COSMHYC
INNOVATIVE H2 COMPRESSION

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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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Application requirement & economic analysis
Deliverable 2.4

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Introduction

The COSMHYC project (COmbined hybrid Solution of Metal Hydride and mechanical Compressors for decentralised energy storage and refuelling stations) was part of European Union's Horizon 2020 (H2020-JTI-FCH-2016-1) program and received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735969. The project was active between 1/2017 and 2/2021.
Further information about the project is available under www.cosmhyc.eu.
This public deliverable includes the key results from work package (WP) 2 "System requirements, analysis of the business case and customer value proposition".

Based on the COSMHYC project technology, two further projects have been started by the consortium also receiving FCH JU funding:

- COSMHYC XL (also available under www.cosmhyc.eu)
- COSMHYC DEMO (https://www.fch.europa.eu/project/combined-solution-metal-hydride-and-mechanical-compressors-demonstration-hysoparc-green-h2)

The COSMHYC concept

The COSMHYC hybrid compression concept uses two supplementing compression technologies. Innovative technology using metal hydrides is used for compressing hydrogen from low to medium pressures. Metal hydrides enable efficient hydrogen compression using heat instead of electricity to drive the compression. Compared to conventional compression technologies, metal hydrides are especially efficient at low to medium pressures. For medium to high compression, which is required e.g. for hydrogen refuelling applications at 70 MPa, a membrane compressor is applied to serve as booster. To enable overall cost and energy efficient compression, a new membrane compression head was also developed within the project. This new head combines various innovations such as e.g. new materials, new shape and improved cooling.
Both compression technologies are combined to achieve efficient compression from low to high pressures. The COSMHYC concept allows both technologies to utilize their strengths.

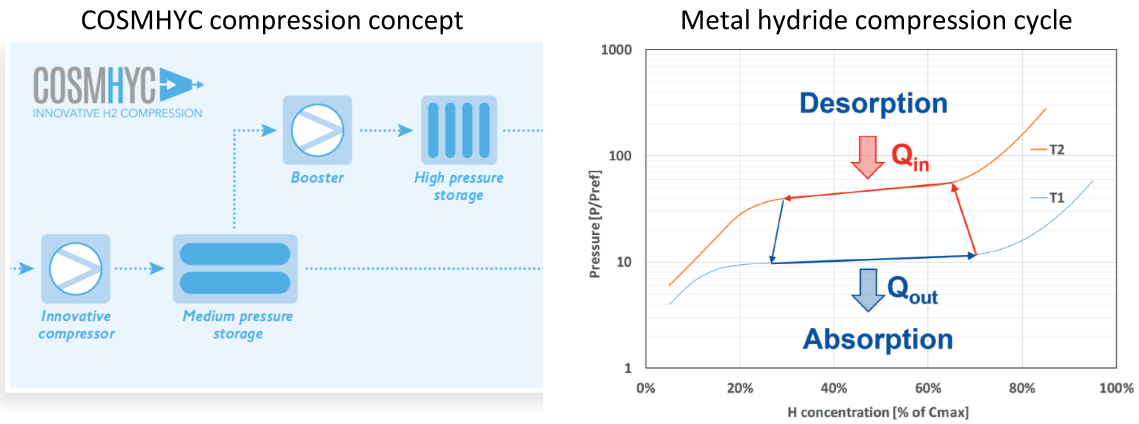

Figure 1: COSMHYC compression concept and metal hydride compression cycle (Source: COSMHYC consortium)

For further information about the compression technologies, please refer to other project documents available at the website. This report covers WP 2 activities, only.

WP 2 – Application requirements and techno-economic analysis

At the very beginning of the project (H1/2017) the consortium selected three applications to be analysed within WP 2 (see Table 1). Further 5 applications have been considered but were discarded due to lower relevance for the proposed compression concept.

The analysis within WP 2 comprises two tasks:

- Task 2.1: Definition of basic requirements for the selected compressor applications at the beginning of the project (H1/2017)
- Task 2.2: Techno-economic analysis based on project results for the selected compressor applications at the end of the project (2020/2021)

The key results of both tasks are presented in the following chapters.

Table 1: Selected applications for WP 2 analysis with rational (2017)

Application	Rational
FCEV refuelling	Refuelling of hydrogen fuel cell powered passenger vehicles. Probably one of the most relevant hydrogen compressor applications in the future. This application requires hydrogen above 70 MPa nominal pressure.
Bus/Train refuelling	This application will quickly gain relevance in the near future as larger hydrogen bus and trains fleets are being introduced in various European countries. Some requirements are identical for 35 MPa material handling vehicle refuelling.
30 MPa CGH_2 trailer filling	30 MPa hydrogen transport trailers are being introduced to major industrial gas suppliers right now. Thus, this application can be considered as being already existing (especially compared to high pressure transport trailers). The case of single cylinder and cylinder bundle filling is similar. Some requirements are identical for higher pressure 50 or 70 MPa trailers.

Application requirements

The main requirements for the three selected applications are listed in Table 2. For a range of parameters, rather similar requirements have been identified for all applications (e.g. H2 purity, operating temperature, reliability, operating dynamics). For other parameters there is a rather strong variation of requirements (e.g. output pressure, throughput, intake pressure).

Table 2: Overview basic application requirements

<table>
<tr><th rowspan="2">Requirement</th><th rowspan="2">Unit</th><th colspan="3">Application</th><th rowspan="2">Comment</th></tr>
<tr><th>FCEV</th><th>Bus/Train</th><th>CGH_2-Trailer</th></tr>
<tr><td>Intake pressure</td><td>MPa</td><td colspan="3">0.1 – 10, likely relevant: 2 - 5</td><td>depends on H_2 supply mode</td></tr>
<tr><td>Output pressure</td><td>MPa</td><td>90 - 100</td><td>50</td><td>40 – 45</td><td></td></tr>
<tr><td>Throughput</td><td>kg/day</td><td>80 – 400</td><td>1,000 – 3,000</td><td>1,000 – 3,000</td><td>per station/location (possibly multiple compr. units)</td></tr>
<tr><td>Dynamics (H_2 demand)</td><td></td><td>High</td><td>Medium</td><td>Medium</td><td>Impact on compr. depends on buffer storage size</td></tr>
<tr><td rowspan="2">H_2 purity</td><td rowspan="2"></td><td colspan="3">ISO 14687-2</td><td rowspan="2">Maximum impurities defined. Factual impurities depend on H_2 source (process, feedstock)</td></tr>
<tr><td></td><td></td><td>Quality 3.0, 5.0</td></tr>
<tr><td>Energy consumption</td><td>kWh_{el}/kg_{H2}</td><td>2.7+</td><td colspan="2">1.5 – 3</td><td>State-of-the-art value (approx.)</td></tr>
<tr><td>Grid connection</td><td></td><td>Limited</td><td>possibly limited</td><td>Not limited</td><td>Depends on location</td></tr>
<tr><td>Heat sources</td><td></td><td colspan="2">HRS components</td><td rowspan="2">Industrial processes</td><td rowspan="3">Probably not available on every site</td></tr>
<tr><td rowspan="2">Heat sinks</td><td rowspan="2"></td><td colspan="2">Vehicle washing</td></tr>
<tr><td colspan="3">Building heating</td></tr>
<tr><td>Reliability</td><td></td><td>High</td><td>Very high</td><td>High</td><td>Very important requirement, possibly back-up units req.</td></tr>
<tr><td>Footprint</td><td></td><td colspan="2">Very relevant</td><td>Less relevant</td><td>The smaller the better</td></tr>
<tr><td>Ambient operation temperature</td><td>°C</td><td colspan="3">-20°C to 45°C</td><td>Compressor usually integrated in container or housing</td></tr>
<tr><td>Noise emissions</td><td>dB(A)</td><td colspan="2">45 – 70</td><td>70</td><td>Depends on location, existing products often < 65 dB(A)</td></tr>
<tr><td>Market size</td><td>kg/day</td><td>50,000</td><td>5,000</td><td>26,000</td><td>Annual capacity build-up in the mid-2020s, possibly lower</td></tr>
</table>

Based on the identified requirements, it was recommended that the COSMHYC compression concept should be flexible in terms of external heat integration and utilization as well as inlet and outlet pressure to be able to efficiently handle different hydrogen sources and refuelling/compression applications. This might also require to be able to integrate and operate both compression technologies independently or even separate from each other.

Techno-economic assessment

A detailed cost assessment was performed based on the prototype which was constructed, build and tested within the COSMHYC project. For the cost assessment an application of the hybrid compressor concept within a hydrogen refuelling station (HRS) for light duty vehicles with a nominal vehicle tank pressure of 70 MPa, was selected. The hydrogen fuel supply to the HRS as well as the basic HRS storage and compression concept is shown in Figure 2.

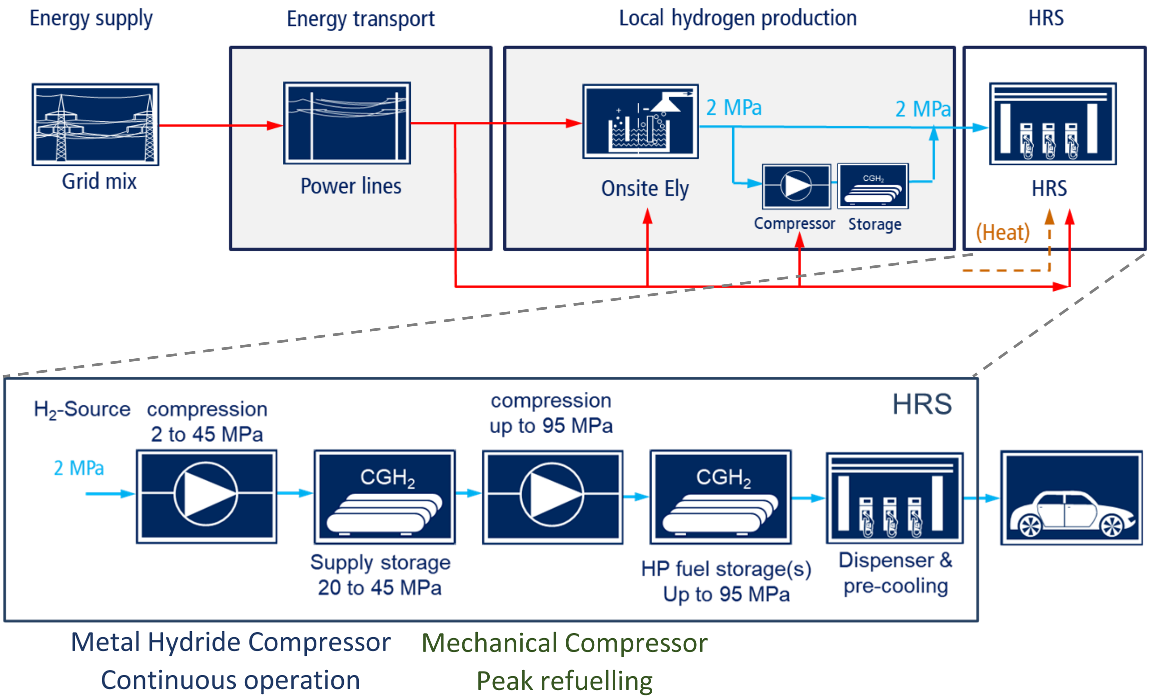

Figure 2: Hydrogen fuel supply and simplified HRS concept

The HRS performance was specified based on H2-Mobility Germany specifications for a 200 kg/day station which is able to serve about 30 vehicles per day. This includes a peak dispensing capacity of 33 kg/hour for 3 consecutive hours as well as a two vehicle back-to-back refuelling capability. The hydrogen supply pressure from the production unit or low-pressure bulk storage to the compressor is 2 MPa. The hydrogen is continuously compressed from 2 MPa to a 45 MPa supply storage using the metal hydride compressor (MHC). The aim is to replenish the medium pressure storage cascade as much as possible to allow quick recompression of the high pressure storage cascade (up to 95 MPa) during peak dispensing periods using the peak refuelling mechanical compressor (MC).

Economic analysis

For the cost assessment, CAPEX and OPEX figures for small and large-series production volumes were developed. Small-series production assumes a production volume of about 20 to 50 compressor units per year, while large-series production assumes 100 compressor units per year.

When going from prototype to series production, investment costs (CAPEX) are reduced. This is achieved e.g. by reducing the complexity of the overall system which leads to a reduction of required components and materials, by improved design which e.g. contributes to quicker assembly, by optimizing the profile of requirements for components as well as by higher purchase volumes which reduces purchase costs (economy of scale).

Operating costs (OPEX) include energy consumption and other operation and maintenance costs. Those are reduced by optimizing thermal management and insulation, by further optimizing design

regarding maintenance friendliness and by optimizing lifetime of components e.g. by adapting operation parameters.
The impact of series production on CAPEX and OPEX is shown in Figure 3 for the metal hydride compressor and in Figure 4 for the mechanical compressor.

Going from prototype to large-series production reduces the specific CAPEX of the MHC by about 2/3. At large production volumes, the CAPEX of the MHC is about on par with the benchmark technology (conventional compressor[1]). OPEX is lower for the MHC series product due to the fact that heat is used to drive the compression instead of electricity. Heat is usually less expensive (per kWh) then electricity. In this analysis electricity costs of 0.15 €/kWh and heat costs of 0.03 €/kWh are assumed.

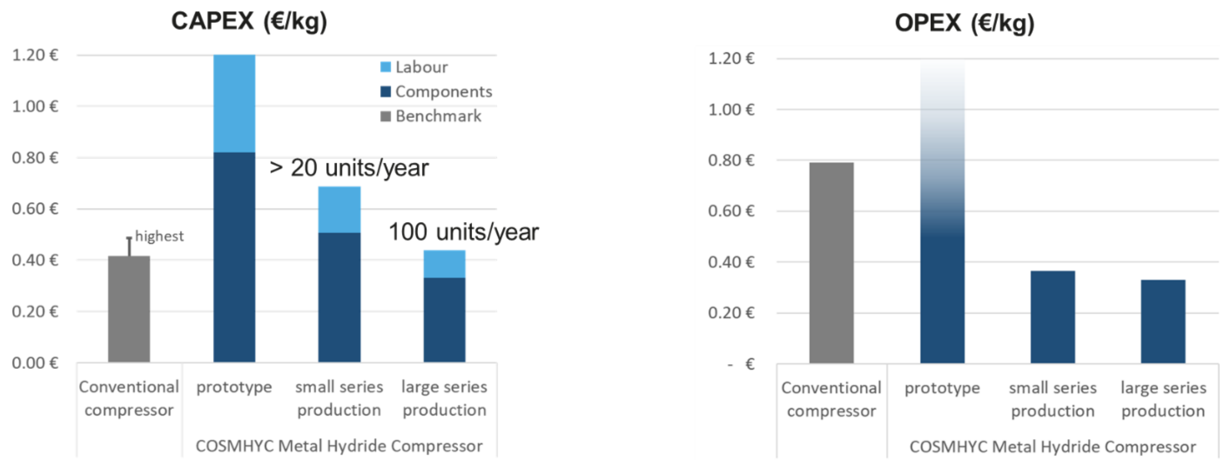

Figure 3: CAPEX and OPEX of the metal hydride compressor compared to benchmark technology

Relevant cost reduction potential was also determined for the mechanical compressor. Here, the CAPEX of the prototype (without costs for development) is already on par with the benchmark technology. Series production reduces CAPEX even below the benchmark technology. Very similar is the potential reduction of OPEX. OPEX is mainly reduced due to higher compression efficiency as a result of improved cooling which then leads to lower electricity consumption as well as by increased lifetime of the compressor membranes and thus reduced maintenance efforts.

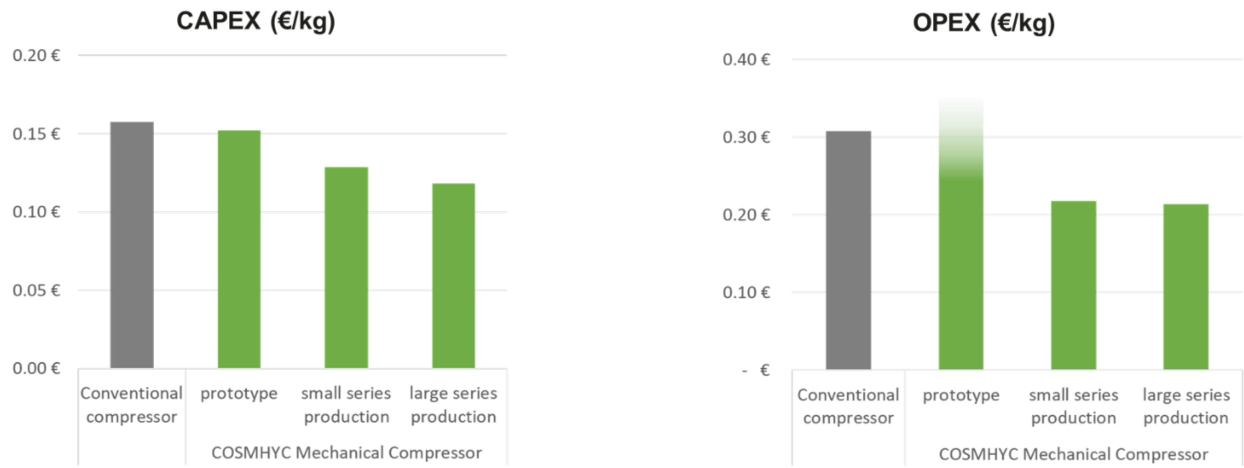

Figure 4: CAPEX and OPEX of the mechanical compressor compared to benchmark technology

[1] The costs for the conventional compressors were estimated based on available supplier data and quotes. The grey bar shows the average.

The left chart in Figure 5 shows the overall fuel costs at the dispenser at round about 8 €/kg. About 5.5 €/kg are related to hydrogen production and low-pressure bulk storage which is required to balance hydrogen production and demand. The remaining costs of roughly 2.5 €/kg come from the HRS. The chart on the right shows the main single cost items within the HRS. Storage, dispenser, pre-cooling and other costs are very much equal in all cases (benchmark, small- and large-series production case). The difference in costs is mainly caused by compressor costs. At small-series production, the HRS based on the COSMHYC hybrid compressor concept is estimated to have an overall cost advantage of about 0.2 €/kg. At large-series production, the analysis indicates a cost advantage of 0.6 €/kg over the benchmark.

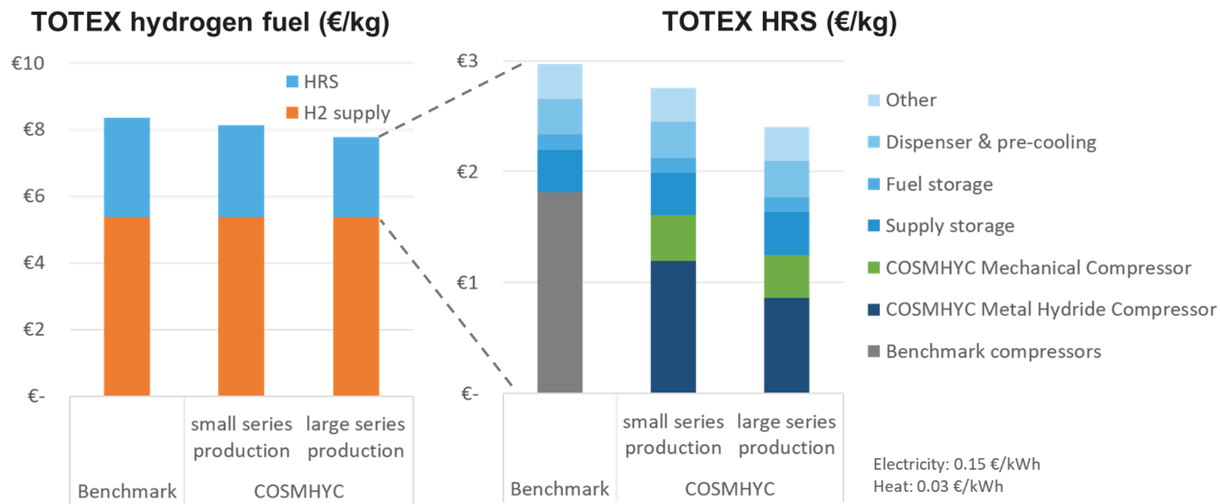

Figure 5: Overall fuel costs and detailed shares of costs with in the refuelling station

The cost delta between the benchmark and COSMHYC based HRS is to a relevant extend the result of differences in electricity and heat costs. Heat is usually less expensive than electricity. However, heat and especially electricity costs are site specific and vary between different European countries and also within a country e.g. depending on the legal status of the operator (e.g. HRS as part of an energy intensive industry serving a captive company fleet vs. public HRS operated by a small company). The quality also impacts on the specific energy costs (e.g. fossil based vs. renewable). As a consequence, a large number of possible combinations of heat and electricity costs exist. Figure 6 shows two energy cost matrixes for small-series and large-series production volumes.

Small-series production

		#1	#2	#3	#4	#5
		Electricity costs (€/kWhel)				
		0.05	0.10	0.15	0.20	0.25
Heat costs (€/kWhth)	0.00	0.1	0.2	0.4	0.6	0.8
	0.01	0.0	0.2	0.4	0.5	0.7
	0.02	-0.1	0.1	0.3	0.5	0.6
	0.03	-0.1	0.0	0.2	0.4	0.6
	0.04	-0.2	-0.0	0.1	0.3	0.5
	0.05	-0.3	-0.1	0.1	0.2	0.4
	0.06	-0.3	-0.2	0.0	0.2	0.3
	0.07	-0.4	-0.2	-0.1	0.1	0.3
	0.08	-0.5	-0.3	-0.1	0.0	0.2

Large-series production

		#1	#2	#3	#4	#5
		HRS electricity costs (€/kWhel)				
	€/kg	0.05	0.10	0.15	0.20	0.25
HRS heat costs (€/kWhth)	0.00	0.4	0.6	0.8	0.9	1.1
	0.01	0.4	0.5	0.7	0.9	1.1
	0.02	0.3	0.5	0.6	0.8	1.0
	0.03	0.2	0.4	0.6	0.7	0.9
	0.04	0.2	0.3	0.5	0.7	0.8
	0.05	0.1	0.3	0.4	0.6	0.8
	0.06	0.0	0.2	0.4	0.5	0.7
	0.07	-0.1	0.1	0.3	0.5	0.6
	0.08	-0.1	0.0	0.2	0.4	0.6

Figure 6: Impact of energy costs on cost delta benchmark vs. COSMHYC based HRS

Analysis of energy consumption and GHG emissions

For the benchmark and COSMHYC HRS described above, an analysis of the primary energy consumption and GHG emissions related to providing hydrogen fuel to light duty vehicles was performed. This well to tank analysis covers all energy consumptions and related GHG emissions from hydrogen production to hydrogen dispensing. It was assumed that heat was produced from fossil natural gas (worst case assumption in terms of primary energy and GHG emission for the COSMHYC concept). Further, electricity from the grid is used to power the HRS. Grid electricity is a mixture of renewable and fossil-based electricity as it is expected in Germany in about 2025 (assumed carbon intensity of about 400 g_{CO2}/kWh).
The result of the analysis is that both, primary energy consumption and GHG emissions, are about on the same level for the benchmark and COSMHYC based HRS. This means that using natural gas to power a COSMHYC based HRS does not result in higher primary energy consumption and GHG emissions compared to using grid electricity in a benchmark HRS, in 2025. Of course, the aim should be to use heat with a low carbon intensity (e.g. waste heat, renewable based heat) to improve the case for the metal hydride based concept. In fact, the integration of renewable heat as well as improved heat recycling (e.g. by heat pumps) is part of the follow-up project COSMHYC XL.

Analysis of further applications

Besides the refuelling of 70 MPa light duty vehicles, two further applications (FC bus refuelling at 35 MPa, filling of a 30 MPa transport trailer) have been analysed. For both applications the metal hydride compressor is sufficient to provide the required maximum pressure of about 30 to 45 MPa. For both applications the metal hydride compressor can reduce compression and thus overall costs compared to the benchmark technology. This is especially the case for very low hydrogen source pressures (near atmospheric pressure e.g. from unpressurized electrolysis) or with available low-cost heat from the hydrogen production process (e.g. onsite steam reforming of biogas at a bus depot).

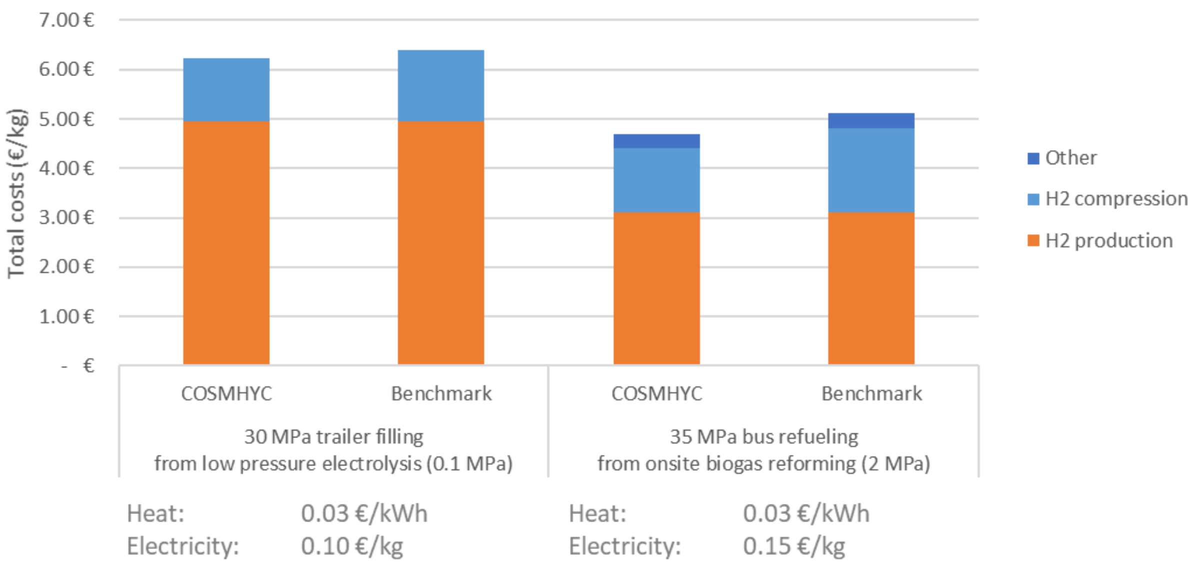

Figure 7: Results of the economic analysis for the 30 MPa trailer filling and 35 MPa bus refueling compressor application case

Conclusion of the techno-economic analysis

- Further development towards mass production are required (End of project: TRL 5)
- Identified system simplifications etc. enable significant reduction of CAPEX compared to prototype
- At mass production, the COSMHYC concept will be on par in CAPEX but will show lower OPEX compared to benchmark technology
- Cost advantage depends on site specific parameters such as energy prices, hydrogen supply pressure and compressor application