

# Final report

## 1.1 Project details

|  |  |
|--|--|
| <b>Project title</b>   | Hybalance DK   |
| <b>Project identification (program abbrev. and file)</b>       | 2015-1-12474   |
| <b>Name of the programme which has funded the project</b>      | Horizon 2020 (FCHJU) & EUDP  |
| <b>Project managing company/institution (name and address)</b> | Copenhagen Hydrogen Network A/S<br>Hoje Taastrupvej 42<br>2630 Hoje Taastrup<br>(cvr. nr. 3364 1389) |
| <b>Project partners</b>  | Copenhagen Hydrogen Network<br>NEAS Energy<br><br>Hydrogen Valley                                    |
| <b>CVR</b> (central business register)                         | 3364 1389  |
| <b>Date for submission</b>                                     | 21/01/2016 (Date of signature of the grant agreement)  |

## 1.2 Short description of project objective and results

HyBalance will demonstrate the link between energy storage in the form of hydrogen and the deployment of hydrogen mobility solutions. It will not only validate the highly dynamic PEM electrolysis technology and innovative hydrogen delivery processes involved but also demonstrate these in a real industrial environment by applying high pressure hydrogen production and delivery equipment.

The partners part of Hybalance Consortium are the following:

- Air Liquide with 3 different entities:
  - Engineering & Construction (E&C): they are responsible of building the plant
  - Air Liquide advanced Business (ALAB): they are in charge of the technical and administrative coordination of the project.
  - Copenhagen Hydrogen Network: Danish subsidiary of ALAB, they are owner of the plant and they are in charge of operating the plant.
- Hydrogenics: they are in charge of manufacturing, installing and maintaining the electrolyser
- Neas Energy: they are in charge of grid-balancing
- Hydrogen Valley: they are responsible for dissemination
- LBST: they are responsible for lifecycle analysis.

## 1.3 Executive summary

HyBalance is a project that demonstrates the use of hydrogen in energy systems. The hydrogen will be produced from water electrolysis, enabling the storage of cheap renewable electricity from wind turbines. The hydrogen produced is used to supply industrial customers as well as the network of five hydrogen stations installed and operated by the Copenhagen Hydrogen Network (CHN), an Air Liquide subsidiary in Denmark. Denmark is a pioneer in the integration of renewable ener-

gies into the national energy mix with more than 40% of the electricity produced on the territory coming from wind turbines.

The budget of the project totals € 15 million. The project has received € 8 million in funding from the Fuel Cells and Hydrogen 2 Joint Undertaking as well as € 2.6 million in funding from the Danish EUDP program.

The Hybalance project is divided into 2 phases:

- Phase 1: Building of the hydrogen production plant and the grid balancing system
- Phase 2: Operation of the plant, demonstration of the concept

The Hybalance DK project funded partly by Danish EUDP program correspond to the phase 1. The main objective was to build the plant and the grid balancing system. This objective was achieved at the end of the project. Hybalance is today the biggest hydrogen production plant operational in Europe.

The next steps for this project – named HyBalance – is to demonstrate the link between energy storage in the form of hydrogen and the deployment of hydrogen mobility solutions. The project will validate highly dynamic PEM (Proton Exchange Membrane) electrolysis technology and demonstrate this at a megawatt-scale (1.2 MW) in a real industrial environment, producing about 500 kg of hydrogen per day. The HyBalance setting is demonstrating the multiple applications of Power-to-Hydrogen technologies, including how carbon-free hydrogen can be used in multiple high value markets such as industry and clean transportation, and the project will help validate the business models for these applications.

#### **1.4 Project objectives**

The Hybalance DK project includes the 2 first periods of the Hybalance project (4 periods in total). In these 2 periods the main objectives were:

For the period 1:

- Freeze the preliminary definition of the plant and to start to manufacture the electrolyser so as to be able to start the demonstration ontime during period 2.
- Define the local mobility and industrial hydrogen markets
- Launch the supporting documents and tools for the project dissemination strategy.

For the period 2:

- Construct, install the electrolyser, and commission the plant
- Continue the assessment of the most appropriate prospects (both from the mobility & industrial markets) and finalize the negotiations & contract signature with the early adopters of Hybalance hydrogen so as to secure customers before the start-up of the plant
- Disseminate around the different step of construction and discuss the timeline and content of the inauguration of the plant.

#### **1.5 Project results and dissemination of results**

The project is divided into 4 main activities: construction of the plant, construction of the electrolyser, design of the grid balancing system, dissemination of the project.

### 1.5.1 Overall system design, interfaces and operational supervision

The erection of the plant consist in:

- HyBalance preliminary definition
- Engineering and Procurement
- management during the engineering and construction of the plant
- Construction and commissioning: construction and commissioning extended from December 2016 to end of 2017 which represents almost all the Second Reporting Period.
- Civil Works contract was awarded to a local company end of November 2016. Site opening was effective mid-December and foundations works were completed beginning of May 2017.



**Figure 1: Hybalance site - foundations completed**

- Contract for Mechanical and electrical/instrumentation erection works was also awarded to a local company on June 1st and the first equipment was delivered to site on June 8th.



**Figure 2 : Delivery of the equipment on site**

**Figure 3 : Hybalance site connected to the main power**



Although the plant was successfully energized by the main power line end of August.

The major difficulty encountered during the testing period was the programming of the plant. Since the Hybalance installation is a “First of its kind” project, a completely new program had to be implemented. The Hydrogen filling sequences in the various storage as well as the multiple trailer filling scenarios are extremely complex.

- **Main technical issues encountered due to the innovative nature of the project:**
  - **HP compressor technology** reciprocating compressor vs membrane compressor. The pros and cons of each solution were thoroughly analyzed
  - Due to the particular trailer filling scheme of this project, **specific control valves arrangement** had to be developed by the supplier.
  - To convert the control strategy into an actual **Operating System**, a totally new and rather complex program had to be developed





**Figure 4: Hybalance plant today**

- management during the tests and operations

In July 2017 a Site manager was hired.

A cloud based maintenance system has been introduced. The maintenance system will keep track of planned, corrective and improved maintenance as well as spare parts.

### 1.5.2 Electrolysis

The activities to build the electrolyser consist in:

- Definition and clarification of interfaces between the electrolyser and the different parts of the whole Hybalance plant
- Grid connection and equipment: the connection to local electrical grid is done through a transformer shelter. The transformer station was installed by mid-June.
- Electrolysis construction: the task is to build, construct, transport to Hobro, erect and install the electrolyser in accordance with the agreed specifications.
- special requirements with respect to environment constraint were integrated in the electrolyser design by Hydrogenics, such as noise reduction.

The electrolyser was fully constructed and installed with hooked up utility container in Hydrogenics Facilities to be able to test and fine tune the functionality of the electrolyser.

The electrolyser was then transported to the Hobro plant, it took 2 days to unload it from 13th to 15th June 2017 and 15 days to install it, installation was completed on 15th July.



**Figure 7: Installation of the electrolyser in the Hybalance, Hobro, Denmark**

### 1.5.3 Grid balancing and trading strategy – NEAS

Neas Energy is responsible for developing a model that simulates the operation of the Power-to-hydrogen plant in Hobro, Denmark. The model is used for determining the optimal trading strategy and estimation of the cost of producing a certain amount of hydrogen. Neas is also responsible for setting up remote control of the hydrogen plant and starting and stopping the plant according to use of the electricity consumption in the different electricity markets, spot market and balancing markets.

- Identification of framework conditions

Studies of the regulatory framework conditions that influence the operation on the power-to-hydrogen plant were performed at the beginning of the project. Also, it describes the general technical characteristics and the different electricity markets that could be interesting for the plant.

- Optimal Trading strategy model

The model was built in Matlab and simulates the operation of the plant on an hourly basis for one full year. The model finds the optimal operation strategy minimizing the operation costs in relation to variable electricity prices, technical limitation of the plant and a certain hydrogen demand.

- Software and hardware for trading and grid-balancing management system (M5-M18)

Physical meetings between Neas Energy and Air Liquide Advanced Business has taken place. Throughout the meetings several things have been discussed including: Grid regulations, market price and settlement, interfaces between Neas Energys software and the electrolyzer and a bilateral agreement concerning balance responsibility and electricity supply.

### 1.5.4 Dissemination – CEMTEC

- General dissemination

The dissemination activities for the HyBalance project have focused on development of information materials (website...) , update of channels, facilitation of visitors at the site and facilitation of media requests.

This includes:

- Development of an overall communication plan for the HyBalance project
- Development of a general Power Point presentation
- Launch of 3 videos at the website and social media platforms
- Development of a Poster for conferences
- Production of a general brochure (more comprehensive than the first one)
- Updating the HyBalance website [www.hybalance.eu](http://www.hybalance.eu) and [LinkedIn-profile](#)

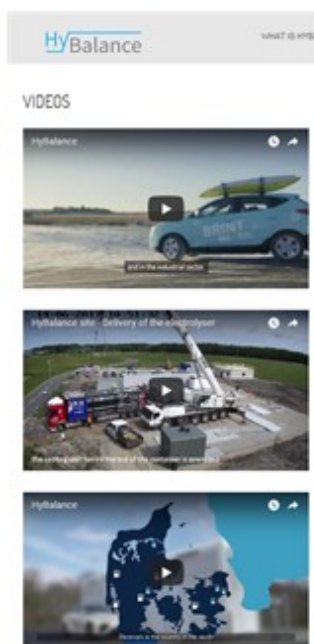
### **Media coverage**

HyBalance has been featured in Danish TV, and in total 14 articles mentioning HyBalance have been registered from 10/2016 to 12/2017. A list of media coverage is available at the website, it includes the following in the English spoken press:

- 11.07.2017: Travel report day 3 (Hansa Green Tour 2017 visited the HyBalance site)
- 07.05.2017: HyBalance mentioned in the HiPS-NET newsletter. DBI Gas- und Umwelttechnik GmbH
- 16.02.2017: Hydrogenics' 1.2MW Electrolyser successful in initial hydrogen production testing. FuelCellsWorks
- 13.02.2017: Hydrogenics' 1.2MW Electrolyser successful in initial hydrogen production testing. FCH JU
- 13.02.2017: HyBalance electrolyser successful in hydrogen production testing. FCH JU
- 13.10.2016: Industrial-scale hydrogen storage on trial. WindPower Monthly
- 07.03.2016: Air Liquide to operate pilot hydrogen plant in Denmark. SeeNews Renewables
- 23.02.2016: Air Liquide leading the first Power to Hydrogen project for clean transportation. FuelCellsWorks
- 23.02.2016: Company Update (NASDAQ:HYGS): Hydrogenics Corporation (USA) Selected to Join €15 Million Power-to-Gas Project. Smarter Analyst
- 23.02.2016: New hydrogen project from Air Liquide aims to develop clean mobility network in Denmark. Gasworld
- 23.02.2016: Denmark: Demonstrating the use of green hydrogen in energy systems. African Hydrogen Power.
- 23.02.2016: Hydrogenics Selected to Join 15 Million Power-to-Gas Project. PressReleasePoint
- 23.02.2016: Hydrogenics Selected to Join €15 Million Power-to-Gas Project. Nasdaq, GlobeNewsWire
- 23.02.2016: Hydrogenics Selected to Join €15 Million Power-to-Gas Project. FuelCellsWorks

### **Visits at the site**

5 delegations have visited the HyBalance plant in the period, among them 2 traffic-spokespeople from the Danish Parliament and 4 from outside Denmark.



## Databases

HyBalance has been registered in the following 9 databases:

|   |   |
|---|---|
| Fuel cells and Hydrogen Joint Undertaking                       | <a href="http://www.fch.europa.eu/project/hybalance">http://www.fch.europa.eu/project/hybalance</a>   |
| State of Green  | <a href="https://stateofgreen.com/en/profiles/cemtec/solutions/the-hybalance-project">https://stateofgreen.com/en/profiles/cemtec/solutions/the-hybalance-project</a>         |
| DOE Global Energy Storage Database                              | <a href="http://www.energystorageexchange.org/projects/2196">http://www.energystorageexchange.org/projects/2196</a>   |
| <a href="https://www.energiforskning.dk">Energiforskning.dk</a> | <a href="https://energiforskning.dk/node/8685">https://energiforskning.dk/node/8685</a>   |
| OpenAIRE  | <a href="https://www.openaire.eu/search/project?projectId=corda_h2020::0eb268011d8b">https://www.openaire.eu/search/project?projectId=corda_h2020::0eb268011d8b</a>           |
| H2FCSUPERGEN  | <a href="http://www.h2fcsuper-gen.com/news/the-hybalance-project-a-full-value-chain-demo">http://www.h2fcsuper-gen.com/news/the-hybalance-project-a-full-value-chain-demo</a> |
| Fabio Disconzi  | <a href="http://www.fabiodisconzi.com/open-h2020/projects/199464/index.html">http://www.fabiodisconzi.com/open-h2020/projects/199464/index.html</a>                           |
| EU Rammeprogram (EUDP)  | <a href="https://www.energiteknologi.dk/da/program/eu-rammeprogram?page=4">https://www.energiteknologi.dk/da/program/eu-rammeprogram?page=4</a>                               |
| European Power to Gas   | <a href="http://www.europeanpowertogas.com/demonstrations">http://www.europeanpowertogas.com/demonstrations</a>   |

Hydrogen Valley started searching for databases in which HyBalance should be included. The research is being done on the internet as well as asking their partners, researchers and people within their (hydrogen)-network to help them identify relevant databases.

Networking, participation and hosting events



The HyBalance project has been presented at 5 conferences and events.



23 November, 2017

The HyBalance project was presented orally by the coordinator at the annual FCH-JU Programme Review Days, which took place in Brussels on Thursday and Friday 23-24 November 2017



14 June, 2017

Hans-Jørgen Brodersen, Project Manager at Hydrogen Valley, presented the HyBalance project at the International Conference on Electrolysis [ICE2017](#) in Copenhagen.



29 April, 2017

Lars Udby, CEO of Hydrogen Valley, presented the HyBalance project at an event, organised within the framework of the Danish Science Festival.

Hydrogenics Europe hosted the Factory Acceptance Ceremony of the HyBalance 1.2 MW PEM electrolyser in Oevel, Belgium.



10 November, 2016  
Lasse Helleskov Ravn, Neas Energy, presented the HyBalance project at the “Danish Hydrogen and Fuel Cell Day” in Odense, Denmark.

Some of the above activities can – together with other activities – be mapped towards specific stakeholders:

| Stakeholders    | Regional | Nordic | Europe | Activities  |        |
|-----------------|----------|--------|--------|---|--------|
| Decision Makers |          | x      |        | Visit at the site by 2 traffic-spokespeople from the Danish Parliament                                  | 8/2017 |
|                 |          |        | x      | Visit by Executive director of the Fuel Cells and Hydrogen Joint Undertaking, Bart Biebuyck             | 4/2017 |
|                 |          | x      |        | Meeting with the French Embassy in CPH for deploying taxis in CPH                                       |        |
|                 |          |        | x      | Factory Acceptance Ceremony of the HyBalance 1.2 MW PEM electrolyser in Oevel, Belgium, 50 participants | 2/2017 |

|                         |   |   |   |   |         |
|-------------------------|---|---|---|---|---------|
| Associations            |   | x |   | Meetings with Hydrogen Denmark - Danish industry association working for improving the framework conditions for hydrogen and fuel cell technologies in the green transition | 2017    |
|                         | x |   |   | Contacts with Copenhagen Capacity - official organisation for investment promotion and economic development in Greater Copenhagen.  | 2017    |
|                         |   |   | x | Factory Acceptance Ceremony   | 2/2017  |
|                         |   | x |   | Presentation of the HyBalance project at the " <i>Danish Hydrogen and Fuel Cell Day</i> "   | 10/2016 |
| Mobility                | x | x | x | Promotion of HyBalance at the Fuel Cell Bus Event, 100 participants   | 9/2017  |
|                         |   |   |   | Participation in 3Emotion-project, providing 3 Fuel Cell buses in Aalborg   | 2017    |
|                         | x |   |   | Showcasing Toyota Mirai (leased)  | 2017    |
| Academics & researchers | x | x | x | Poster at the International Conference on Electrolysis, 200 participants  | 6/2017  |
|                         |   |   | x | Factory Acceptance Ceremony   | 2/2017  |
|                         |   | x |   | Presentation of the HyBalance project at the " <i>Danish Hydrogen and Fuel Cell Day</i> "   | 10/2016 |
| Citizens                | x |   |   | Danish Science Festival, event in Hobro   | 4/2017  |

|                      |   |   |   |  |        |
|----------------------|---|---|---|--|--------|
| Cross audi-<br>ences |   |   | x | Visit at the site by Hansa<br>Tour, professionals in sustain-<br>ability, 28 participants. | 6/2017 |
|                      | x | x | x | LinkedIN and Twitter updates<br>on a regular basis   | 2017   |
|                      | x | x | x | Media coverage – 14 articles<br>and broadcasts   | 2017   |

As part of the communication plan, key topics to address according to the Stakeholder group targeted were defined and a Q&A was prepared in order to define the key messages and to be prepared to explain issues, hurdles and ways of overcoming them.

### 1.6 Utilization of project results

Now that the plant has been built, the second part of the Hybalance project will focus on validating the highly dynamic PEM electrolysis technology and an innovative hydrogen delivery process in a real industrial environment.

### 1.7 Project conclusion and perspective

Building an hydrogen production plant via electrolysis allow the consortium to have significant learnings, for example:

- On compressor technology: **HP compressor technology** reciprocating compressor vs membrane compressor. The pros and cons of each solution were thoroughly analyzed
- On programming the operating system: a totally new and rather complex program had to be developed

The consortium expect additional learning while operating the plant and using the grid balancing system.

The Hybalance project is the first of its kind project demonstrating the use of dynamic PEM electrolysis in a real industrial environment. The results of this demonstration project is key to be able to deploy bigger sites in other locations.

In order to do so, Air Liquide and Hydrogenics have entered into a technology and commercial agreement to jointly develop PEM (Proton Exchange Membrane) electrolysis technologies for the rapidly growing hydrogen energy markets around the world.