Integrated design for demonstration of efficient liquefaction of hydrogen (IDEALHY)

Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

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Publishable summary

This report documents the outcomes from Task 1.3 in the IDEALHY project.

It is important to have an understanding of the properties of existing processes and concepts in order to evaluate new liquefaction concepts. To create a level playing field for process benchmarking, the concepts found in the open literature (already described in deliverable D1.1) require modelling and simulation with the common IDEALHY boundary conditions and process parameters described in D1.2.

A reference case, the standard Linde large-scale cycle, was simulated by all institutions and the results compared, to ensure that the different institutions in IDEALHY could produce consistent results while using different simulation tools. Most of the stream states compared were within 1 % deviation and all results were within a 4 % margin.

Including the Linde reference case, seven different processes were modelled and simulated. The differences between the cycles were examined using exergy analysis, as breaking the process efficiency losses down by this method reveals to what magnitude the different components and sub-processes contribute to irreversibilities and thus to efficiency losses. Key observations from this analysis include the severe penalty of utilising liquid nitrogen for hydrogen pre-cooling, and the importance of efficient turbomachinery.

The liquefaction process was divided into four stages, to elaborate further on the different concepts and develop a new and more efficient cycle:

1. Pre-compression of the feed
2. Pre-cooling down to about 80 K
3. Cryogenic cooling down to 20–30 K
4. Final expansion and liquefaction.

From a process point of view, it was concluded that a higher pressure is advantageous, primarily because of reduced variation in the hydrogen heat capacity, but this pressure is limited by the efficiency of heat exchangers. This and other consequences of elevated hydrogen pressure will be investigated further in WP2.

For pre-cooling it was found that mixed refrigerant (MR) cycles have a thermodynamic advantage compared to Brayton cycles in higher temperature intervals. The optimum temperature split between MR (pre-cooling) and Brayton (cryogenic cooling) in a liquefier will also be investigated further in WP2.

For cryogenic cooling, Brayton cycles are the main process option. The choice of possible working fluids is primarily a question of the targeted temperature before expansion/liquefaction of hydrogen, as well as of the ease of compression. A helium/neon mixture seems to be the most promising solution; it is a compromise between low temperature and high molecular mass to enable efficient compression.

For the final expansion and liquefaction stage, a power-generating liquid expander is the only viable solution for high efficiency. It would also be beneficial to have a once-through configuration, i.e. one with no flash gas at the liquid expander outlet. This, however, depends on a sufficiently low temperature at the expander inlet, which in turn depends on the cryogenic cooling cycle being able to provide required low temperature.

Based on the evaluation described in this document the stated goal of 45–48 % reduction in specific power consumption should be achievable.

Key words

efficient hydrogen liquefaction, pre-compression, pre-cooling, cryogenic cooling, flash gas, mixed refrigerant

List of abbreviations

UA:	Product of heat transfer coefficient and heat transfer area
MITA:	Minimum internal temperature approach
LMTD:	Logarithmic mean temperature difference
NTU:	Nephelometric turbidity unit

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