of the mechanical compressor

After a successful commissioning phase in Denmark in the facility of NEL, the Mechanical Compressor was operated and different test campaigns and profiles were performed, enabling to assess the performances of both the compressor itself as well as subsystems.



In particular, the following results could be achieved:

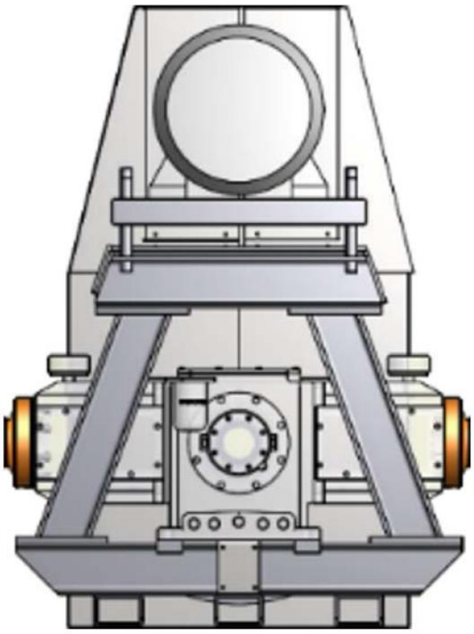
- More than **4000 hours** of operation took place successfully, enabling to demonstrate the robust design of the new membranes and compressor heads of Nel. In particular, the innovative cooling strategy of the compressor head of NEL enabled to reduce wear and tear and thus to increase the lifetime of the compressor.



Internal cooling of components

- Cold and hot tests were performed **from -10°C to +50°C**. This validate the possibility of external use of the compressor under ambient conditions, as well as the possibility to couple the MC with the outlet of the MHC, as long as the hydrogen temperature exiting the MHC does not exceed 50°C.

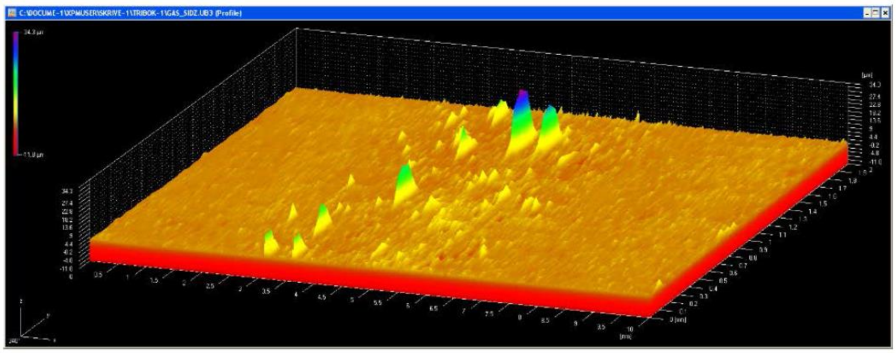
- The new power-frame developed by NEL proved to be reliable and enables the overall integration of the compressor into a single compression unit.



- A capacity of **60 kg/h** was demonstrated for an inlet pressure corresponding to the outlet pressure of the MHC. This is of high relevance as it demonstrates the boosting capacity of the MC compressor and confirms its ability to provide a significant flexibility to the HRS when coupled with a MHC.

- Energy tests could be performed. An energy consumption of **1.18 kWh/kg** was demonstrated, well in line with the project expectations. This important result validates the interest of using the MC with low pressure ratios in a booster mode, thanks to the presence of the MHC.

- A lifetime of more than **100 million cycles** was demonstrated for the diaphragm, thereby highlighting the high reliability of the membrane technology, the roughness of which was carefully investigated during the project.



Diaphragm surface profile

- Noise tests were performed and the ability to reach **<60 dB in an HRS** was demonstrated, which is far better than the state of the art and enables to strongly reduce the noise disturbance of typical mechanical compressors.

4. Conclusions and outlook

The long-term tests conducted on both MC and MHC enabled to draw the following conclusions:

- Both technologies could be successfully tested under representative conditions, incl. their own BoP, an autonomous controller and monitoring system, at representative scale. **Therefore, it is demonstrated that both technologies have achieved a maturity level of TRL, in line with the project objectives.**

- Some highly relevant KPI's were reached during the project, including: an **overall capacity** of the hybrid compression solution 10 times higher than the state-of-art, **pressure** of 450 bar reached by the MHC and 950 bar for the combined solution, strong reduction of the **noise level** down to 50.6 dB for the MHC in night mode. This highlights the interest of both technologies developed during the project and brings the European industry at the forefront of the global competition for technology leadership in hydrogen compression

- The pertinence of coupling both technologies was also demonstrated, especially the potential of achieving **very high output pressure** with a **low energy consumption**, as well as the possibility to reach a **high level of flexibility** in a HRS thanks to the reliable innovative baseload technology and the high-speed mechanical booster.

- Further **optimisation potential** has been identified, especially regarding the reliability of the BoP concept of the MHC as well as the increase of thermal performances (e.g. through a better insulation strategy). Also, the capacity must be further improved to meet the requirements of heavy mobility applications. All these optimisations will be pursued in the frame of the follow-up project COSMHYC XL.