Work Package 7

Deliverable 7.7

Final Economical performance report

Public

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Disclaimer

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Acronyms and abbreviations

CAPEX: CAPital EXpenditure

DSO: Distribution System Operator

EPC: Engineering Procurement and Construction

FC: Fuel Cell

FCEV: Fuel Cell Electric Vehicle

FCR: Frequency Containment Reserve

H2: Hydrogen

HP: High Pressure

MP: Medium Pressure

O&M: Operation and Maintenance

OPEX: OPerational EXpenditure

PEM: Polymer Electrolyte Membrane

PSO: (Danish) Public Service Obligation

TCO: Total Cost of Ownership

TSO: Transmission System Operator

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Introduction

HyBalance demonstrates how hydrogen can be used as means to store wind farm excess energy, which in turn successfully supplies industrial process decarbonization or refueling stations of FCEV (Fuel Cell Vehicles).

HyBalance plant, as described in the work package 2 also includes hydrogen pressurized storage tanks in a way to buffer the mismatch between power grid constraints and H2 logistics constraints.

The economic assessment relies on the case studies analysis performed in the Work Package 7. The main objective is to evaluate the consistency of the business model with real investments and operational figures and to draw a sensitivity analysis for future projects.

Several HyBalance picture scenario have been analyzed :

1. HyBalance business model (2016)
2. HyBalance at start-up phase (2020)
3. HyBalance at full production capacity (2025)

Furthermore, future projects' perspectives have been assessed based on 2020 State of the art technology design. The analysis of several power size units cases - small scale ~1MW like HyBalance as well as large scale units of 20MW and 100MW - aims at evaluating the trends for future business, highlights important parameters and the conditions in which it can become profitable.

1. Methodology

1.1 Project boundaries

The business model of a Power-to-H2 plant like HyBalance is the result of the following parameters.

- Actual investment, net of FCHJU and EUDP subsidies which includes :
  - 1,25 MW dual stack PEM electrolyzer and its ancillaries (power rectifier, water filtering, cooling system…)
  - Electrical connection to the grid and transformer
  - High pressure compression unit and storage capacities
  - Tube trailers refuelling center for hydrogen distribution across Denmark
  - Pipeline connection to an industrial site nearby
  - Engineering, Procurement and Construction of the infrastructure

- The costs of sales that include the fixed and variable costs :
  - Average electricity costs
  - Operation and Maintenance costs including plant manager costs and support services for the operations as well as spare parts
  - The subsidies on the operational costs only during HyBalance project (up to 2020)
  - The transportation of Hydrogen to the point of use

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- The sales composed of the hydrogen sales by CHN to Air Liquide Denmark for the industrial market, the hydrogen transfer value to CHN refuelling stations but also some revenues that will come from the power grid system services if any

The assessment will cover only CHN scope i.e economical conditions to produce and condition hydrogen onsite. The transport of hydrogen in trailers and the molecules sales are excluded from this analysis as it is not performed by a project partner.

1.2 Use cases analysis

The methodology considers 3 different cases to compare the initial plan with effective operational data.

- **HyBalance business plan** (2016), the consolidated business plan for the whole plant has been drawn-up at the beginning of the program in the Work Package 2, considering the hypothesis available in 2016. In the Work Package 5, NEAS has simulated the optimal strategy to source electricity on the spot market and provide grid system services to the power TSO (Transport System Operator). Based on this strategy, the right power price arbitration shall be monitored to produce the hydrogen volumes to match both the industrial and mobility demand on a daily basis.

- The actual **Start-up case**, which corresponds to the Hybalance effective economical results in 2020, almost two years after the start of the operations.

- **A third scenario "Hybalance after 5 years"**, which is the estimation of the plant after completion of the ramp-up with optimised and stabilised O&M costs :
    - This scenario will be computed because the period assessed might not be representative of the actual average operations of the electrolyser.
    - Exceptional issues leading to O&M costs higher than standards might occur during the first years of operation

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2. Results of the case studies analysis

The results of the studies show that there is a gap between the target HyBalance business plan and start-up status to date which seems logical considering the early stage of operations. However a full recovery of the gap per the initial target is expected in the HyBalance case of 2025.

Total investments for the infrastructure equipment and Engineering Procurement and Construction (cf. details in section 1.1) accounted for approximately 15 M€ (without subsidies) as expected in the program budget for a demonstration project.

The CAPEX being fixed, thus it represents an important share of the costs until the production ramp-up of the plant is fully completed. The impact is progressively reduced and full recovery is expected in the next few years.

The same mechanism applies for the operation and maintenance expenses where the total costs of services and spare parts is globally in line with the target today. The budget is expected to remain stable seeing the high availability of the megawatt scale PEM electrolyzer. The increase of production rate as well as continuous improvement of the plant management will help to contain the end of subsidies on OPEX from the funding program.

The operation of the plant fulfilling a viable economic model under real industrial conditions is a great achievement considering the First Of Its Kind nature of the HyBalance program.

In the context of energy transition, the electricity market is evolving quickly and the forecasts for the future are not easy to assess. It will result mainly from the consumption increase on the market due to massive electrification of processes as well as policies and local regulations. The incentive from the Danish government to push forward the investments in renewables could benefit the plant accessing more profitable prices on regulation power markets. Even if the spot price and tax hypothesis considered them stable over the next year, a decrease of electricity impact on H2 costs is expected resulting from revenues of grid balancing services.

Experimentation performed on HyBalance allow to identify two sources of revenues which can be activated with bids on the energy market:

- Lower electricity prices on the spot market (day ahead or intraday) than the imbalance cost
- Payment against reserve capacities set at disposal of the TSO who decide to activate them or not. These services are deemed very beneficial for the PEM water electrolysis plant able to bid on the primary reserve market (FCR) where few energy consumers can apply due to the short reaction time.

Raw forecasts show a reduction by 15% to 25% of the HyBalance power input bill with an efficient energy trading strategy, namely accurate plannings of the production and electricity markets bids.

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3. Perspectives for future projects

HyBalance project addresses the target of the FCH JU 2014 Annual Work Plan (call publication) and the plan has been designed per 2015/2016 State of the art.

Since then, improvements on technologies efficiency and reliability plus equipment manufacturing process improvements especially for the electrolyzer lead to investments and operational costs savings compared to the reference case of HyBalance.

In order to provide a more updated picture of today's achievements the following cases have been analyzed based on current knowledge :

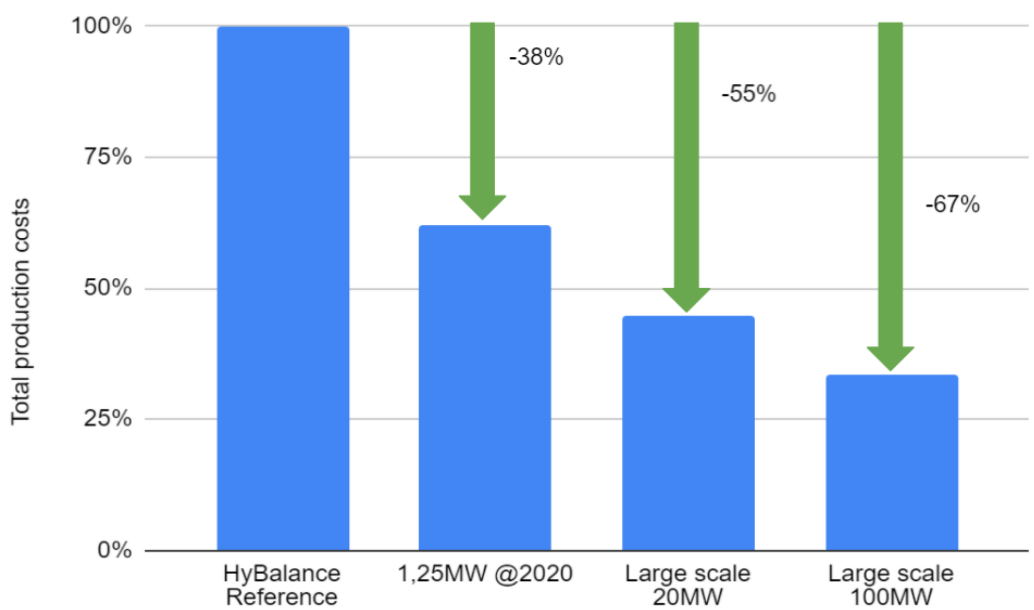
- 1,25 MW electrolyzer
- Large scale electrolyzer of 20MW
- Very large scale 100MW demo project

The assumptions taken rely on the partner's background and benchmark of PEM electrolyzer project developments and implementation considering designs per 2020 state of the art. The boundaries of the case study are limited to the production systems and balance of plant and doesn't include the conditioning and transportation to the point of use. It excludes as well any subsidies on CAPEX or OPEX.

A first analysis of the cost of sales shows the great potential of reduction for 2020 projects in comparison to the reference case HyBalance.

It is made possible due to :

- **Electrolyzer capital cost improvements** : the MAWP 2020 targets 900 €/kW whereas the target was set at 1500€/kW in 2014
- The **engineering costs have significantly decreased** reaping from the knowledge of First Of Its Kind projects achievements
- Construction and installation works improvements with standardized solutions



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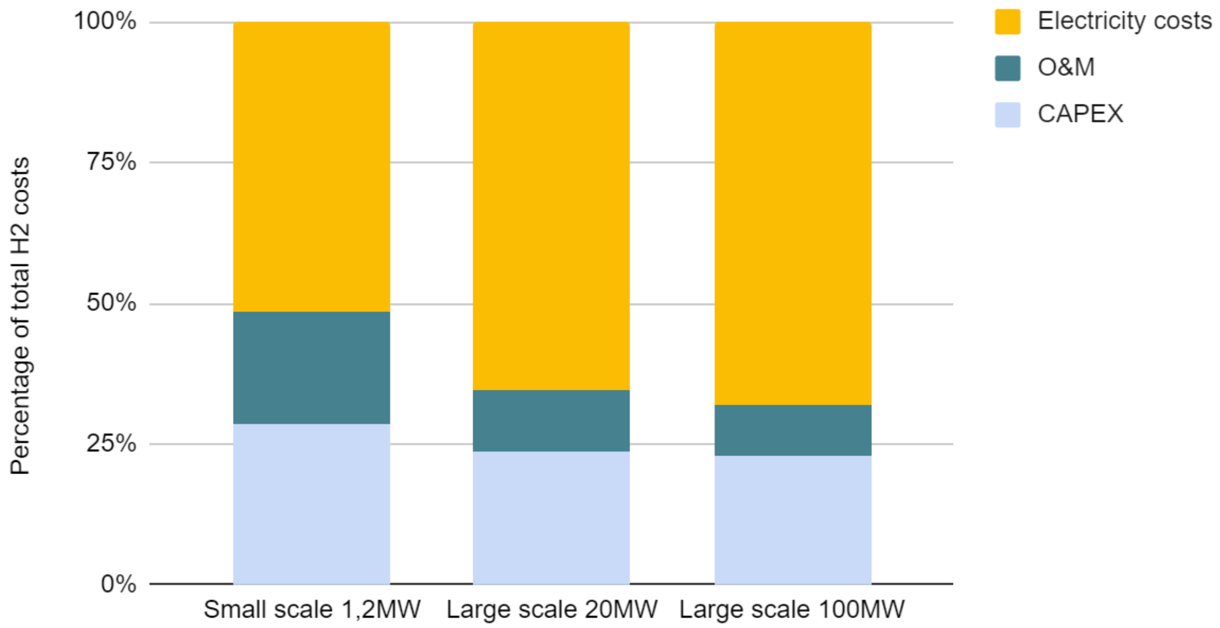
The second analysis is focusing on the hydrogen production cost breakdown to identify the main pathways for optimization.

The results in the graph below show that the ratio **OPEX / CAPEX is increasing with the size of the unit**. In fact, higher H2 quantities produced combined with the mutualization of equipment for the balance of plant as well as a lower cost of technology due to mass production reduced the investment per MW of future projects.



The investment share of CAPEX will be more important than pictured to **include the conditioning and transport of hydrogen to the point of use**; The sizing of the compression unit and storage varies a lot depending on the customers requirements. Additional systems for the conditioning of hydrogen will be necessary to transport the molecules. Depending on the design it could increase by 15% to 30% the total investments.

Concerning future cost trends of the electrolyzer, it really depends on what is being considered in the furniture. For small scale, the design is likely to be a containerized turnkey solution including the stacks and the auxiliaries. For large scale, the electrolysis unit is integrated into the plant as well as the auxiliaries which requires additional costs for EPC. The **target for large scale projects is to keep the global cost of electrolyzer, auxiliaries and its installation below 1000€/kW.** This goal relies on technology industrialization improvements and increasing production quantities of material.

Regarding operational performance, the HyBalance electrolyser reached a high level of availability for a demo project which gives confidence in the budget definition on future development. The continuous improvement of technologies will also help to reduce Operational and Maintenance costs with more reliability and better knowledge of the systems to implement preventive actions.
By reaching a critical number of Power to H2 plants in service, the human and material resources can be mutualized between several production sites.

Transportation to the point of use is also important as a direct connection by pipeline will be less time consuming than managing the constant rotations of truck trailers.

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In all cases, electricity costs represent the largest part of total costs of hydrogen (at least 50%).

Several solutions will help to reduce the impact of electricity on the cost of sales :

- **The electricity market is very dependent on countries' power production means and their regulations.**
  Reduction of fees in Denmark with the reduction and finally exemption of the PSO tax is an example of the regulation mechanism which can impact positively or negatively the competitiveness of one country with another.
  Funding mechanism to subsidize OPEX could also be another mechanism to limit the impact of electricity on the H2 cost. Indeed, current support from agencies helps to reduce investment expenses but their impact will be proportionally less significant on a large scale.

- Grid balancing services revenues is also identified as a major lever for reducing the settlement. Again, the source of revenues will depend on the countries with differences in the grid mix and intermentacy of the primary energy resources as well as local regulations and tax policies and purchase agreement between regions/countries. Based on the Hybalance experimentations, a **great potential has been identified on the provision of reserve capacities for the primary market**. Again the reserve capacities offered on each market may be limited and the energy trading strategy will have to be **adapted depending on the location of the plant**.

  On the other hand, reserving a power share for up and down regulation will affect the hydrogen production quantity over the year as the plant will not run at full capacity. This will automatically increase the CAPEX and O&M components of costs. Thus, **energy management becomes key to evaluate the right match between customer sales and bidding revenues from the electricity market** in order to generate more benefits than the increase of the CAPEX share per kg of hydrogen. A small scale electrolysis plant is likely to maximise the production hours whereas a more important power reserve is available for large scale providing more flexibility to bid on energy trading markets and generate more benefits from these services.

- The improvement of the efficiency of the electrolysis process is a way to reduce the energy consumption per kg of H2. The efficiency achieved during the HyBalance program on the electrolyzer and its ancillaries (water cooling & purification…) is 56,5 kWh/kgH2. The recent product optimization will lead **to an efficiency around 52 kWh/kgH2 for the new design**.

4. Lessons learnt

The HyBalance case studies comparisons enable us to validate numerous hypotheses.

❖ A careful estimation of the investments has to be carried on during the preparation of the projects to build economically viable business models. The electrolyzer represents the major share but the other equipment and electrical works as well as engineering shall not be underestimated.

  Considering only the electrolyser costs and installation in preliminary budget estimation may be misleading. The global costs of the Power to H2 plant infrastructure has to be estimated and accurately sized for the project requirements. Then, the definition of **a standard case for sake of comparison of future projects is difficult to establish as all projects will have their own specificities**.

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The customer requirements and the project constraints depending on the location of the plant can vary a lot impacting the supply chain for delivery of the hydrogen per demand profiles as well as site arrangement works like establishment of an appropriate power supply.

❖ Technology and industrialization improvements will be key. Indeed, a product design to cost approach and rationalization of components will reduce investments as well as **improve the efficiency** (kWh/kg of hydrogen) and reliability/operability of equipment will also help to reduce OPEX costs.

❖ Oversizing of the electrolyzer to increase profitability from grid services shall be limited.

The HyBalance economical results demonstrate the importance to reach an optimal level of gas production to lower the cost of the molecule. It appears that overizing the plant to allow more flexibility is not really profitable. This is particularly true on small units as fixed costs are predominant. In consequence, the plant will need to produce to amortize the investments as is the case for Hybalance.

Accurate design to size properly the electrolyzer power in accordance with the volumes that need to be produced is still the first driver. The following requirements will also have to be taken in consideration carefully during the development phase : customer demand profile (constant, sporadic peak..), delivery and logistic scheme, energy market set up in the country and potential revenues from grid services, electrical connection available on-site.

Then a thin adjustment of buffers capacities to smooth the operation is key to enable the plant to provide up and down regulation services respectively increasing and lowering the production, this without repercussions on the supply of hydrogen.

❖ Solutions to reach a competitive cost of electricity compare to the average spot must be implemented

If great progress is observed on the prices of technology and technical knowledge helping to reduce the investments, the major concern to achieve competitive price of hydrogen is the access to low cost of electricity. Looking at the electricity cost in Europe, the MWh price required to converge to hydrogen costs of conventional means of production seems difficult to reach.

The case of the Danish energy market shows that local tariffs can sustain or not the development of electrolysis sites. Indeed the PSO tax - equivalent to half of the MWh price - implemented by the government has been progressively removed during the project. It highlights the fact that regulations have a significant impact on the business model.

Regarding the Nordpool DK1 energy market, a great potential has been observed in the Primary reserve regulation (FCR) for which PEM technology is specially adapted (ramp-up/down in less than 15 sec). The preliminary estimation of 20% electricity costs revenues has been confirmed by the last simulation established after bidding trials by the plant especially for the participation in the up-regulation.

Simulations on future installations show that **grid services revenues are key for large scale** installations which will have more interest to reserve quantities of power for bids as the variable cost of electricity will be the main driver of H2 cost.

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