COSMHYC XL
INNOVATIVE H2 COMPRESSION

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Deliverable 4.6
Public report on the mechanical compressor

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Change Control

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Table of content

Introduction

The COSMHYC-XL project aims at developing a hybrid compression concept for HRS with a combination of a baseload Metal Hydride Compressor (MHC), enabling a high level of reliability thanks to the absence of moving parts, and a new Mechanical Compressor (MC), enabling very large flow rates.

Work Package 4 (WP4) covers the development efforts on achieving a full-scale state-of-the-art mechanical diaphragm compression (MC) technology with improved operational parameters, such as efficiency, lifetime and costs.

This document serves as the deliverable D4.6 in WP4 outlining public results from the development of the MC.

Deviations

No material deviations have occurred during the execution of tasks and activities in relation to this deliverable.

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1. Objectives of development and test of the mechanical compressor

The objective of WP4 in the COSMHYC-XL project has been to double capacity of the mechanical diaphragm compression (MC) technology developed in the previous COSMHYC project from 30kg/hour to 60kg/hour. Specifically the following objectives were to be achieved:

- Develop 1st stage compression head achieving scale 1:1 and 60kg/hour, together with the already developed 2nd stage head in the previous COSMHYC project
- Develop a complete mechanical compressor (MC) for dual-head operation
- Construction of a laboratory prototype of the developed MC
- Conduct manufacturing assessment validating 25% cost reduction

WP4 have involved the following subtasks, which are covered in this deliverable:

- Task 4.1 – Development of 1st stage compression head
- Task 4.2 – Development of compressor dual-heads operation
- Task 4.3 – Prototype construction
- Task 4.5 – Cost and manufacturing assessment

Main and public results from each of the tasks are elaborated in following sections.

2. Task 4.1 – Development of 1st stage compression head

The objective of task 4.1 has been to develop a 1st stage compression head covering the pressure range of 20-45MPa for Mechanical Compressor (MC). When combined with the 2nd stage compression head developed in the previous COSMHYC project the MC will achieve 60kg/hour from 20MPa inlet and up to 95MPa outlet.

The lower inlet pressures required design of a much larger compression head and supporting equipment, compared to the existing 2nd stage head. Also handling of temperatures has been in focus as heat generation at the lower pressure ranges are higher – here focus has been to reduce friction and wear by optimizing material selection and surface treatments for the various components in the head.

2.1 CFD/FEA modelling of the compressor system

Advanced CFD/FEA modelling of the mechanical compressor from the previous COSMHYC project, have been further developed, to now include two compression heads, as well as the new 1st stage head.

The 1st stage head operates at different pressure levels and temperatures, than the already developed 2nd stage head, and the models needed to be updated to reflect this.

Also the overall model of the entire compressor and balance-of-plant needed to be updated with operation of both heads simoustanesly.

The models have been applied on the various components in the compressor that in particular are exposed wear, pressure and temperatures. Various materials and designs were simulated in the models to identify a suitable design with regards to handling of dynamics during operation, whilst reducing wear.

2.2 Diaphragm development

A new diaphragm has been developed for the 1st stage head.

Compared to the already developed 2nd stage diaphragm, size had to be increased substantially, in order to achieve the same capacity on both heads combined. As the 1st stage is operating at a lower inlet/outlet pressure than 2nd stage, the compression displacement volume needs to be lager in order to accommodate the same hydrogen quantity per compression stroke.

Concerning materials and surfaces simulation and assessments showed that ones similar to the 2nd stage head can be used.

The diaphragm is placed in between a hydraulic cavity plate in the bottom, and a gas cavity plate on the top.

The compression displacement volume are carved out into the plates.

The plates and diaphragms are placed in between the upper and lower compressor heads which holds the assembly together.

2.3 Compressor head development

A new compressor head design has been developed for the 1st stage head.

The head consist of a top plate and a lower plate, as shown in picture below. Overall the design is similar to the 2nd stage, however lager in size to accommodate same capacity at lower inlet/outlet pressure.

The two plates hold the diaphragm and cavity plates together (see section 3) using bolts around the outer edge. The top plate has integrated gas inlet and outlet valves. The lower plate has integrated hydraulic monitoring. Also both head plates have integrated cooling channels in order to improve efficiency and reduce component wear.

2.4 Piston rod seal house

A new piston rod seal house design has been developed as shown in picture below.

Compared to the 2nd stage head, the design has been made more robust in order to handle the higher temperatures and dynamics from the lager head size and lower inlet/outlet pressures.

The hydraulic rod is assembled onto the crankcase using a mounting plate. A hydraulic rod holder has been designed to both hold and guide the rod when moving forth and back through the mounting plate.

3. Task 4.2 – Development of compressor dual-heads operation

The objective of task 4.2 has been to develop a new compressor system for dual-heads operation (2 stage and duplex) and the ability to configure this for both LDV and HDV inlet/outlet configurations.

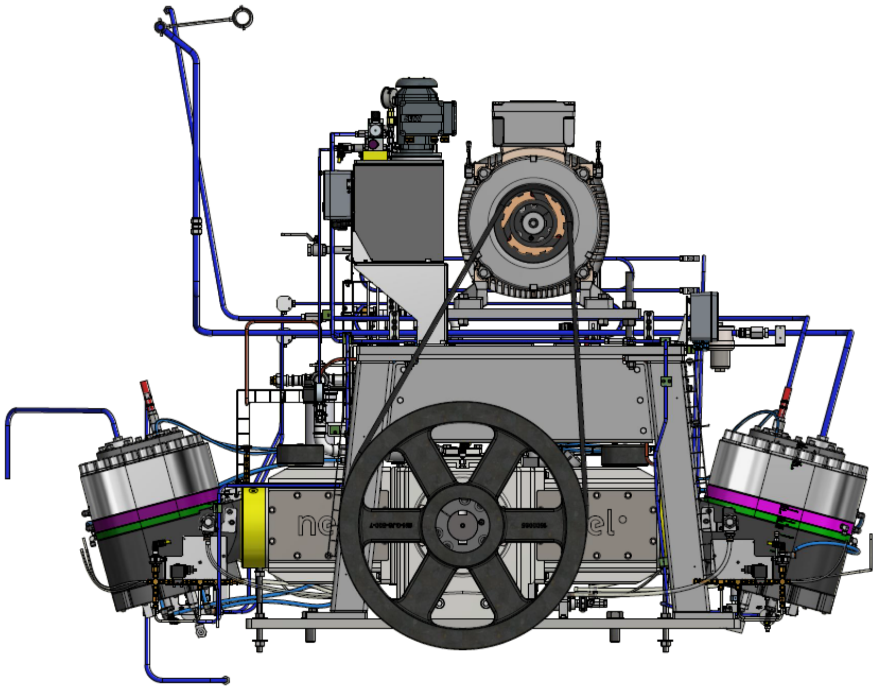
3.1 Compressor power-frame, crank and motor

A new compressor power-frame design with crank and motor has been developed.

The power-frame integrates both the crank and motor as well as all the other balance of plant components. Compared to the power-frame used in the previous COSMHYC project, the design has been completely redone – both to allow for dual-head operation but also to provide an optimized design.

The motor is larger in order to accommodate dual-heads, and thus the supporting frame also made stronger. The power-frame allows for configuring the balance-of-plant and heads to either fuelling of LDV or HDV with inlet/outlet operation ranges of respectively 45-95MPa and 20-45MPa.

Picture below show the entire compressor design including balance-of-plant components.



3.2 Balance-of-plant components

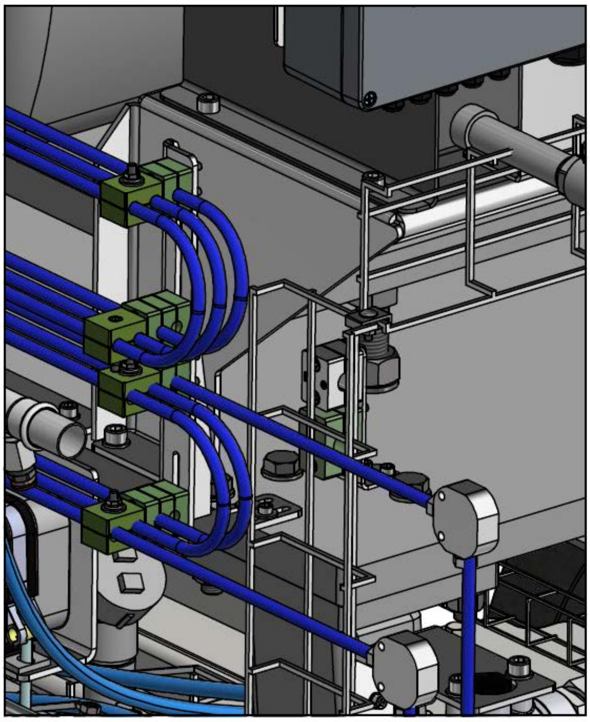
A new balance-of-plant system across the two compression heads has been developed.

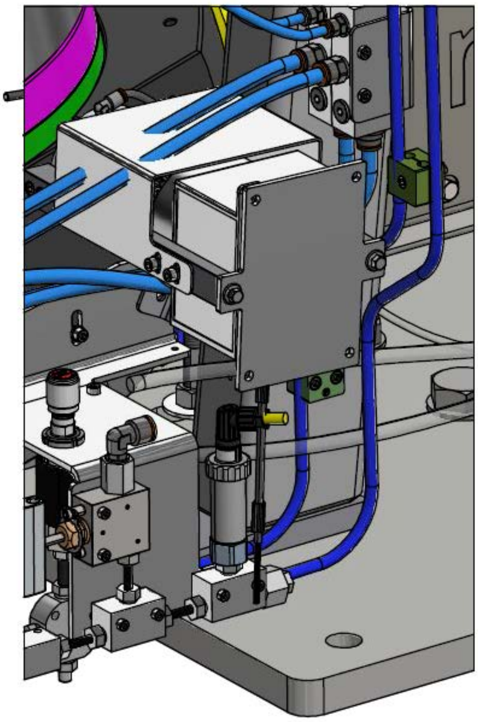
This required a new control philosophy taking into account the complex operational parameters of each compression head and also the different dynamics of 2-stage and duplex operations.

New hydrogen piping's and valve blocks has been developed allowing for flexible use of the various compression steps and head configuration.

A supporting cooling pipeline system for the compressor heads has also been developed. This ensures routing of cooling lines to both heads, as well as oil for the two piston rod houses.

Below are shown zoom in on selected balance-of-plant design on the compressor power-frame.





4. Task 4.3 – Prototype construction

The objective of task 4.3 has been to assemble the various components developed in task 4.1 and 4.2 into a working prototype compressor.

Based on the compiled development efforts in task 4.1 and 4.2 and 5.3 a complete prototype of the compressor has been constructed, see pictures below.

The compressor has been installed at a new test facility at NEL in Denmark, that allows for conducting of the following WP6 tests. Further about the test facility is elaborated in D6.2.

Compressor prototype constructed at NEL test facility

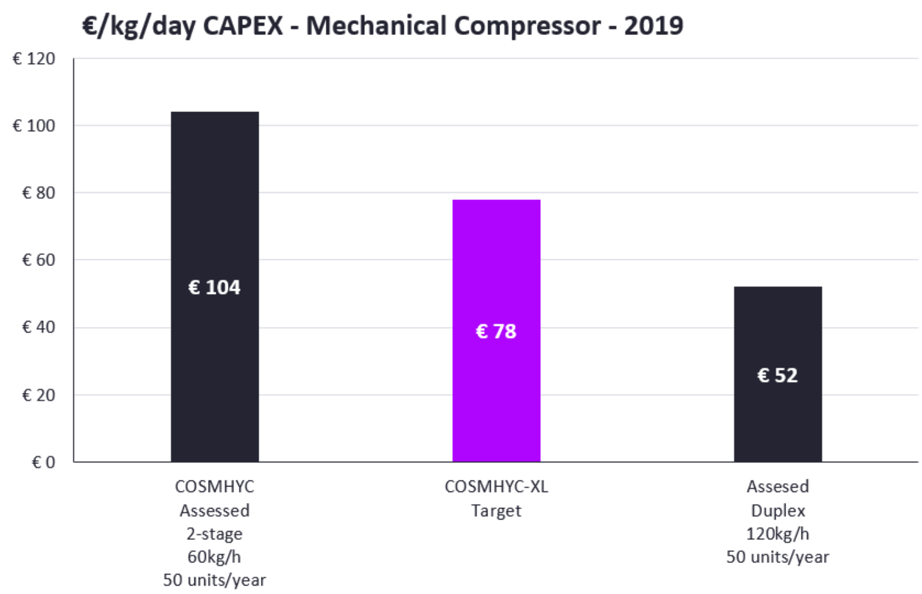
5. Task 4.5 – Cost and manufacturing assessment

The objective of task 4.5 has been to conduct a cost reduction potential of the duplex and dual-crank Mechanical Compressor configurations developed in COSMHYC-XL, when moving into high volume manufacturing. The aim is to validate that at least a 25% cost reduction is possible at 50 unit volume manufacturing per year. This would help reduce compressor CAPEX from €104 per kg per day compressor capacity down to €78.

5.1 Cost and manufacturing assessment at start of COSMHYC-XL (2019)

The former COSMHYC project conducted a cost and manufacturing assessment showing the potential to reach €104/kg/day for a 2-stage 60kg/h compressor, operating in the pressure range of 20MPa inlet and 95MPa outlet. As part of COSMHYC-XL designs have been developed for various duplex compressor configurations that increase capacity up 120kg/h and reduce cost to €78/kg/day.

Various cost and manufacturing assessments have been conducted at 50 units/year scale. Results are shown in the graph below.



The COSMHYC-XL target was at least to achieve 25% cost reduction, from €104 to €78 kg/day capacity. The cost assessment however showed that a configuration (120kg/h) can achieve €52/kg/day, 50% below that of the original COSMHYC 2-stage configuration.

5.2 Cost assessment and fossil price parity post COVID-19 and war in Ukraine (2022)

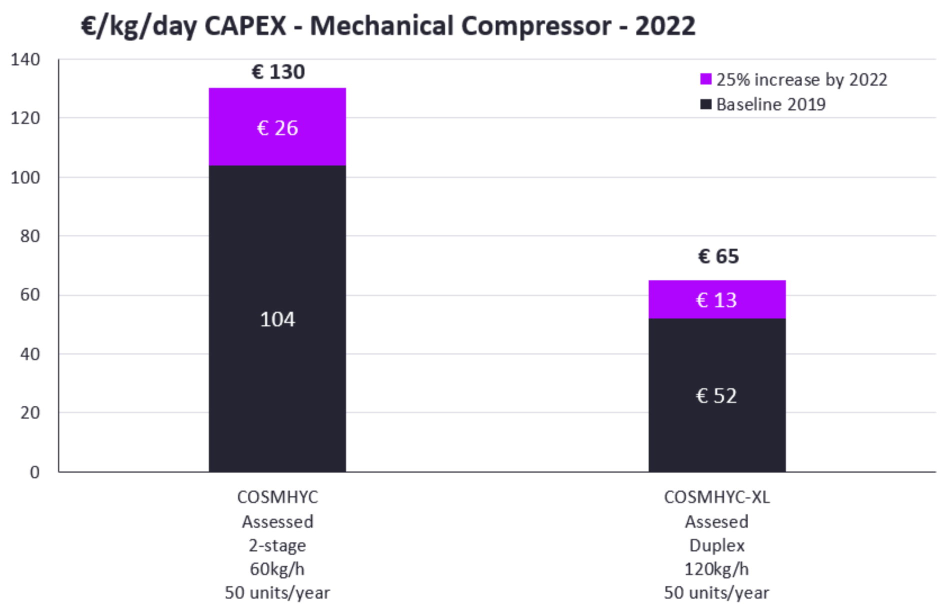
At the start of COSMHYC-XL in 2019 price inflations were at a low level, and had been so for many years. The normal approach in the compressor cost assessments at that time was not to include inflations for several reasons: 1) To keep assessments simple, 2) The low inflation had limited impact on results, 3) Inflations were generally similar across cost parameters (materials, labour, fuel etc.).

As an example, inflation levels of 1-2% would increase compressor costs, thus HRS CAPEX, and eventually hydrogen price accordingly, but the competing technology (fossil fuels) were likely to experience a similar increase over time, despite fluctuations in the short term. Overall impact of inflation, generally in 2019 was negligible.

Since start of COSMHYC-XL in 2019 the situation has however change, firstly with COVID-19 and latest with the war in Ukraine. This has resulted in great price fluctuations and huge inflations, and most importantly, these varies at lot across the industry sectors. Inflation is therefore no longer negligible in the cost assessments.

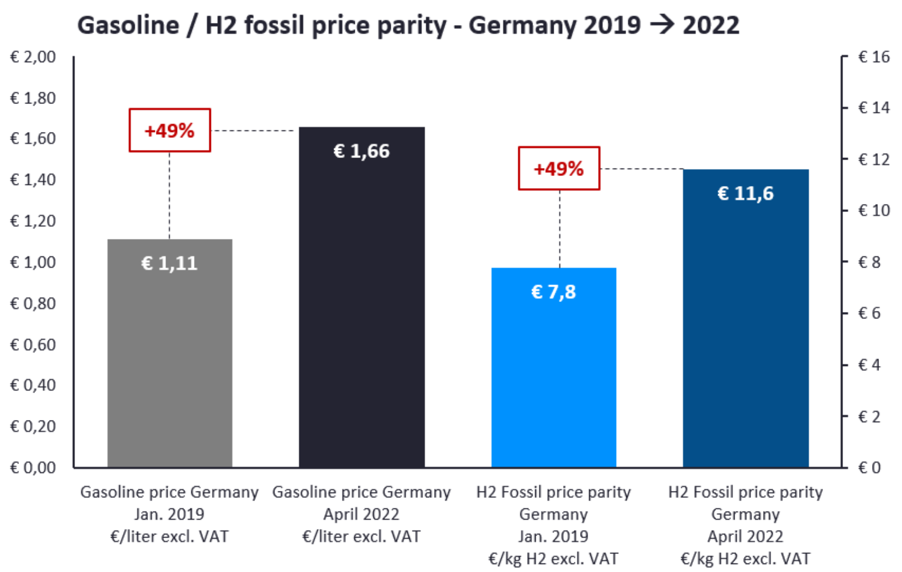
Since the cost compressor assessments in 2019, the baseline cost have increased approximately with 25% by April 2022. This have been caused by increases on steel, raw materials, electronics, labour etc. - some cost components with extreme increases, others with less – but overall 25%.

Graph below shows the impact of the 25% increase to the COSMHYC-XL assessed compressor costs.



Naturally, the increased compressor costs will increase the HRS CAPEX and eventually the achievable hydrogen price at dispenser.

However, at the same time, price of fossil fuels have also increased, meaning that the fossil price parity for hydrogen is higher today than in 2019. Graph below shows the gasoline price increase from 2019 to 2022 in Germany compared with the resultant fossil price parity for hydrogen.



Gasoline excl. VAT: https://www.adac.de/verkehr/tanken-kraftstoff-antrieb/deutschland/kraftstoffpreisentwicklung/
Fuel consumption: Toyota Camry Hybrid gasoline NEDC 18,8km/liter vs. Toyota Mirai NEDC 0,76kg/100km

As can be seen both the gasoline price and hydrogen fossil parity price have increased 49%.

The fact that fuel price have increased twice that of the compressor cost, does however not necessarily mean that the case for hydrogen have improved. Assessing this would require a full business case review taking into account the CAPEX/OPEX/Feedstock price changes and share of the fuel price – which is out of scope for this deliverable.

As an example grid electricity prices have also increased and in some cases even more than gasoline. If hydrogen production is based on grid electricity the higher costs of hydrogen supply could easily level out the lower increase on the compressor cost and HRS CAPEX as compared to the increase in the fossil price parity level. On the other hand if hydrogen production is directly connected directly to renewables where the Levelized Cost of Electricity has not increased as much as the Grid electricity price, the overall case for hydrogen may have improved.

As mentioned it is out scope for this deliverable to conduct an update of the overall business case – however the 49% increase in fossil price parity target, at least shows that there should be room to accommodate the 25% increase in the compressor costs, depending on the specific case.