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Performance and Economic Competitiveness Comparison of Advanced Hydrogen Production Processes

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1 Introduction

Hydrogen demand is already strong. It should significantly increase in the next few years due to the refinery industry growing needs and new applications such as synthetic fuel or biofuel production. To meet the demand advanced processes are developed throughout the world in a sustainability context. The most studied ones are thermochemical cycles: the sulphur-iodine and hybrid-sulphur cycles, and high temperature steam electrolysis. In order to compete with available technologies – alkaline water electrolysis is the only process that could enable sustainable massive hydrogen production today – advanced processes need to demonstrate their economic potential. Based on recent progress, a thorough study was carried out at CEA, from the flowsheet development to the final hydrogen production cost assessment. The methodology is first presented. Then the sulphur-iodine and hybrid-sulphur cycles coupled to a high temperature nuclear reactor are assessed. High temperature steam electrolysis also underwent a detailed study in order to identify the cost drivers.

2 Methodology

The methodology implemented at the CEA is divided into several steps (cf. Figure 1):

- a flowsheet is first developed from the experiments that are carried out at the CEA (thermodynamic data collection, corrosion test, cf. [1] for instance);
- the components are then designed and the energy consumption is assessed from the flowsheet and the process simulation;
- the investment cost is therefore evaluated based on material selection [2] as are other cost items;
- finally, the hydrogen production cost is estimated through a levelized production cost model. A common set of assumptions is of course used for the different processes that are examined.

This techno-economic model was selected because it enables quite simple production cost estimates, by limiting the number of needed assumptions, especially as regards the plant financing (contrary to the H2A model for instance, for which equity and debt shares should be provided [3]). Only one major parameter is necessary: the discount rate, the impact of which can be assessed through a sensitivity study. Consequently, this model is a relevant tool to identify the main cost drivers for advanced processes.

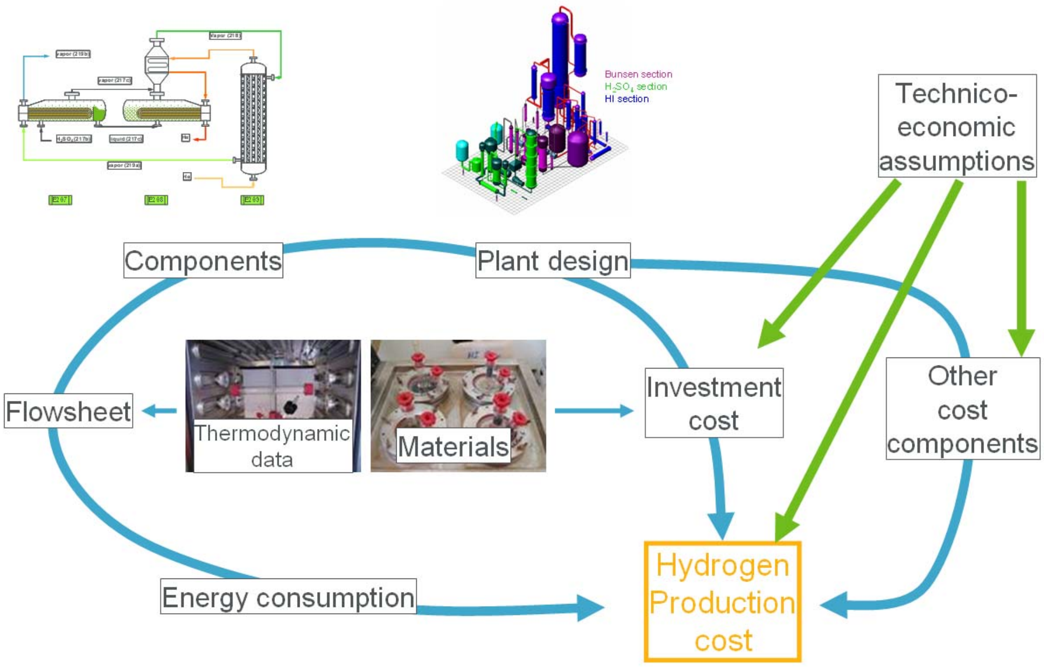

Figure 1: Methodology.

3 Considered Processes and Performance Comparison

Three processes are studied here:

- the sulphur-iodine cycle (S/I) [4],
- the hybrid-sulphur cycle (HyS) [5],
- high temperature steam electrolysis (HTSE) [6].

For space matters, they will not be detailed hereafter. One could refer to the provided references if needed.

We first examine their performances in terms of energy consumption cost. The energy consumption is assessed from a detailed flowsheet and is then not restricted to theoretical needs.

To produce 2 kg_{H2}/s, the energy demand is the following, depending on the considered process:

- 600 MW_{th} and 66 MW_e for the S/I process;
- 410 MW_{th} and 118 MW_e for the HyS process;
- 79 MW_{th} and 255 MW_e for the HTSE process.

Let us mention that the HTSE electricity consumption should be increased to consider the electrolyser performance degradation along time. To assess the energy consumption cost, 40 €/MWh_e was assumed and the thermal energy cost was calculated based on the electricity cost and the heat-to-electricity efficiency. The previous hypotheses lead to an energy consumption cost of 2 €/kg_{H2} for the S/I process and 1.8 €/kg_{H2} for HyS. Contrary to these thermochemical cycles, HTSE does not require high temperature heat when being operated in the autothermal mode. Therefore, low cost heat can be supplied to the process. The energy consumption amounts to approximately 1.8 €/kg$_{H2}$ when including the degradation of the electrolyser performances.

From these results it appears that efficiency still needs to be improved to compete with available mature processes. The mere energy consumption cost is quite high.

4 Main Cost Drivers

The cost drivers are very different according to the considered process.

First let us consider the S/I thermochemical cycle. Given the model that was implemented, the hydrogen production cost was evaluated at 12.0 €/kg [4]. Let us recall that the energy consumption cost was estimated at 2.0 €/kg$_{H2}$. If the investment was reduced by 30%, for instance through learning effects, the production cost would be reduced to about 9 €/kg. These facts highlight the impact of the plant investment. It is related to the material selection (for the components but also the pipes): highly-resistant materials are selected (e.g. Nb-Zr liners), in order to stand the high-temperature, corrosive environment.

As a result from the high investment, the maintenance cost accounts for half the O&M cost and parameters such as the load factor or the discount rate influence quite significantly the production cost (cf. Figure 2).

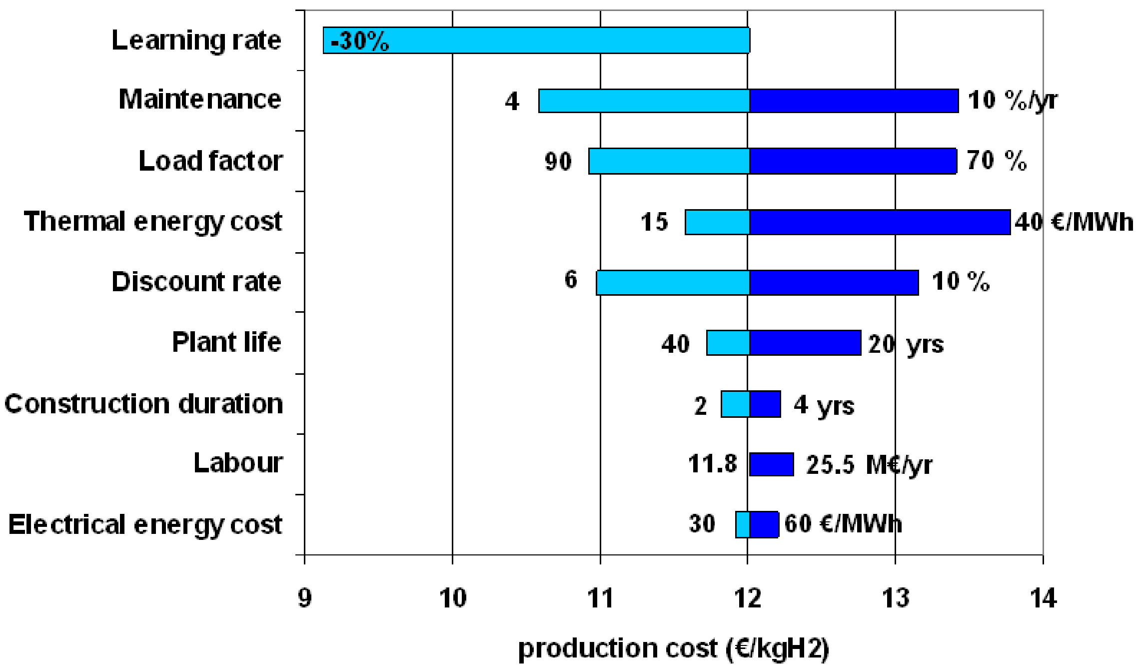

Figure 2: Parametric study around the S/I cycle production cost [4].

As regards the HyS process, the influence of the electrolyser on the final production cost should be underlined (cf. Figure 3). The electrolyser investment was based on alkaline electrolyser data and specific characteristics of HyS electrolysers (catalyst, membrane). Therefore it is quite uncertain. If the electrolyser price was increased by 50%, its investment cost would amount to about 0.7 €/kgH2 but the total production cost would be increased by 0.5 €/kg. Besides, given its high price, if sooner replacement was needed, the hydrogen production cost would rise significantly.

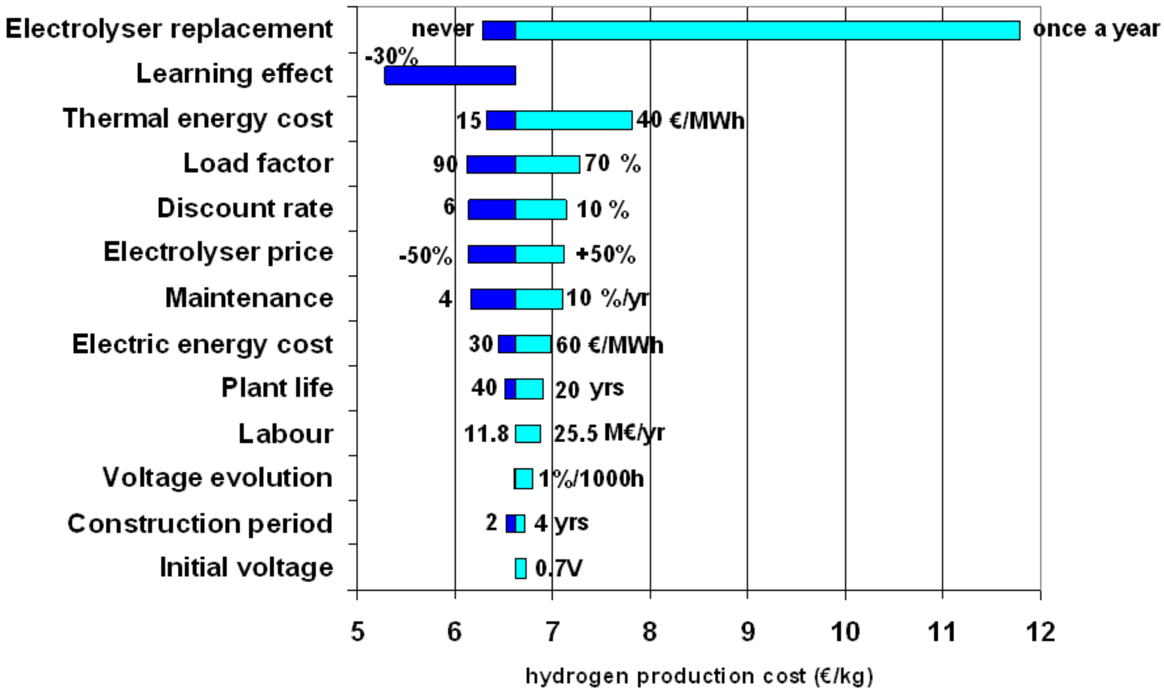

Figure 3: Parametric study around the HyS cycle production cost [5].

HTSE is an electrolysis process. Contrary to the above mentioned thermochemical cycles, an electrolyser forms the process heart. Therefore and quite logically, the electricity consumption is a major cost factor and performances should be optimised. This means that a minimum voltage should enable satisfactory current density (i.e. hydrogen production) but also that this voltage needs not to dramatically increase during operation. The other major cost driver of the process is stack replacement. Indeed, electrolysis is performed at high temperature and regular replacement should be expected. As it can be seen on Figure 4 and due to discounting, stack replacement has a high impact for 3-year lifespans (or shorter). From 3 to 5 years, its influence is mitigated. For longer lifespans, it can hardly make a difference. This could provide R&D targets.

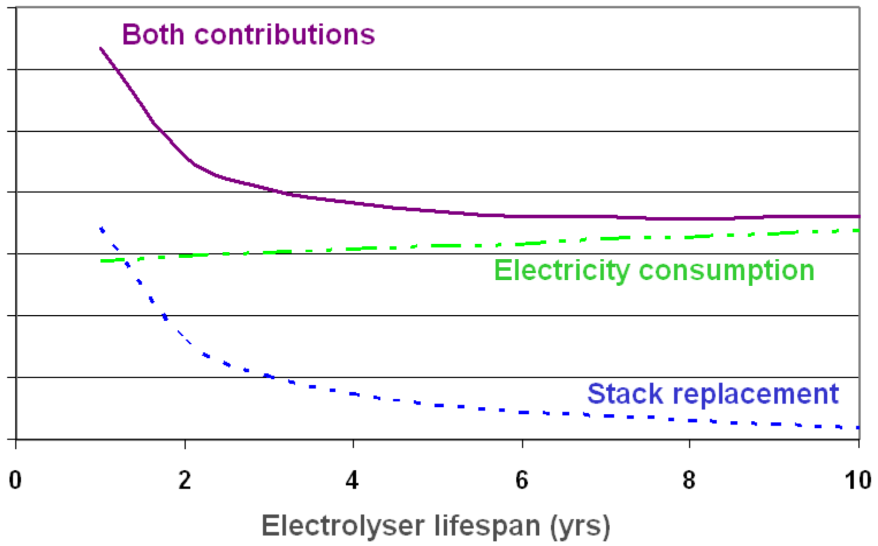

Figure 4: Impact of the electrolyser lifespan on HTSE cost items.

5 Conclusion

Economic assumptions are characterised by many uncertainty sources: raw material prices, accuracy of the cost method, high temperature thermal energy cost, only to name a few. Besides, advanced hydrogen production processes have different specificities and cost drivers: high investment cost for S/I, thermal energy consumption cost for processes appealing to high temperature heat (S/I and HyS), electrolyser performance and durability for hybrid or electrolysis processes (HyS and HTSE). Comparing hydrogen production costs, even with a common model, is then tricky. One should not focus on final figures which very much depend on the model assumptions, but use such assessments to identify trends and R&D priorities.

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