Flexible Hybrid separation system for H_2 recovery from NG Grids

Newsletter – Issue 6 – October 2021

Editorial

Welcome to this final HyGrid newsletter. HyGrid is a 5 years-and two months project targeting the development of a high-performance, cost effective separation technology for the direct separation of pure hydrogen from natural gas grids. Three different technologies - membrane separation, electrochemical separation and temperature swing adsorption - have been combined in a new separation system to decrease the total cost of hydrogen recovery. The new separation & purification system increases the value of hydrogen blended into the natural gas grid.

The present newsletter is the final release and it is highlighting the outcome of the project and highlighting information related to the R&D fields addressed. You will also find some pictures of the final prototype tested. Hope you will find the info in this newsletter interesting. Overall, the consortium presented 9 peer-reviewed articles and participated in 31 conferences or events (23 oral presentations, one proceeding, and 8 posters), presented 1 PhD thesis, one book chapter and 17 public technical reports. We should point out that 3 patents have been granted and one spin-off company set-up. On our website www.hygrid-h2.eu you will find the public presentations, all the public deliverables of the project and many other interesting news.

In this Issue:

What is HyGrid?

The concept

One of the main problems for the implementation of the hydrogen-based economy is the transportation from production centres to the end user both industries and population. To solve this problem, besides the in-situ production of hydrogen, the use of the existing Natural Gas network has been proposed for storing and distributing hydrogen. However, cost effective separation technologies for direct separation of hydrogen from the natural network should be developed for separating and purifying the hydrogen to match the end user requirements.

The HyGrid project proposes an integral solution for developing of an advanced high performance, cost effective separation technology for direct separation of hydrogen from natural gas networks. By using a novel membrane based hybrid technology combining three technologies integrated in a way that enhances the strengths of each of them (Figure 1): membrane separation technology is employed for removing H_2 from the “low H_2 content” (e.g. 2-10 %) followed by electrochemical hydrogen separation (EHP) optimal for the “very low H_2 content” (e.g. <2 %) and finally temperature swing adsorption (TSA) technology to purify from humidity produced in both systems upstream, pure hydrogen production (ISO 14687) will be obtained.

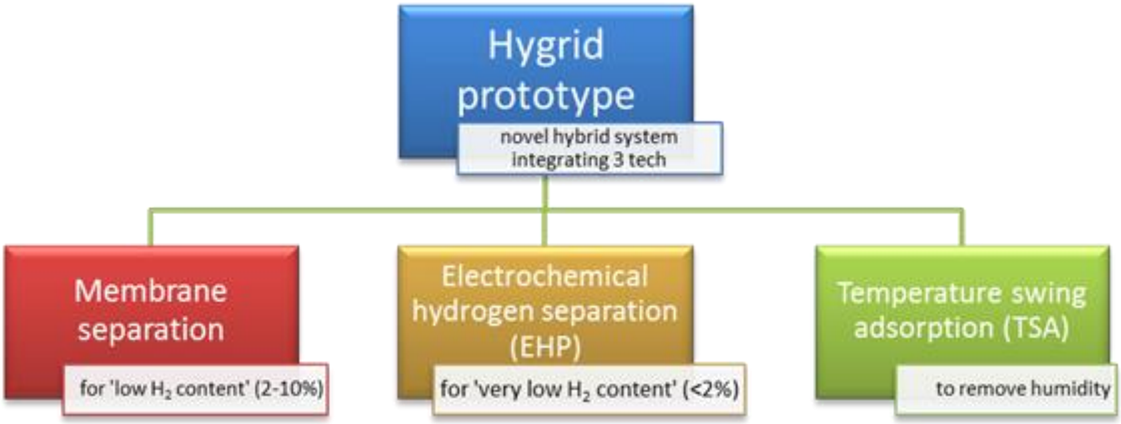


Figure 1. HyGrid concept

The new separation & purification system will increase the value of hydrogen blended into the natural gas grid, improving the economics of central hydrogen production from excess renewable energy couples with natural gas grid injection. In addition, it will reduce cost, and therefore increase the use of hydrogen from very dilute hydrogen streams in energy and transport applications. On the other side, further applications could be found in separating hydrogen from mixtures produced in chemical or biological processes, where it otherwise would be used to generate heat or even be vented.

Project objectives

The HyGrid project will develop, build and demonstrate at industrial relevant condition a novel advanced high performance, cost effective separation technology for the direct separation of pure hydrogen from natural gas grids. By combining the three different technologies (membrane separation, electrochemical separation and temperature swing adsorption) the total cost of hydrogen recovery will be decreased. The project targets a pure hydrogen separation system with power and cost of < 5 kWh/kg_{H2} and < 1.5 €/kg_{H2}. The pilot will be designed for the separation and purification of >25 kg/day of hydrogen (ISO 14687).

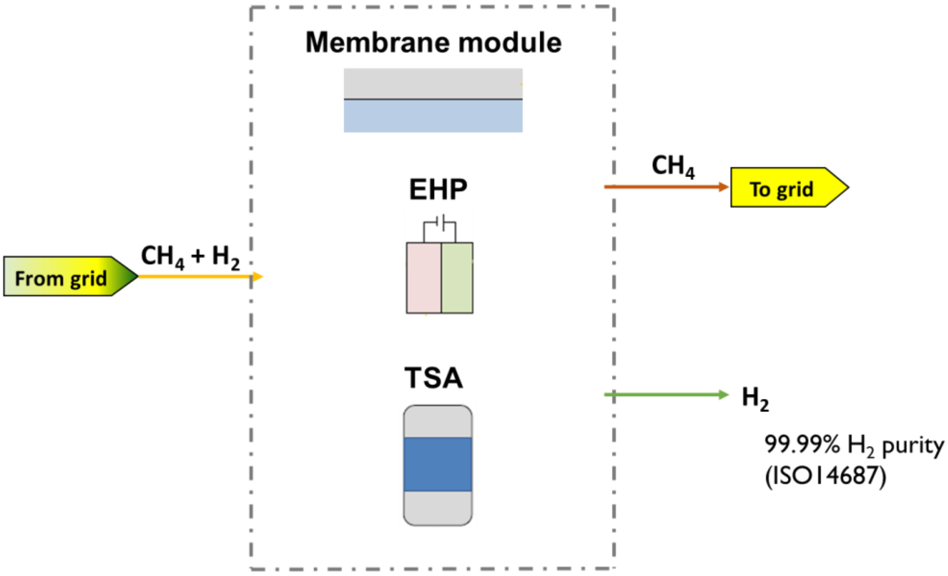


Figure 2. System schematic layout

The main objectives of the HyGrid project are:

- Design, develop, demonstrate and optimise an advanced hydrogen separation system for the production of at least 25 kg/day of hydrogen as per ISO 14687 from low (2-10%) and very low (<2%) H_2 blends in natural gas grids
- Development of stable, high performance and long durability membranes for hydrogen recovery from low (2-10%) hydrogen content streams.
- Development of more stable sealing methods for the membranes at moderate temperatures and reductive atmospheres.
- The further development of EHP for hydrogen recovery from very low (<2%) concentration streams.
- The further development of TSA for water removal from hydrogen/water streams.
- The integration of the new membranes, TSA and EHP in novel hybrid system to achieve high recoveries with low energy penalties.
- Energy analysis of the new HyGrid technology on different scenarios:

- recovery of H_2 from low concentration streams (2% -10%) up to 99.99% H_2 purity (ISO14687) in the whole range of pressures of the NG grid.
- Different configurations/combinations of the three separation technologies

- The validation of the novel hybrid system at prototype scale (TLR 5)
- The environmental analysis through a Life Cycle Assessment of the complete chain.
- Dissemination and exploitation of the results.

Latest news from the project

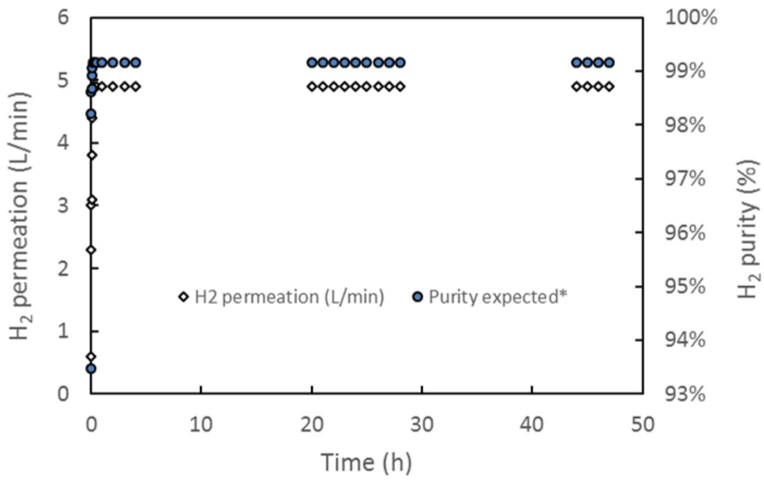
The latest news on different WP activities are now reported:

Membranes module FAT

Following the integration of the membranes into the membrane module prototype the Factory Acceptance Test has been carried out before delivering the membrane module to HYGEAR (Figure 3). This test comprises the following:

- First heating up to 400 °C under N2 to check if the membrane separation module can reach the temperature easily and temperature distribution along the module is appropriated. This will also allow to check the correct operation on the thermocouples, tracing elements and insulation.
- The second heating will address the activation of the membranes at 400 °C under a fix protocol.

a)



b)

Figure 3. Membrane module prototype: a) Protype at the test rig for FAT, b) H2 permeation and purity when feeding a gas mixture containing 40% of H2 in N2 (Total feed: 25 L/min, $P_{retentate}$: 4 bar(a), $P_{permeate}$: 1 bar(a), T aprox: 400 °C).

Electrochemical hydrogen separation development

The main objective of this task was the development of an electrochemical hydrogen purifier (EHP) prototype for the recovery of the hydrogen from low concentration streams (H2 ≤2 %) to be integrated into the final hybrid separation/purification prototype.

Since the previous newsletter, a dedicated EHP sub-system has been engineered, built, and tested successfully in the complete HyGrid system (see Prototype development in this newsletter). It is the first time that HyET has built a system capable of processing 85 Nm3/h of a gas mixture containing hydrogen. The pressure drop of the gas from the feed side to the retentate side proofed to be also within specifications of less than 0.5 bar. The system contains two full-size stacks of 144 cells each, which is a novelty compared to HyET's standard stack size of 120 cells.

Figure 4. EHP sub-system skid installed in the HyGrid system at HyGear

Testing in the complete HyGrid system showed that the system was capable of extracting 65 mol H_2/h or 3.1 kg H_2/day from the gas mixture at less than 4 kWh/kg H_2, which is the energy demand target of the EHP stacks. Operation of up to 199 mol H_2/h or 9.6 kg H_2/day has been tested with an energy demand close to 4 kWh/kg H_2 where 53% of the hydrogen in the feed gas was recovered by the EHP sub-system alone.

Temperature Swing Adsorption development

HyGear has finished the integration of the TSA system with the hydrogen separation module, consisting of the membrane separator by partners TECNALIA and TU/e and the EHP by partner HyET. Testing of the TSA combined with the hydrogen separation module proved successfully; the hydrogen product gas of the TSA had a dew point of between -70 and -40 °C. As the water content of the hydrogen gas exiting the separation module was higher, the cyclic loading of the TSA was slightly lower.

System modelling and simulation

The validated models have been used for carrying out optimization of different plant configurations. An example is reported in Figure 5. We have studied configurations where several membranes modules are used in series or parallel, with or without electrochemical separator or TSA, and different other combinations. All these configurations have been compared in terms of efficiencies and costs and the results used for a optimizing the prototype for the next scale. These optimizations have helped identifying the costs of hydrogen separation for different separation scales. For a small-scale separation, with first of its kind separators, costs are reported in the Figure 6.

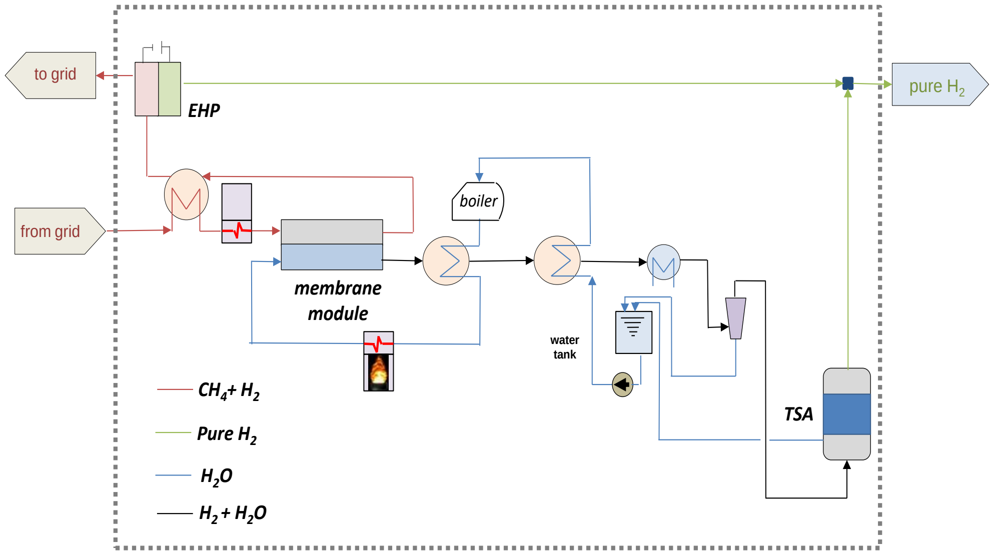


Figure 5. Example of one of the configurations studied

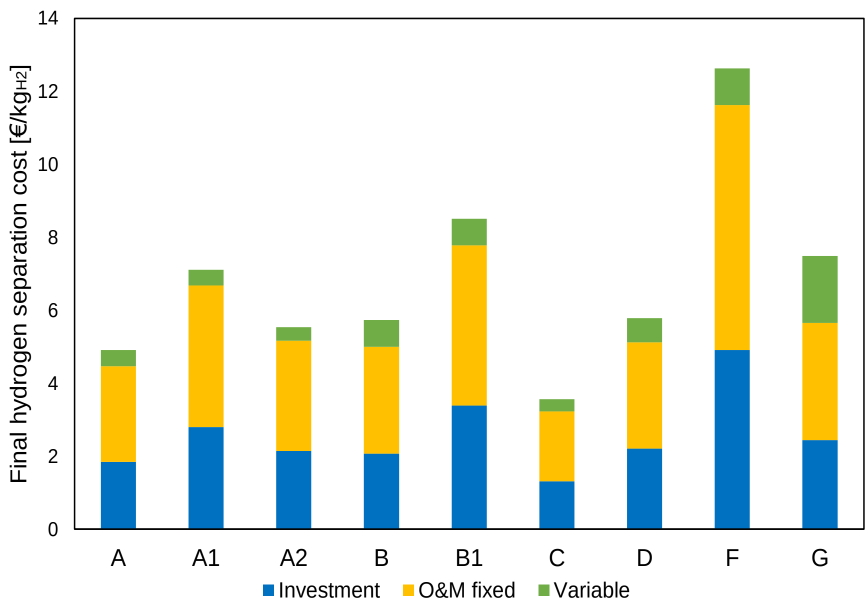


Figure 6. Costs breakdown of different configurations for small scale (25 kg/day) hydrogen separation unit.

It can be seen that several configurations have variable opex within the target of the project. More info on this kind of models and the results of the project can be found in the PhD thesis of Dr. Maria Nordio (repository of TU/e).

Prototype development

In previous newsletter the design of the HyGrid prototype was presented. Assembly of the HyGrid prototype was successfully finished during the last year. Integration of the membrane separator module by partners TECNALIA and TU/e and the EHP system by partner HyET with the Balance-of-Plant and the TSA was completed successfully (Figure 5).

Figure 5. HyGrid prototype

The system is CE certified. Finally, the full prototype was tested using hydrogen mixtures of approx. 10 vol% in nitrogen and natural gas. The prototype performed well when processing nitrogen / hydrogen mixtures. The influence of different operation parameters on the performance of the membrane separator and the EHP was tested. It was noted that, a.o., higher operating temperature of the membrane separator did not lead to increased hydrogen permeance, while increased steam sweep flow on the permeate side decreased the hydrogen permeance. When processing natural gas / hydrogen mixtures in the membrane module, the performance of the EHP system was negatively influenced by the retentate gas exiting the membrane separator. The performance of the EHP system was partially restored when processing nitrogen / hydrogen mixtures. Also, the TSA was tested successfully in conjunction with the HyGrid separation module (see above).

Environmental and economic assessment

The environmental and economic assessment of the new hydrogen recovery systems developed within the HyGrid project will also be evaluated. The aim is not only to compare the developed technologies to current hydrogen recovery systems, but also to guide the design of the investigated technologies towards more environmentally friendly solutions. The core methodology that will be used to achieve this is life cycle assessment (LCA), a quantitative environmental assessment tool which estimates the environmental impacts of products or services looking at their entire life cycle as shown in Figure 6 below.

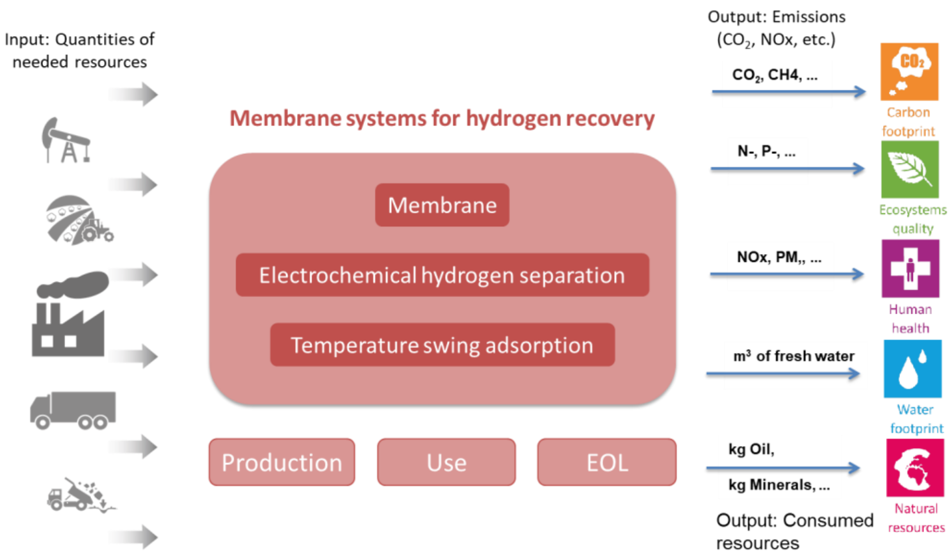


Figure 6. LCA approach.

In the first 12 months, the first task of this assessment was completed which involved developing the framework for the environmental and economic assessment. In technical LCA terms, this corresponds to developing the goal and scope of the study which involves clearly defining which different systems will be analysed, which system boundaries and functional unit will be used for the study and which reference technology the HyGrid system will be compared to. The economic assessment of the HyGrid system was done using the Life Cycle Costing method, following the same system boundaries as the LCA

The functional unit for this study was determined to be: "the recovery of 1 kg of hydrogen with a purity of at least 99.97% from an average European natural gas grid". Pressure swing adsorption (PSA) had been identified as a suitable reference technology and was assessed for comparison.

The final LCA and LCC results are presented in the public deliverable D9.3 (Integrated final environmental life cycle assessment, life cycle costing and business plan) that could be downloaded from the public website. Drawing upon the results presented in this study, it can be said that the separation of hydrogen from natural gas has less potential environmental impacts with the small-scale HyGrid prototype system than with a PSA reference system of comparable size.

For both technologies the operation phase is dominating the impacts, whereby HyGrid operates with significantly higher energy efficiency than the PSA system, i.e. consumes less energy per kg hydrogen separated.

To ensure that this advantage over the reference technology persists with scale-up to commercial size and to further improve the HyGrid technology for environmental performance, we identified four main recommendations for the further development of the HyGrid technology beyond the end of this project. Our recommendations along with an indication of their impact on the life cycle costs are summarized in Table 1.

Table 1. Recommendations for the future improvement of the HyGrid technology's environmental performance.

Recommendations to improve HyGrid's environmental performance	expected impact on life cycle costs
Reduce energy consumption: largest improvement potential	
Reduce heat demand: Investigate CMSM membrane option	
Material efficiency of infrastructure & scale-up	
System operation: **low-impact electricity** sources	

Business plan

The business plan presented a market survey, a stakeholder survey and a risk analysis. Potential end-users were identified and market size for HyGrid estimated. Moreover, deployment targets and strategies for future commercialisation were defined. From the risk analysis it was deduced that no or late adapting national and international legislations for the presence of hydrogen in natural gas has highest risk to result in failure to marketize HyGrid. It is also concluded that creating public awareness of the HyGrid system and further performance improvement should not wait for national and international law makers to adapt legislation.

Highlights

HyGrid Workshop 2021
Flexible Hybrid separation system for H_2 recovery from Natural Gas Grids
July 24th, 2021, online

HyGear hosted the final HyGrid Workshop on "Flexible hybrid separation for H_2 recovery from NG grids" online due to the Covid pandemic. While in previous 2018 workshop the focus was on, a.o., challenges of distributing hydrogen into the NG networks and the purity requirements, this time important results on EHP and membrane development were presented. Also, the full HyGrid prototype was discussed in detail, a prelude to a commercial system was shown and the results of the life cycle assessment were presented. The workshop was the final transfer of knowledge event of the HyGrid project, contributing to the increase of knowledge, and competitiveness of the hydrogen economy in the EU community. Presentations are available in the HyGrid website (https://www.hygrid-h2.eu/content/publications) as technical report of the project (deliverable D10.17 Final conference workshop).

Dissemination activities, publications and presentations:

HyGrid public presentations as well as open access articles and public reports are available online in the dissemination section of the project website: www.hygrid-h2.eu. The number of relevant dissemination and communication activities during the implementation of the project is detailed in the figure hereafter.

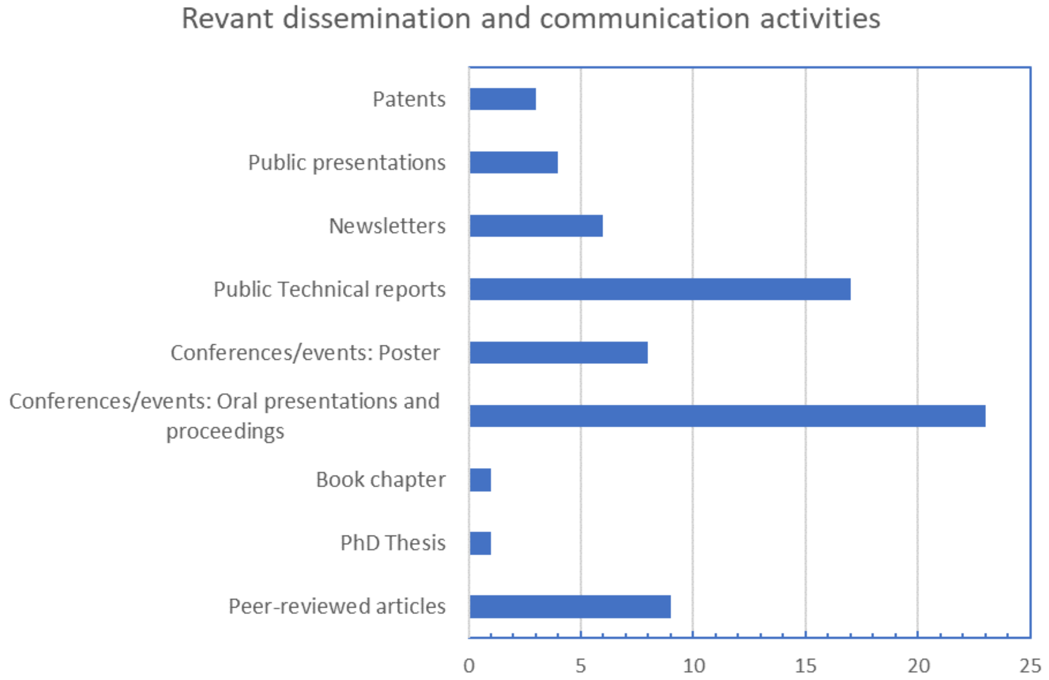


Figure 7. Relevant dissemination and communication activities.

The three patents related to the HyGrid project are:

- WO/2020/122709. Method for low hydrogen content separation from a natural gas mixture.
- WO2020106152A1 "Cell plate assembly for a solid-state compressor, solid-state compressor and method for operating a solid-state compressor".
- WO 2021/116319 A1: Carbon molecular sieve membrane and its use in separation processes.

In addition, a new company Hydrogen Onsite, S.L. (H2SITE, https://www.h2site.eu/en/) was created by TECNALIA and TUE in 2019 to exploit the technology of Pd-based Membranes and Membrane Reactors for the production of pure hydrogen. In 2020, ENGIE invested in the company, through its corporate venture capital arm ENGIE New Ventures.

HyGrid in figures:

- *7 partners (2RES, 2 IND, 3 SME)*
- *4 countries*
- *2,847,710 € project (2,527,710 € EU funded)*
- *Start May 2016*
- *Duration: 62 months*

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More information on HyGrid (including the non-confidential presentation of the project) is available at the project website: www.hygrid-h2.eu

Acknowledgement:

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700355. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N. ERGHY.

Disclosure: