





HYGRID

FLEXIBLE HYBRID SEPARATION SYSTEM FOR H2 RECOVERY FROM NG GRIDS

FCH-2 GRANT AGREEMENT NUMBER: 700355

Start date of project: 01/05/2016 Duration: 5 years

WP10 - Environmental LCA and economic assessment

D 10.17: Final conference / workshop

Topic: Development of technology to separate hydrogen from low-concentration hydrogen

streams

Funding scheme: Research and Innovation Action

Call identifier: H2020-JTI-FCH-2015-1

Funding: The project leading to this application 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, Hydrogen Europe and Hydrogen Europe research.

Due date of deliverable: 31-08-2021	Actual submission date: 27-10-2021	Reference period: 4 th period
Document classif	Prepared by (**):	
HYGRID-WP10-D1017-DLR-I	HT&S	

Version	DATE	Changes	CHECKED	APPROVED
v0.1	27-10-2021	First Release	HyGear	M. Rep

	Project funded by the FCH-2 JU within the H2020 Programme (2014-2020)					
	Dissemination Level					
PU	Public	X				
PP	Restricted to other programme participants (including the Commission Services)					
RE	Restricted to a group specified by the consortium (including the Commission Services)					
СО	Confidential, only for members of the consortium (including the Commission Services)					
CON	Confidential, only for members of the Consortium					

^(*) for generating such code please refer to the Quality Management Plan, also to be included in the header of the following pages; (**) indicate the acronym of the partner that prepared the document.



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 2 of 98

Table of contents

1	EXECUTIVE SUMMARY	3
	1.1 Description of the deliverable content and purpose	3
	1.2 Brief description of the state of the art and the innovation	3
	1.3 Deviation from objectives	3
2	INTRODUCTION	4
3	Online pre-announcement of the webinar on the website of HyGrid	6
4	Final announcement of the workshop on the website of HyGrid	7
5	Opening speech workshop by Prof. Dr. Eng. F.Galucci, TU/e	9
6	Partner Tecnalia - Development of membranes for hydrogen separation	19
7	Partner TU/e – Development of separation systems for hydrogen separation	34
	Partner HyET - Electrochemical Hydrogen Separation and Compression from latural Gas - Scaling up the technology	49
9	Partner HyGear - HyGrid prototype experiences	61
10	0 Partner Quantis – Environmental LCA & Economic Assessment	71
1	1 Engie - GRHYD : a successful demonstration for the new gas H2NG	86



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 3 of 98

1 EXECUTIVE SUMMARY

1.1 Description of the deliverable content and purpose

The objective of the H2020 EU research project HyGrid is the design, scale-up and validation of a novel membrane-based hybrid technology for the direct separation of hydrogen from natural gas grids. This novel technology separates hydrogen through a combination of membranes, electrochemical separation (EHP) and temperature swing adsorption (TSA). The target is to achieve high hydrogen purity at low energy consumption and hence decreased cost of hydrogen separation compared to existing technologies. Moreover, the environmental impacts of hydrogen separation via the HyGrid technology should not be higher than via conventional technologies. A small-scale pilot system with a capacity of 12.6kg hydrogen separated per day was designed, built and tested during the project.

This deliverable presents the announcements, the presentations and some of the moments of the workshop are presented.

1.2 Brief description of the state of the art and the innovation

Since the system under study is currently being developed within the HyGrid project, no LCA results or literature on this specific topic exist. The results of the LCA of the hydrogen recovery systems developed within HyGrid will therefore shed new light on the contributions which these devices can bring in the shift towards more sustainable energy distribution systems.

1.3 Deviation from objectives

No deviation from the objectives.



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 4 of 98

2 INTRODUCTION

HYGRID Workshop 2021; On Flexible Hybrid Separation System for H2 Recovery from Natural-Gas Grids

HyGear hosted the final HYGRID Workshop on flexible hybrid separation for H₂ recovery from NG grids online due to the Covid pandemic on June 24, 2021. 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 details, 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.

The successful online workshop was held with 38 attendees (and over 70 registrations) enjoying contributions of the HyGrid partners and Engie, France, entitled "GRHYD: a successful demonstration for the new gas H2NG". The audience interacted strongly with the presenters during the Q&A moments.

Regarding the registrations a split between two groups: IND-SME and research-University was made. The split between two groups IND-SME and research-University is shown in next figure. Also policy makers could be identified among the group of registrations and, finally, a small group of registrations who did not indicate their affiliation.



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 5 of 98

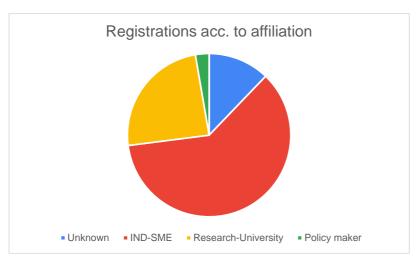


Figure 1: The split between three groups (IND-SME, Research-University, policy makers) and unknown as by registration.

In the following section the announcements and the presentations are presented.



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 6 of 98

3 Online pre-announcement of the webinar on the website of HyGrid



After the successful HyGrid workshop of 2018, HyGrid proudly presents its second workshop to be held in June 2021.

Increasing demand on highly efficient hydrogen transport is foreseen within the EU to make its large energy transition to hydrogen as a clean energy source become viable. Hydrogen transport in existing natural gas infrastructure has been recognised as a possible means to facilitate this. It is recognised by the EU that this will impose severe challenges to existing users of natural gas. Additionally, the hydrogen requires a certain purity to be used as chemical feedstock / fuel.

Within the European funded project HyGrid, new technology consisting of novel Pd-membranes, hydrogen purification by electrochemical and temperature swing adsorption is developed for the cost-effective removal and purification of hydrogen from natural gas.

Project partners HyET, HyGear, NorteGas, Quantis, Technical University of Eindhoven and Tecnalia will take you through the recent developments in gas distribution, hydrogen membrane separation and electrochemical purification development etc. Efficiency and purity results and life cycle assessment of the combined HyGrid prototype are also discussed.

The 2nd HyGrid workshop is taking place virtually in June this year and all sessions will be accessed online from your computer, tablet or mobile, giving you the flexibility at your chosen location and device. The exact date and agenda will be announced in due time. Registration for this online venue will soon start. Stay focussed on the announcements on our website.

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 679933 (HyGrid project).





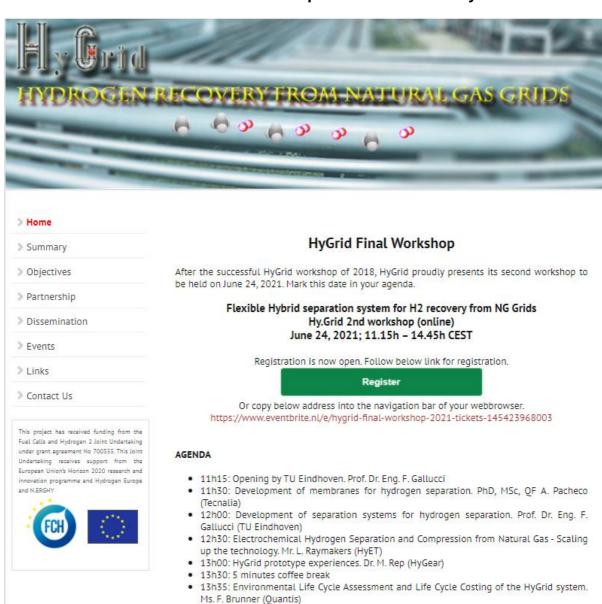


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 7 of 98

4 Final announcement of the workshop on the website of HyGrid



. 14h35: Closing remarks. Prof. Dr. Eng. F. Gallucci

14h05: GRHYD: a successful demonstration for the new gas H2NG. Ms. I. Alliat (Engie)



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 8 of 98

Flexible Hy brid separation system for H2 recoveryfrom NG Grid s

Project Duration: 5 years and 2 months

Starting date: 01-May-2016

Project Coordinator: Fausto Gallucci, TUE, The Netherlands

Grant agreement no.: 700355

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





















© 2019 TECNALIA. All rights reserved.

Parque Científico y Tecnológico de Bizkaia - C/ Geldo. Edificio 700. E-48160 Derio (Bizkaia). Tel.: 902.760.000 - International calls: (+34) 946.430.850

Legal information | Privacy policy | Cookie preferences

In the following sections the presentations held on June 1 are presented.



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 9 of 98

5 Opening speech workshop by Prof. Dr. Eng. F.Galucci, TU/e



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 10 of 98





Project Overview

- Call year: 2015
- Call topic: H2020-JTI-FCH-2015-1 Development of technology to separate hydrogen from low-concentration hydrogen streams
- Project dates: 01 May 2016
- % stage of implementation 24/06/2021: 98%
- Total project budget: €3,167,710.00
- FCH JU max. contribution: €2,527,710.00
- Other financial contribution: €300,000 from Switzerland
- Partners: Eindhoven University of Technology, Tecnalia, SAES (T), Hygear, HYET, Quantis, Naturgas







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 11 of 98



Project Summary

HyGrid aims at developing of an advanced high performance, cost effective separation technology for direct separation of hydrogen from natural gas networks. The system will be based on:

Design, construction and testing of an novel membrane based hybrid technology for pure hydrogen production (ISO 14687) combining three technologies for hydrogen purification integrated in a way that enhances the strengths of each of them: membrane separation technology is employed for removing H2 from the "low H2 content" (e.g. 2-10 %) followed by electrochemical hydrogen separation (EHP) optimal for the "very low H2 content" (e.g. <2 %) and finally temperature swing adsorption (TSA) technology to purify from humidity produced in both systems upstream.

The project targets a pure hydrogen separation system with power and cost of < 5 kWh/kgH2 and < 1.5 €/kgH2. A pilot designed for >25 kg/day of hydrogen will be built and tested at industrially relevant conditions (TRL 5).

Workshop Hygrid 2021





Project Summary

Membrane module

EHP

TSA

TSA

H₂

99.99% H₂ purity (ISO14687)

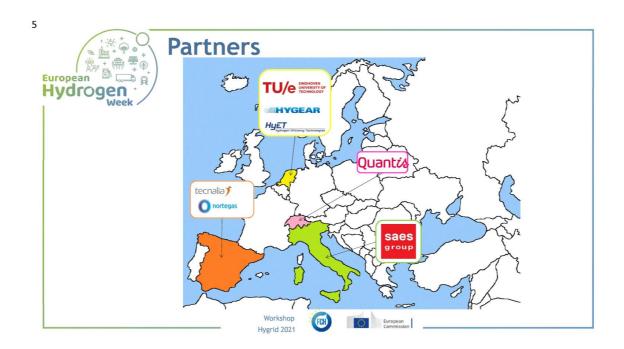
Workshop
Hydrid 2021



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 12 of 98



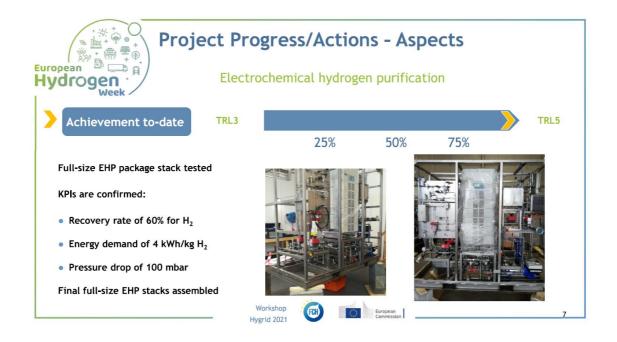


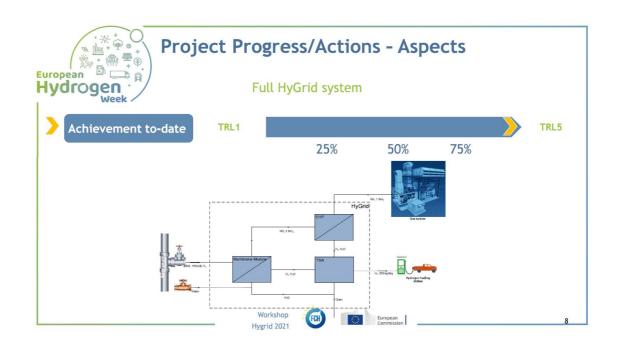


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 13 of 98





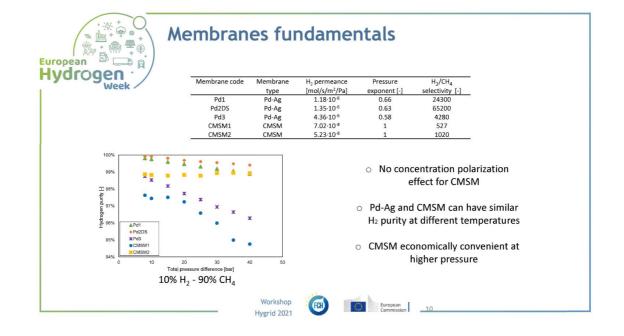


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 14 of 98



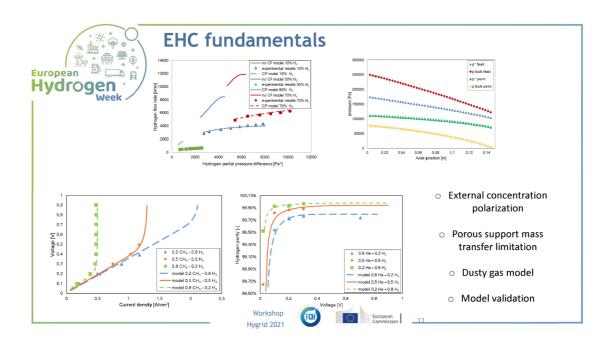


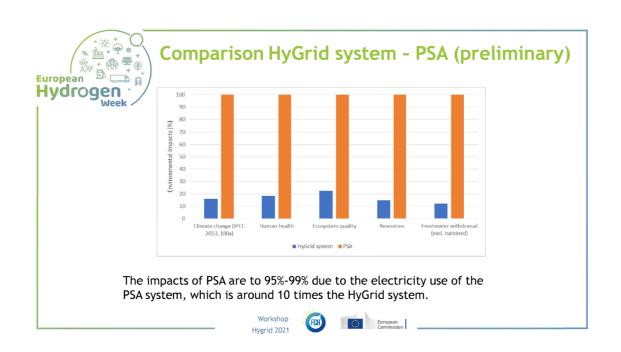


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 15 of 98







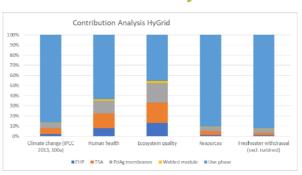
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 16 of 98



Contribution analysis



The contribution analysis shows that the use phase (energy use) is main contributor to the impacts.

In the next phase, scenarios will be caculated to better understand the importance of different parameters of the HyGrid scenarios, concentrating on the most important contributors.

Workshop Hygrid 2021







HyGrid system optimization

Configuration	Membrane	Membrane	Hydrogen	Purity from	% H ₂	Total	Electricity	Heat
	area 1 [m ²]	area 2 [m²]	separated	membrane	from	purity [%]	consumption	consumption
			[kg/day]	[%]	EHC	. ,. ,	[kWh/kg _{H2}]	[kWh/kg _{H2}]
Α	1.62	-	25	99.92	34.92	99.93	5.19	
A1	2.92	-	25	99.9876	34.92	99.99	5.05	-
A2	2.80	-	25	99.92	23.13	99.94	4.29	-
A3	1.07	-	25	99.41	34.92	99.42	5.09	-
A4	5.27	-	25	99.00	34.92	99.00	4.36	-
В	2.53	-	25	99.90	34.92	99.91	6.23	11.23
B1	4.22	-	25	99.96	34.92	99.97	6.29	11.23
С	3.85	-	25	99.92	0	99.92	3.94	-
D	2.42	0.5	25	98.75	34.92	99.9997	7.95	-
E	6.32	0.5	25	91.61	34.92	99.99	5.62	-
E1	2.97	0.5	25	96.28	34.92	99.99	6.38	-
E2	2.51	0.62	25	96.11	34.92	99.99	6.30	-
E3	2.23	0.78	25	96.02	34.92	99.99	6.22	-
E4	5.85	0.62	25	91.53	34.92	99.99	5.48	-
E5	5.33	0.78	25	91.40	34.92	99.99	5.40	-
F	-	-	25	-	100	100.00	12.64	-
G	3.67	0.5	25	99.94	32.92	99.95	8.02	11.23

Workshop Hygrid 2021





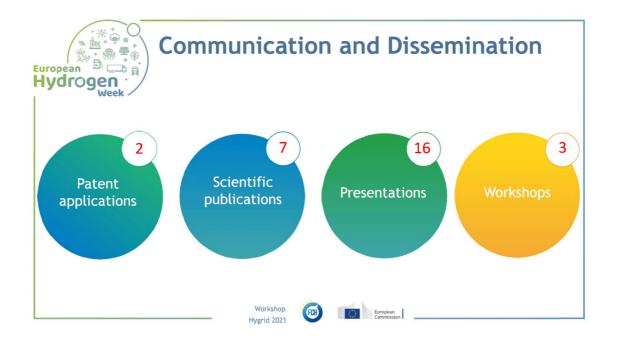


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 17 of 98







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 18 of 98

Flexible Hybrid separation system for H2 recovery from NG Grids

HyGrid

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







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 19 of 98

6 Partner Tecnalia - Development of membranes for hydrogen separation



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 20 of 98

Flexible <u>Hy</u>brid separation system for H2 recovery from NG <u>Grids</u>

Development of membranes for hydrogen separation

Online Workshop June 24, 2021

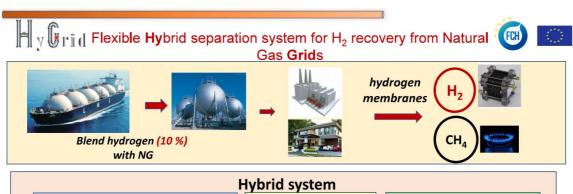


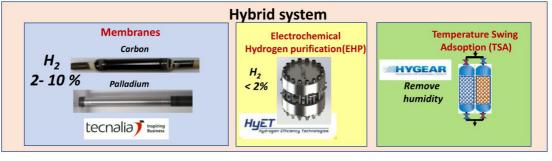


This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700355. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY

Duration: 5 years. Starting date: 01-May-2016 Contacts: F.Gallucci@tue.nl

The present publication reflects only the author's views and the FCH JU and the Union are not liable for any use that may be made of the information contained therein.







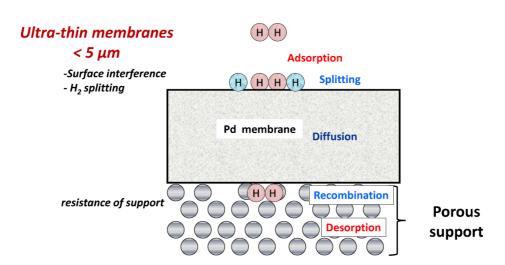
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page Nº: 21 of 98

TU/e tecnalia) MEMBER OF BASOUR RESEARCH BASOUR RESEARCH H₂ selective membranes Palladium Relative Hydrogen permeation $$^{\circ}$_{0}$ Palladium alloys Mesoporous Carbon Ceramics (nm) Microporous Ceramics (Å) Zeolites 0.1 1000 10000 H2/N2 selectivity HyGrid Page 3 Workshop June 2021

H2 permeation in Pd membranes

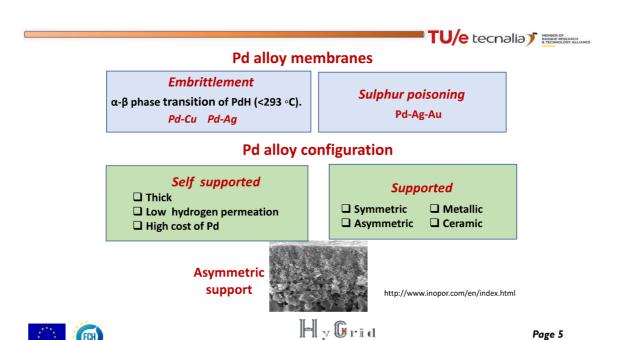




Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 22 of 98



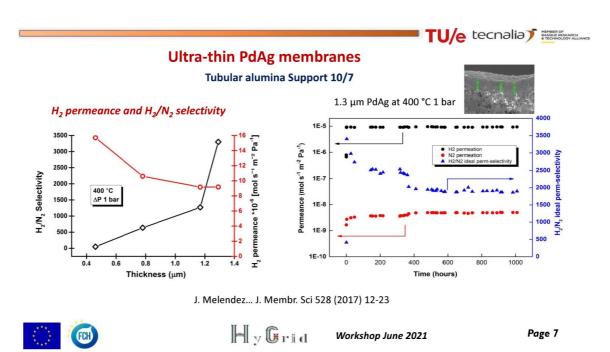
TU/e tecnalia) MEMBER OF MAGGIE RESEARCH RESEARCH RECHROLOGY ALLIANCE Ultra-thin PdAg membranes (≈ 1 μm) on porous alumina support Long term permeation (< 1000 h) 1,3 μm thick PdAg membrane H₂ permeance 400 °C 1 bar Journal of Membrane Science 528 (2017) 12–23 4000 1E-5 Permeance (mol s⁻¹ m⁻² Pa⁻¹) 1E-6 3000 2500 1E-7 Porous alumina support 2000 1E-8 1500 Leak zone 1000 1E-9 500 1E-10 200 400 600 800 1000 Time (hours) Page 6



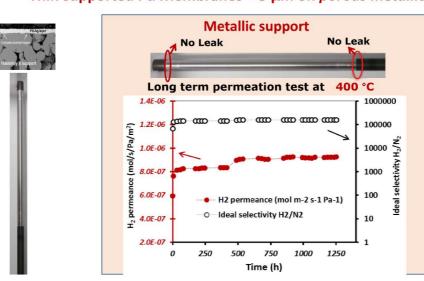
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 23 of 98



Thin supported Pd Membranes < 5 μm on porous metallic support



Page 8



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

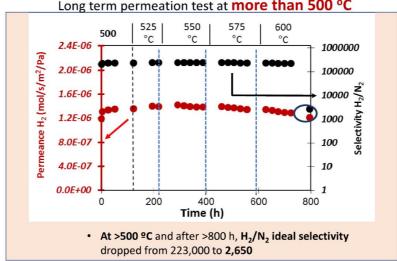
v01.docx

27/10/2021 Date: Page No: 24 of 98

TU/e tecnalia) MEMBER OF BASQUE RESEARCH BASQU **Metallic supported Pd-Ag membranes**

Long term permeation test at more than 500 °C

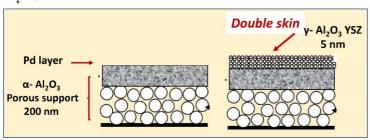




Page 9

HyGrid

Double sking Pd membranes











Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

TU/e tecnalia

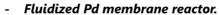
v01.docx

Date: 27/10/2021 25 of 98 Page No:









- 500 °C 12 bar max
- Nobel metal on fluidizable support.
- Hydrogen production capacity 100 kg/day.
- Calculated efficiency < 70 %
- Hydrogen purity > 99.9

Page 11



H2 SITE







MODEL	H2-INTENSE-5	H2-INTENSE-20	H2-INTENSE-50	
Nominal hydrogen flow (Nm3/h)	2 - 5	20	50	
Hydrogen purity range (%)	98,00 - 99,99	98,00 - 99,99	98,00 - 99,99	
H2 from NG conversion Yield (%)	50 - 65,0	50 - 65,0	50 - 65,0	
Size (ft)	20	40	40	









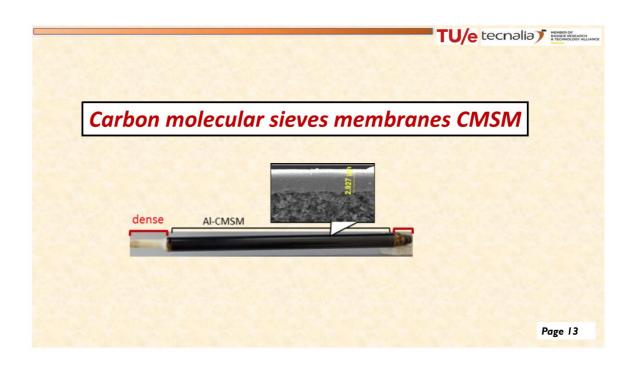
TU/e tecnalia) MEMBER OF BASQUE RESEARCH RECHROLOGY ALLIANCE

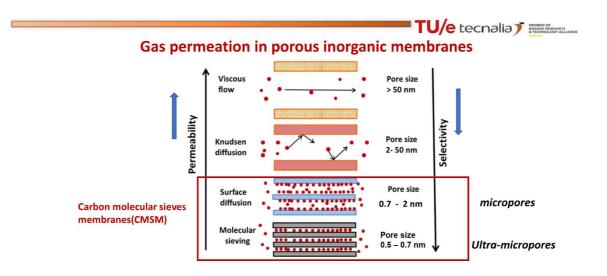


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 26 of 98











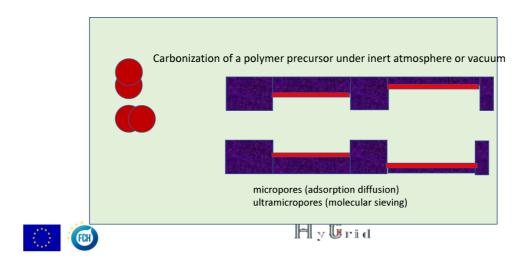
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

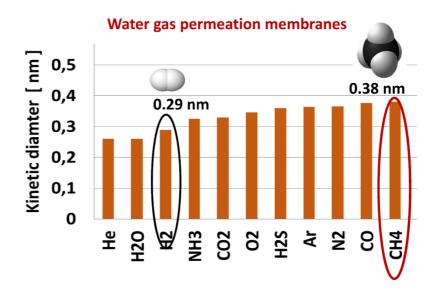
Date: 27/10/2021 Page Nº: 27 of 98



Carbon Molecular sieves membranes



Page 15

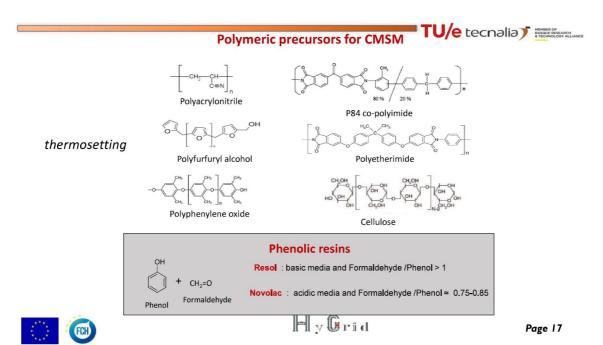


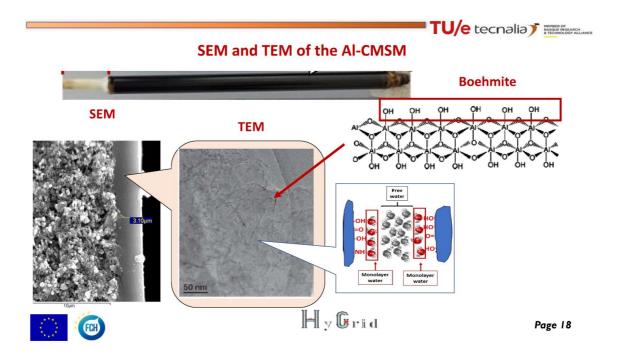


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 28 of 98







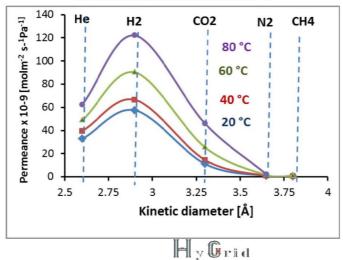
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 29 of 98

TU/e tecnalia) MEMBER OF BASQUE RESEARCH BASQU

Gas permeance as a function of temperature AI-CMSM carbonized at 500 °C

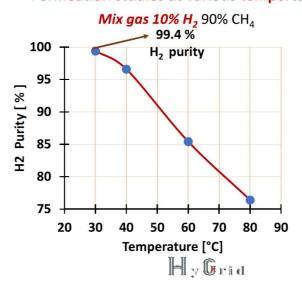




Page 19

TU/e tecnalia) MEMBER OF BASQUE RESEARCH A BASQU

Permeation studies at various tempertures





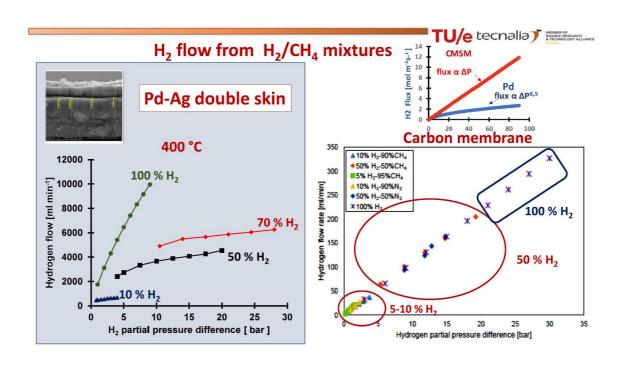


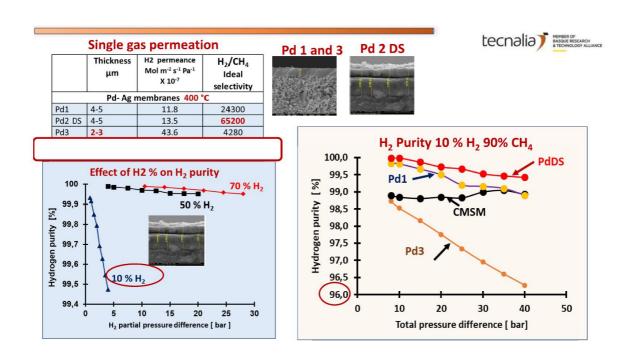


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 30 of 98







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

TU/e tecnalia) MEMBER OF BASQUE RISSEARCH RESEARCH RESEAR

v01.docx

27/10/2021 Date: 31 of 98 Page No:

CO₂ valorization

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

$$CO_2 + 3 H_2 \longrightarrow CH_3 OH + H_2O$$

$$n CH_3OH + H_2 \longleftrightarrow CH_3(CH_2)_{n-2}CH_3 + nH_2O$$
 Gasoline

$$n CH_3OH + H_2 \longleftrightarrow CH_2=CH(CH_2)_{n-2}CH_3 + nH_2O$$
 Light olefines

$$2CO_2 + 6H_2 \longleftrightarrow CH_3 O CH_3 + 3H_2O H_3C O CH_3 Dimethyl ether$$

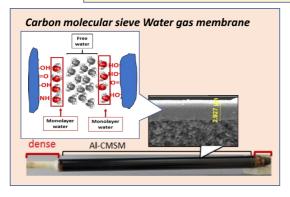
Page 23

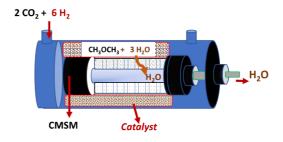
TU/e tecnalia) MEMBER OF BASQUE RESEARCH RASCULORY ALLIANCE Synthesis of dimethyl ether (DME) using membrane reactors

CO₂ + 3 H₂ ←→ CH₃ OH + H₂O MeOH synthesis



2 CO₂ + 6 H₂ CH₃OCH₃ + 3 H₂O Direct DME synthesis





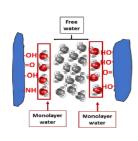


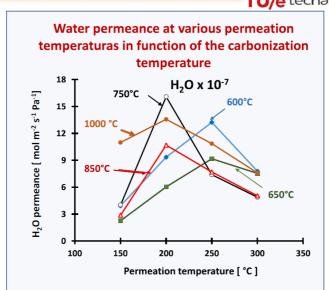
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 32 of 98







Page 25

Conclusions

PdAg Membranes

- √ Very high H2 permeation and selectivity
- ✓ Double skin membranes are resistant against attrition
- √ Working temperature 300 450 °C
- ✓ Pd membrane reactor for H₂ production









AI- CMSM

- ✓ High H2 permeation and selectivity
- ✓ Working temperature: room temperature 200 -250°C
- √ H2 recovery from Natural Gas Grids
- ✓ CMSM membrane reactors for synthesis of fuels from CO₂ and H₂





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page Nº: 33 of 98

Flexible <u>Hy</u>brid separation system for H2 recovery from NG <u>Grids</u>

HyGrid

Thank you for your attention

Contacts: F.Gallucci@tue.nl



D10.17

Final conference / workshop

Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 34 of 98

7 Partner TU/e – Development of separation systems for hydrogen separation



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 35 of 98





Flexible <u>Hy</u>brid separation system for H2 recovery from NG <u>Grids</u>

HyGrid

Development of separation systems for hydrogen separation

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

Contacts: F.Gallucci@tue.nl

The present publication reflects only the author's views and the FCH JU and the Union are not liable for any use that may be made of the information contained therein.





27/10/2021 Page I

Summary



- Study of the individual elements
- Type of confgurations
- Techno-economic analysis
- Conclusions





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 36 of 98



Research themes - SIR



Novel intensified reactor concepts via:

- > Integration reaction and separation (membrane reactors, chemical looping)
- > Integration reaction and heat/energy management (endo/exothermic, plasma systems)







We design and develop new processes by controlling the interaction between electrons, molecules, catalysts and membranes

27/10/2021 Page 3

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





Hy Grid Research themes - SIR

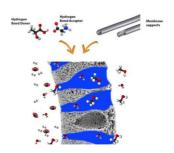


Integration reaction + separation

- Packed bed and fluidized bed membrane reactors (H₂, syngas, oxidative dehydrogenations, partial oxidations)
 - Use membranes to improve fluidization and fluidization to improve membrane flux
 - Liquid supported membranes











Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: 37 of 98 Page No:



Study of the individual elements



Optimization hydrogen recovery system

An Aspen simulation has been carried out for the optmization of the HyGrid system:

Membrane module 1-D membrane model

Electrochemical hydrogen compressor 1-D matlab model

Temperature swing adsorption Visual basic model from Hygear



27/10/2021 Page 5

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



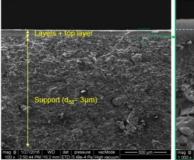


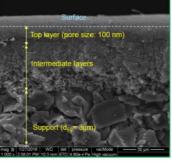
Pd Membranes – any limitation?















Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 38 of 98



Pd Membranes - any limitation?



$$\begin{split} J_{H2} &= \frac{P_0}{\sigma} \, e^{-\frac{E_a}{RT}} \left(p_{H2ret}^n - p_{H2perm}^n \right) A \\ N_{H_2} \big|_{y=R^*} &= k_g cln \left[\frac{P - P_{H_2}^*}{P - P_{H_2,bulk}} \right] = Q \left(P_{H_2}^{*n} - P_{H_2,perm}^{*n} \right) \end{split}$$

$$\begin{split} N_{H_2}|_{y=R^*} = \ k_{g,perm} cln \left[\frac{P - P_{H_2,permbulk}}{P - P_{H_2,perm}^*} \right] = Q \left(P_{H_2}^{*n} - P_{H_2,perm}^{*n} \right) \\ N_1 = - \frac{D_{K1}}{RT} (1 + \frac{B_0 P}{\mu D_{KA}}) \frac{dP}{dz} \end{split}$$

$$\begin{cases} \frac{P-P_{H2,ret}^*}{P-P_{H_{2,bulk}}} = \exp\left[\frac{Q}{ckg_{ret}} \left(P_{H2,ret}^{*n} - \left(\left(P_{tot\;perm} + \Delta P\right)x_i^*\right)^n\right)\right] \\ N_1 = \frac{P}{RTL} ln \left[\frac{1-x_{1(L)}}{1-x_{1(0)}}\right] \left[\frac{1}{D_{12}} + \frac{1}{D_{K1}} \frac{1+B_0PD_{KA}}{1+B_0PD_{K2}}\right]^{-1} \\ \Delta P = P(L) - P(0) = -\frac{ln \left[\frac{1-x_{1(L)}}{1-x_{1(0)}}\right]}{\frac{D_{K1}}{D_{12}} + \frac{B_0}{\mu D_{K2}} + \frac{B_0}{\mu D_{K2}} \frac{PD_{K1}}{\mu D_{K2}} \frac{1}{\mu D_{K2}}}{PD_{K1}} \\ N_{H_2}|_{y=R^*} = k_{g,perm} cln \left[\frac{P-P_{H_2,permbulk}}{P-P_{H_2,perm}^*}\right] = Q\left(P_{H_2}^{*n} - P_{H_2,perm}^{*n}\right) \end{cases}$$

27/10/2021 Page 7

Disclosure or reproduction without prior permission of HyGrid is prohibited)

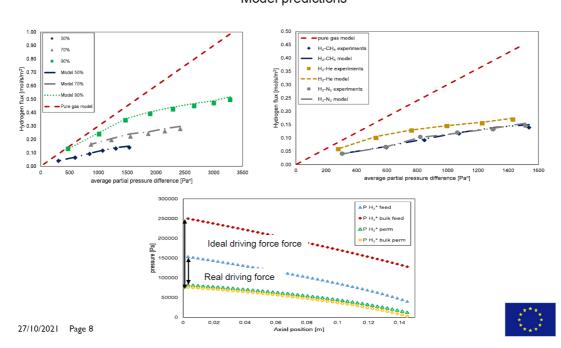




Pd Membranes - any limitation?



Model predictions





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

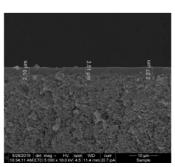
Date: 27/10/2021 Page N°: 39 of 98

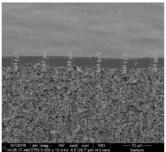


Carbon membranes









27/10/2021 Page 9

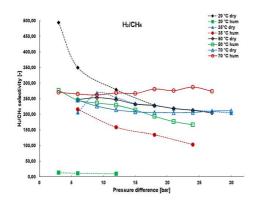
(Disclosure or reproduction without prior permission of HyGrid is prohibited).

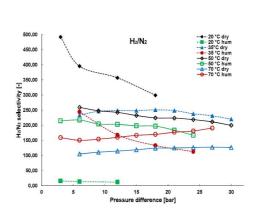




Carbon membranes











Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

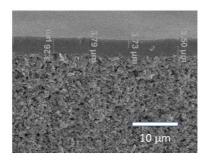
v01.docx

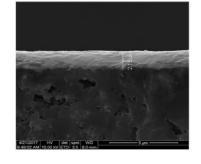
Date: 27/10/2021 40 of 98 Page No:



Comparison Carbon vs Pd







PdCarbon

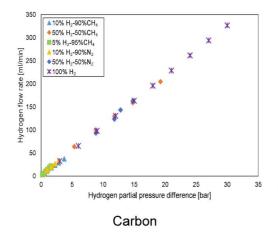
27/10/2021 Page II

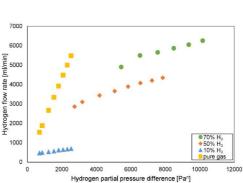
(Disclosure or reproduction without prior permission of HyGrid is prohibited).



Comparison Carbon vs Pd







Pd





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

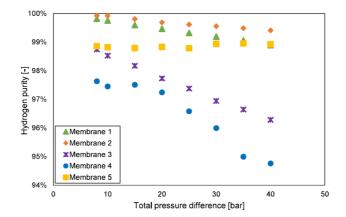
v01.docx

Date: 27/10/2021 Page N°: 41 of 98



Comparison Carbon vs Pd





Membrane code	Membrane	H ₂ permeance [mol/s/m²/Pa]	Pressure exponent [-]	H ₂ selectivity [-]
	type		exponent [-]	
Pd1	Pd-Ag	1.18·10 ⁻⁶	0.66	24300
Pd2DS	Pd-Ag	1.35·10 ⁻⁶	0.63	65200
Pd3	Pd-Ag	4.36·10 ⁻⁶	0.58	4280
CMSM1	CMSM	7.02·10 ⁻⁸	1	527
CMSM2	CMSM	5.23·10 ⁻⁸	1	1020

27/10/2021 Page 13

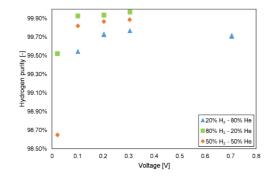
(Disclosure or reproduction without prior permission of HyGrid is prohibited)

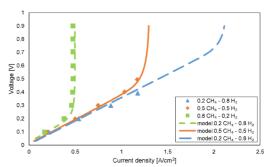


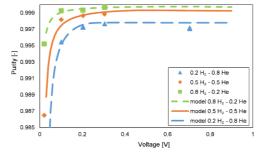


EHP study











27/10/2021 Page 14

(Disclosure or reproduction without prior permission of HyGrid is prohibited)



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

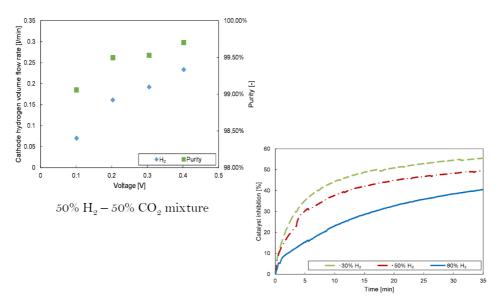
v01.docx

27/10/2021 Date: 42 of 98 Page No:



EHP study effect of CO₂





Catalyst inhibition at different hydrogen concentrations for a $H_2 - CO_2$ mixture at 0.1 V

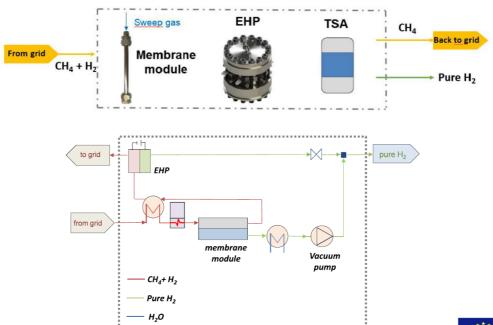
27/10/2021 Page 15

 $({\it Disclosure or reproduction without prior permission of HyGrid is prohibited}).$













Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 43 of 98



Possible configurations for H2 separation



Configuration	Membrane type	Membrane permeance [mol/s/m²/Pa]	Membrane ideal- selectivity	Membrane 2 permeance	Membrane 2 ideal selectivity	Retentate pressure [bar]	Permeate pressure [bar]	Sweep gas flow rate [mol/h
Α	c-PdDS	2.10-6	65000	-	-	8	0.15	-
A1	m-Pd	10-6	200000	-	-	8	0.15	-
A2	c-PdDS	2.10-6	65000	-	-	8	0.15	-
A3	c-PdDS	10-6	200000	-	-	40	0.15	-
A4	CMSM	2.10-6	65000	-	-	40	0.15	-
В	c-PdDS	2.10-6	65000	-	-	8	1	1000
B1	m-Pd	10-6	200000	-	-	8	1	1000
С	c-PdDS	2.10-6	65000	-	-	8	0.15	-
D	c-Pd	4.10-6	5000	2.10-6	20000	8	0.15	-
E	c-Pd	4.10-6	5000	2.10-6	20000	40	3	-
E1	CMSM	5.10-8	550	2.10-6	20000	40	3	-
E2	c-Pd	4.10-6	5000	2.10-6	20000	40	2.5	-
E3	c-Pd	4.10-6	5000	2.10-6	20000	40	2	-
E4	CMSM	7.10-8	5000	2.10-6	20000	40	2.5	-
E5	CMSM	7.10-8	5000	2.10-6	20000	40	2	-
F	EHP	-	-	-	-	8	8	-
G	c-Pd	4.10-6	5000	2.10-6	20000	8	1	1000

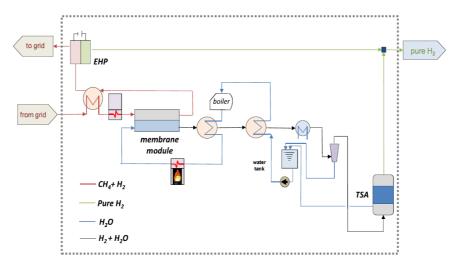
27/10/2021 Page 17

(Disclosure or reproduction without prior permission of HyGrid is prohibited).













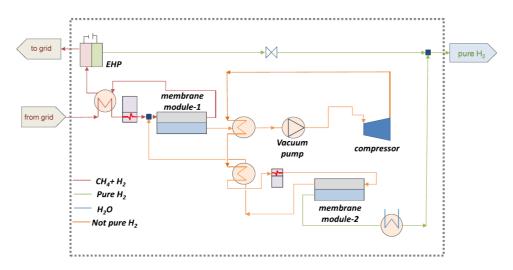
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 44 of 98

Possible configurations for H2 separation



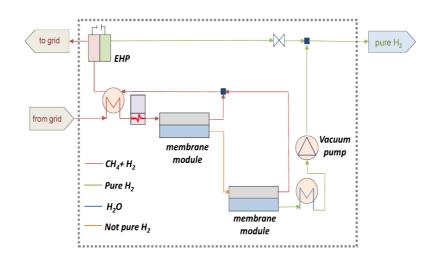


27/10/2021 Page 19













Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

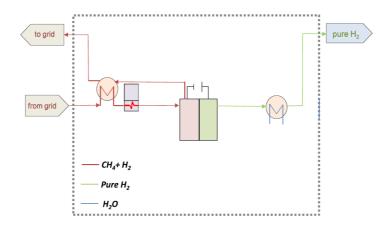
v01.docx

27/10/2021 Date: Page No: 45 of 98



Possible configurations for H2 separation



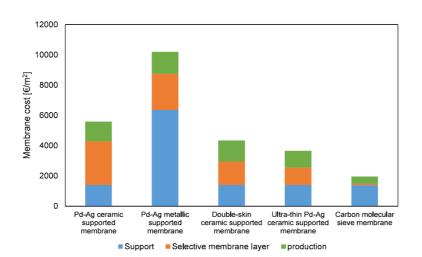


27/10/2021 Page 21

(Disclosure or reproduction without prior permission of HyGrid is prohibited).











Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 46 of 98



Possible configurations for H2 separation



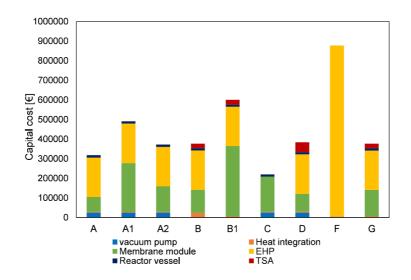
Configuration	Membrane	Membrane	Hydrogen	Purity from	% H ₂	Total	Electricity	Heat
	area 1 [m²]	area 2 [m²]	separated	membrane	from	purity	consumption	consumption
			[kg/day]	[%]	EHP	[%]	[kWh/kg _{H2}]	[kWh/kg _{H2}]
Α	1.62	-	25	99.92	34.92	99.93	5.19	-
A1	2.92	-	25	99.9876	34.92	99.99	5.05	
A2	2.80	-	25	99.92	23.13	99.94	4.29	-
A3	1.07	-	25	99.41	34.92	99.42	5.09	-
A4	5.27	-	25	99.00	34.92	99.00	4.36	-
В	2.53	-	25	99.90	34.92	99.91	6.23	11.23
B1	4.22	-	25	99.96	34.92	99.97	6.29	11.23
С	3.85	-	25	99.92	0	99.92	3.94	
D	2.42	0.5	25	98.75	34.92	99.99	7.95	-
E	6.32	0.5	25	91.61	34.92	99.99	5.62	
E1	2.97	0.5	25	96.28	34.92	99.99	6.38	-
E2	2.51	0.62	25	96.11	34.92	99.99	6.30	-
E3	2.23	0.78	25	96.02	34.92	99.99	6.22	-
E4	5.85	0.62	25	91.53	34.92	99.99	5.48	-
E5	5.33	0.78	25	91.40	34.92	99.99	5.40	-
F	-	-	25	-	100	100.00	12.64	-
G	3.67	0.5	25	99.94	32.92	99.95	8.02	11.23

27/10/2021 Page 23

(Disclosure or reproduction without prior permission of HyGrid is prohibited).











Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

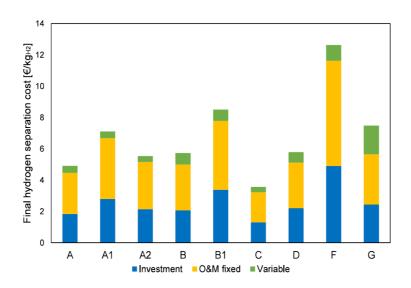
v01.docx

27/10/2021 Date: Page No: 47 of 98



Possible configurations for H2 separation





27/10/2021 Page 25

(Disclosure or reproduction without prior permission of HyGrid is prohibited)



Conclusions





- Individual steps studied in details and models validated
- · Several configurations studied and found the ones within targets
- Costs decrease with scale, recycle of materials (membranes) and life time of components
- Costs decrease sharply with concentration in the feed





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 48 of 98



27/10/2021 Page 27





Flexible <u>Hy</u>brid separation system for H2 recovery from NG <u>Grids</u>

HyGrid

Thank you for your attention

Contacts: F.Gallucci@tue.nl

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 49 of 98

8 Partner HyET - Electrochemical Hydrogen Separation and Compression from Natural Gas - Scaling up the technology



D10.17

Final conference / workshop

Proi. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 50 of 98



y Frid HyET Hydrogen



Electrochemical Hydrogen Separation and Compression from Natural Gas - Scaling up the technology Final Workshop

Leonard Raymakers

HyGrid

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

Contacts: leonard.raymakers@hyethydrogen.com

The present publication reflects only the author's views and the FCH JU and the Union are not liable for any use that may be made of the information contained therein.

24-06-2021 Page I

(Disclosure or reproduction without prior permission of HvGrid is prohibited).

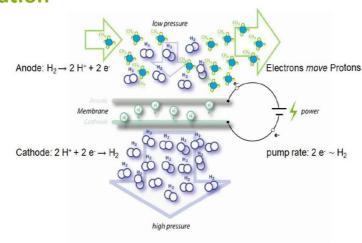








Working principle Electrochemical Hydrogen **Purification**



- EHP entails extraction + purification + compression of H₂
- Water management critical for proton conductivity





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 51 of 98



HyET Hydrogen



Previous projects EHP CH₄/H₂

Scale: single cell, small cell area

Flow: 10 NI/h to 250 NI/h, CH₄/H₂ mixture

Current density: < 0.1 A/cm²

Energy demand: 8 - 13 kWh/kg

Field test in Rozenburg, The Netherlands



24-06-2021 Page 3

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





HyET Hydrogen



Previous projects EHP CH₄/H₂

· Scale: single cell, small cell area

Flow: 10 NI/h to 250 NI/h, CH₄/H₂ mixture

Current density: < 0.1 A/cm²

Energy demand: 8 - 13 kWh/kg

· Field test in Rozenburg, The Netherlands

Project targets HyGrid

Key Performance Indicator	Unit	Start project	Target
Energy demand EHP at atmospheric pressure	kWh/kg	6	4
Hydrogen recovery rate of feed gas with 2% $\rm H_2$	%	30	60





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

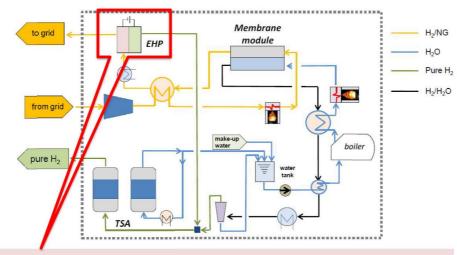
v01.docx

Date: 27/10/2021 Page N°: 52 of 98





EHP sub-system specification and goals



- EHP takes in retentate from Pd(alloy) membrane module (P=8 bar, T=30-65 C)
- H₂ concentrations: feed gas: ~6% (60% recovery expected)
- EHP output: 1.5 Nm³ / hour (= max 65 mol/hour);

24-06-2021 Page 5

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





Summary of R&D performed

- Modelling
- · Cell optimization
 - Pressure drop reduction
- · Membrane screening, catalyst development
- · Engineering stack platforms
- Lab testing
 - Water management
 - Stable performance meeting KPIs
- Demo EHP sub-system





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 53 of 98

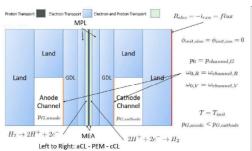


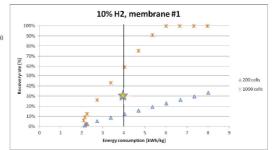
Modelling

Purpose: gain knowledge on best

- EHP cell configuration: Comsol

- System configuration: Matlab/Aspen





24-06-2021 Page 7

(Disclosure or reproduction without prior permission of HvGrid is prohibited).



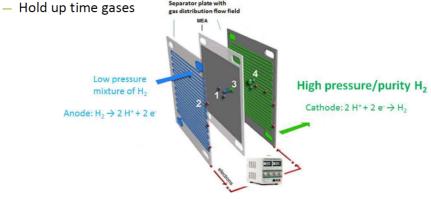






EHP cell configuration

- Compression -> Purification/compression
- Gas distribution, balance between
 - Sufficient support to the membrane/MEA
 - Low pressure drop from feed to retentate







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 54 of 98



HyET Hydrogen



EHP stacks design developed and tested

- 100 cm²
- Round design



- 500 cm²
- Square design



24-06-2021 Page 9

(Disclosure or reproduction without prior permission of HyGrid is prohibited).

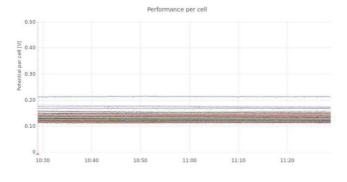


HyET Hydrogen



Scaling up testing

- Single cell (2016 2021) screening of new iterations
- 5-cell stacks (2017 2020) cell to cell performance
- 24-cell stacks (package, 2020), 12 cells
- 2 full-scale stacks, 144 cells each (2021)



- 60 min
- Pressure: 15 bar
- 3.58 kWh/kg





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

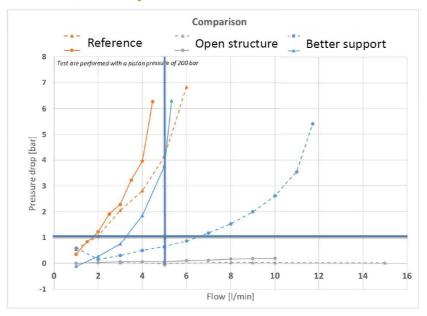
v01.docx

Date: 27/10/2021 Page No: 55 of 98





Pressure drop reduction



24-06-2021 Page 11

(Disclosure or reproduction without prior permission of HyGrid is prohibited).

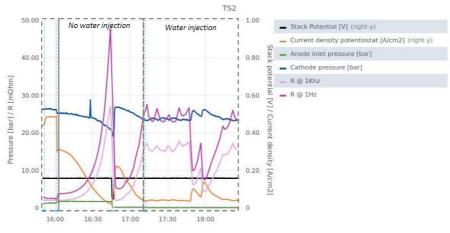


HyET Hydrogen

FCH

Water management study

- Needed for proton conductivity
- · High pressure on cathode helps water management







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 56 of 98



HyET Hydrogen

FCH

FAT - Duration test

50 h in straight run



24-06-2021 Page 13

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



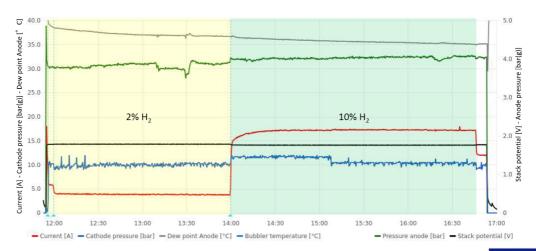






FAT - Variation of concentrations

Concentrations of 2% and 10% tested







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 57 of 98



Hy Grid HyET Hydrogen



System engineering

Specifications

- Flow rate feed: $85 \text{ Nm}^3/\text{h}$, $2 6 10\% \text{ H}_2$
- Flow rate permeate: 65 mol $H_2/h \sim 3 \text{ kg } H_2/\text{day}$, pure H_2
- Stacks: 2 in parallel, 144 cells each
- Power consumption of the EHP stacks: 4 kWh/kg H₂

Specificities

- Fully automated operation
- Placed inside shipping container
- Cooling power from HyGear
- Additional humidification of feed gas
- Utilities: N₂

24-06-2021 Page 15

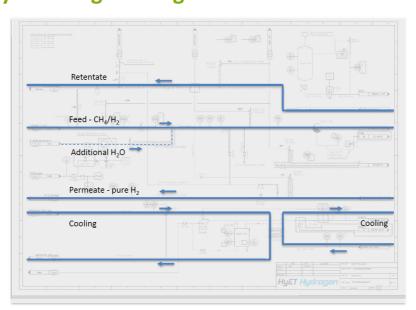
(Disclosure or reproduction without prior permission of HyGrid is prohibited).







System engineering







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 58 of 98 Page No:



Hy Grid HyET Hydrogen

System engineering



24-06-2021 Page 17

(Disclosure or reproduction without prior permission of HyGrid is prohibited).









Complete EHP sub-system







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 59 of 98



Hy Grid HyET Hydrogen

EHP sub-system at HyGear



24-06-2021 Page 19

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



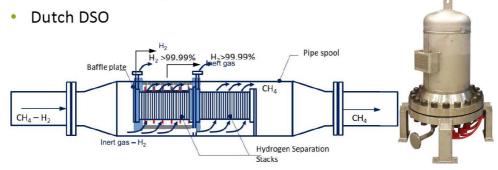


HyET Hydrogen



Outside / after HyGrid project

- Scaling up to 100 kg H₂/day extracted
- · Study on implementation of systems in the NG grid
- US Gas Network operator







D10.17

Final conference / workshop

Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 60 of 98









ANY QUESTIONS?

Flexible Hybrid separation system for H2 recovery from NG Grids

HyGrid

Thank you for your attention

Contacts:

leonard.raymakers@hyethydrogen.com

24-06-2021 Page 21

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 61 of 98

9 Partner HyGear - HyGrid prototype experiences



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 62 of 98





Flexible <u>Hy</u>brid separation system for H2 recovery from NG <u>Grids</u>

HyGrid prototype experiences

Online Workshop June 24, 2021

HyGear Technology & Services

HYGEAR

Member of the Nather group

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

Duration: 5 years. Starting date: 01-May-2016

Contacts: <u>F.Gallucci@tue.nl</u>

The present publication reflects only the author's views and the FCH JU and the Union are not liable for any use that may be made of the information contained therein.





26/10/2021 Page I

Contents



- Who is HyGear?
- Demands HyGrid system
- HyGrid prototype
- TSA development
- Commercial Design HyGrid and beyond HyGrid





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 63 of 98



Facts and Figures





- With own offices in Europe, Asia and US (support)
- o Since Jan. 1, 2021, member of the Xebec group

26/10/2021 Page 3

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





Products & Services



- Delivering gases through on-site technology
 - Small-scale gas processing experts







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 64 of 98



Demands HyGrid system



- Remove hydrogen from NG to protect downstream users
 - Max 1 vol% H₂ in NG
 - Transition period
- Extract clean hydrogen for energy use from natural gas
 - ISO 14687:2012
- Target at commercial scale
 - < 5 kWh / kg H₂ and < 1.5 € / kg H₂

Consu	mers		
	State-of-the-Art	Impurities (a.o.)	Cause
CH ₄	Gas turbines	1-5 vol% H ₂	Ineff. of rotor blade cooling, NOx abatement etc.
	Automotive applications	2 vol% H ₂	Embrittlement of storage and leakage of valves
	Gas engines	2-5 vol% H ₂	Sensitivity systems for increase of flame speed
	Household appliances	< 25 vol% H ₂	Potential backdraft burner
H ₂	Internal combustion engines Grade A: 98 vol% H ₂	100 ppm CH ₄ : NC H ₂ O	
	Automotive fuel cells Grade D: 99.99 vol% H ₂	100 ppm CH ₄ : 5 ppm H ₂ O	
	Stationary fuel cells Grade E: > 99.99 vol% H ₂	100 ppm CH ₄ : NC H ₂ O	

26/10/2021 Page 5

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



HyGrid prototype layout



- Prototype consists of:
 - Membrane separator (Tecnalia / TUe)
 - Electrochemical Hydrogen Purifier (HyET Hydrogen)
 - Temperature Swing Adsorber (HyGear)
 - <u>Separation System BoP (HyGear integration)</u>





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 65 of 98



Design specifications demo



HyGrid prototype

- Prototype design, incl. membrane separator and EHP
 - Feed stock: 90 Nm³ (NG + 10vol% H₂) / h
 - o Operating pressure NG blend: 8 bar(g)
 - Pressure drop NG < 100 mbar(g)
 - o Overall Hydrogen Recovery Factor: 65% (membrane dev. will increase this)
 - → NG spec. current users (industrial / automotive) not yet met
 - o H₂ product ambient pressure
 - o Product flow approx. 5.6 Nm³ H₂ /h
 - Dew point (controlled) : < 56°C (after TSA)
 - o Temperature H₂: 12 15°C
- System is self operating (controlled by PLC : 24/7 operation)
- NG recycling (recompression needed) and buffering
 - Reduction of green house gas emissions from plant during testing

26/10/2021 Page 7

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





Design HyGrid prototype



2 containers:

- Operating pressure zones separated
 - H₂ separation system; PED Cat. IV
 - H₂ TSA at low pressure
- Zone 2NE container design
 - o Only secondary gas release expected
 - High dilution flammable gas ensured
- System controls fully integrated
- Systems CE certified





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

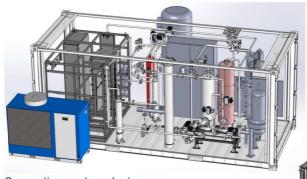
v01.docx

Date: 27/10/2021 Page No: 66 of 98

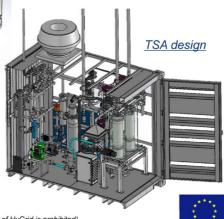


Design HyGrid prototype (Cont'd)





Separation system design



26/10/2021 Page 9

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



Separation system: A photo shoot

















Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 67 of 98



TSA development



TSA development within HyGrid

- TSA designed and assembled for 25 kg H₂ /h
- Sorbent variation
- Testing with water saturated air and hydrogen
 Influence of carrier gas
- Water adsorption capacity H₂ > N₂
 Smaller MTZ, faster adsorption kinetics

Test	Description	Adsorption capacity variation compared to base case
#1	Base case (air)	
#2	Lower feed temperature	++
#3	Lower regeneration temperature	-/+
#4	High er regeneration temperature	+
#5	Lower feed flowrate	+
#6	Increased feed flowrate, and higher regeneration	_
	temperature	
#7	Low feed water content	++
#8	Influence of gas species	+

: results in lower adsorption capacity compared to base case

: no significant deterioration or improvement compared to base case

+, ++ : results in higher (+) or much higher (++) adsorption capacity compared to base case

26/10/2021 Page 11 (Disclosure or reproduction without prior permission of HyGrid is prohibited).



TSA Model validation



- Existing in-house models extended for hydrogen drying
 - Saturated conditions incorporated
 - Sorbent variation incorporated successfully
 Applicability Dubinin-Ashtakov (zeolite) isotherm validated
 - Model prediction in line with experimental results





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 68 of 98



Commercial Design HyGrid



- Envisioned capacity: 200 kg H₂ / day
- Improved HRF:
 - Membrane separation module: > 80%
 - EHP module: > 50%
- Commercial design will be extended with:
 - DeS system to remove THT and/or mercapthanes
 - Odorisation of NG prior to feeding into NG grid
 - Wobbe index meter
 - NG fired heaters (replacing electrical heaters)
 - (NG recirculation system not required)

26/10/2021 Page 13

(Disclosure or reproduction without prior permission of HvGrid is prohibited).



Commercial Design HyGrid (Cont'd)



- HyGrid located at pressure 8 bar(q) transition stations
 - Near residential areas (100 mbarg network)
 - No need for recompression of hydrogen depleted natural gas
- Design specs commercial system similar as for demo
 - Ease of system scaling (8 barg network)
- Electrical consumption estimated:
 - 1.3 kWh per kg H_2 (at a HRF of 90%)
- Integration in high pressure (80 16 bar(g)) network
 - Similar layout
 - Higher product pressure H₂
 - Smaller TSA and less cooling duty
 - o System energy eff. increased





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 69 of 98



Beyond HyGrid



- Growing interest in > 1000 kg H₂ / day refueling stations
 - Esp. for heavy duty trucks and buses (30 50 kg H₂ storage capacity)
 - Large roll-out expected of refueling stations in US and Europa till 2030

					E	
		Passenger vehicles	Buses and coaches	Trucks**	Forklifts	Refueling stations
	Current	7,271 44	35 active, 39 in development	prototype test	>30,000 335	-42 online 32
US	Target		5,300,000 FCEVs on US roads by 2030 ³³⁷		300,000 by 2030 ³³⁷	7,100 by 2030 337
	Current	0	2,000+ 6483 8485	1,500+94	2	23 89
China	Target	3,000 by 2020 87 1,000,000 by 2030 ³³⁶	11,600 commercial vehicles by 2020 87			100 by 2020 500 by 2030
	Current	~1000+ 42	~76 42 73 36	~100 ss	~300 42	~152 71
Europe	Target	3,700,000 by 2030 ⁸⁴	45,000 fuel cell trucks and buses by 2030 ³⁴			~3,700 by 2030 ²⁴
	Current	3,219 44	18	N/A	160	127; 10 in progress
Japan	Target	40,000 by 2020	100 by 2020		500 by 2020	160 by 2020
		200,000 by 2025 800,000 by 2030 ²⁴	1,200 by 2030 ²⁴		10,000 by 2030 ²⁴	900 by 2030 ²⁴

Bron: Fueling the Future of Mobility, Volume 1, Deloitte China, 2020

26/10/2021 Page 15

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



Conclusions HyGrid demonstration



- Requirement H₂ in NG currently not met
 - Membrane development will increase HRF > 90%
- Existing drying models extended with hydrogen drying
- A prelude to a commercial system is presented





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 70 of 98





Flexible <u>Hy</u>brid separation system for H2 recovery from NG <u>Grids</u>

HyGrid

Thank you for your attention

Contacts: F.Gallucci@tue.nl



26/10/2021 Page 17

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 71 of 98

10 Partner Quantis – Environmental LCA & Economic Assessment



D10.17

Final conference / workshop

Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 72 of 98



Flexible Hybrid separation system for H₂ recovery from NG Grids



Environmental LCA & Economic Assessment

Final Workshop 2021-06-24

Florentine Brunner, Sustainability Consultant Mireille Faist, Senior Senior Sustainability Consultant

Quantis

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

Duration: 62 Months. Starting date: 01-May-2016 Contacts: F.Gallucci@tue.nl

The present publication reflects only the author's views and the FCH JU and the Union are not liable for any use that may be made of the information contained therein.

27/10/2021 Page I

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



01 METHODOLOGY OVERVIEW

LIFE CYCLE ASSESSMENT (LCA)
LIFE CYCLE COSTING (LCC)

- **02** SYSTEM BOUNDARIES & INVENTORY DATA
- 03 LCA

RESULTS & SCENARIOS

COMPARISON TO REFERENCE CASE: PRESSURE SWING ADSORPTION (PSA) IMPACT REDUCTION PATHWAY

04 LCC

RESULTS & SCENARIOS

COMPARISON TO PSA & H₂ PRODUCTION

05 CONCLUSIONS & RECOMMENDATIONS

CONTENT



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

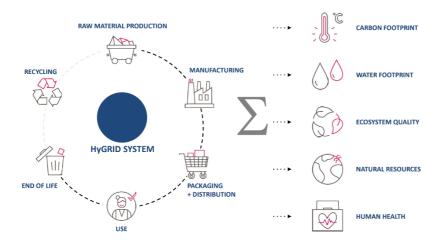
Date: 27/10/2021 Page N°: 73 of 98



HyGrid

Life Cycle Assessment (LCA)





- → LCA quantifies the whole value chain of a product or a service on a broad variety of indicators.
- → Standardized in ISO 14040-44.
- → LCIA Method: IMPACT 2002+





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 74 of 98



Life Cycle Costing (LCC)



- Assessment of costs associated with the life cycle of a product that are directly covered by one or more of the actors in the product life cycle
- LCC is done in parallel with LCA
 - Framework is based on the physical product life cycle
 - Same functional unit, same system boundaries as LCA
 - Considers non-physical flows and externalities (carbon cost)

27/10/2021 Page 7

 $({\it Disclosure}\ or\ reproduction\ without\ prior\ permission\ of\ HyGrid\ is\ prohibited).$



02

SYSTEM
BOUNDARIES &
INVENTORY DATA



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 75 of 98



System boundaries & inventory data



Considered life cycle stages	HyGrid	PSA
Infrastructure construction		
Type + amounts of raw material inputs	primary data	primary data
Processing of raw materials, e.g. welding of steel	ecoinvent data	ecoinvent data
Production of manufacturing consumables	ecoinvent data	ecoinvent data
Energy consumption for manufacturing	primary data	ecoinvent data
Transport of component to HyGrid assembly site	average based or	n primary data
Manufacturing waste & wastewater	ecoinvent data	ecoinvent data
System Operation		
Energy consumption (electric & thermal)	primary data	modelled data
Consumables (water, glycol, equipment with shorter lifetime)	primary data	primary data
System End of Life (EOL)		
EOL recycling processes	ecoinvent data	ecoinvent data

Not considered are upstream processes which are equal for HyGrid & PSA (hydrogen production, natural gas grid operation)

27/10/2021 Page 10

 $({\it Disclosure}\ or\ reproduction\ without\ prior\ permission\ of\ HyGrid\ is\ prohibited).$





HyGrid System Specification



- Primary data obtained from Tecnalia, HyET, HyGear
- LCA: represents HyGrid prototype
 - Small Scale system: 12,6 kg H₂ recovered/day
 - Pressure output flow: 8 bar
 - H_2 feed concentration: 5 15%
 - H₂ Recovery Factor (HRF): 60% 71%
 - H₂ purity: 99.76% 99.86%
 - Electricity consumption: 3 7.5 kWh/kg H₂ (scenarios)
- LCC: represents expected commercial size system
 - Scaled up to large (commercial) scale of 200 kg H₂ recovered/day

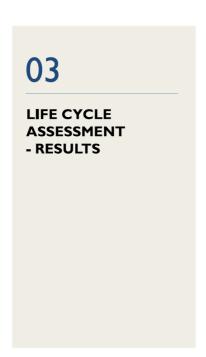




Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

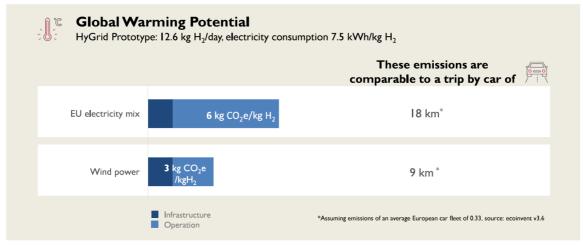
Date: 27/10/2021 Page N°: 76 of 98





LCA – Results & Scenarios









Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

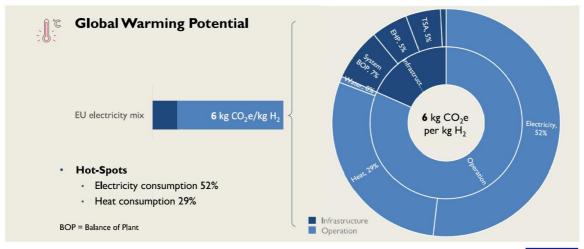
v01.docx

Date: 27/10/2021 Page N°: 77 of 98

HyGrid

LCA - Results & Scenarios





27/10/2021 Page 14

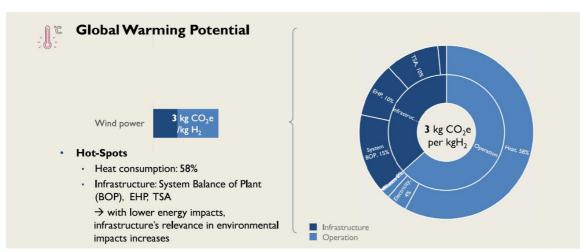
(Disclosure or reproduction without prior permission of HyGrid is prohibited).



Hy Grid

LCA Results & Scenarios









Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

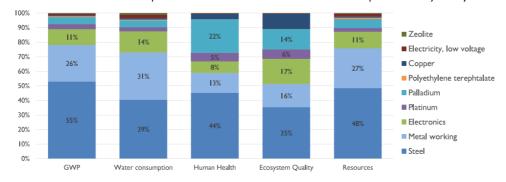
Date: 27/10/2021 Page No: 78 of 98



LCA - Results & Scenarios



Infrastructure: Which material inputs contribute the most to the environmental impacts of the HyGrid System?



- Steel + the related steel working (e.g.machining, cutting, welding of steel), electronics
- for these main contributors it is expected that economies of scale apply
- → Conclusion: for a large scale system, it can be expected that infrastructure impacts per kg H₂ will be significantly lower than currently shown for the prototype

27/10/2021 Page 16

 $({\it Disclosure}\ or\ reproduction\ without\ prior\ permission\ of\ HyGrid\ is\ prohibited).$



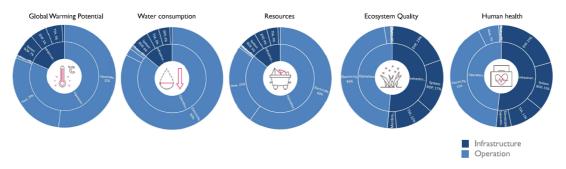


LCA – Results & Scenarios



Comprehensive environmental assessment

- → The relative contribution shows different proportions for different indicators
- → Not all indicators follow the pattern of Global Warming Potential







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 79 of 98



LCA - Comparison HyGrid vs. PSA



Reference case

Pressure Swing Adsorption (PSA)

- Mature technology for large scale applications with high H₂ feed concentrations
- Not developped for
 - · Low H₂ feed concentrations as required for HyGrid
 - High H_2 purity as required for HyGrid
- → **Limitation**: applicability of PSA as a reference technology is limited
- → chosen as reference case for a lack of more appropriate alternatives

27/10/2021 Page 18

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





PSA System Specification



Reference case

Pressure Swing Adsorption (PSA)

- · Data used for LCA
 - Obtained from WP2 (D2.2) → theoretical model by TUE
 - Flowrate: 520 mol/h \rightarrow approx. 0,5 kg H₂/h \rightarrow 12 kg H₂/day
 - H₂ feed concentration: 10%
 - Pressure of output flow: 16 bar
 - Electricity consumption: I 9.41 kWh/kg $\rm H_2$

Data used for LCC

- · no LCC performed
- for comparison to HyGrid, recovery cost from literature are used (Source: NREL, 2010, Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues)





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

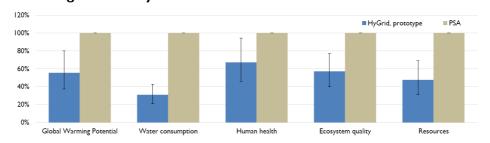
Date: 27/10/2021 Page N°: 80 of 98



LCA - Comparison HyGrid vs. PSA



EU average electricity Mix



- · Using the average electricity grid mix, HyGrid performs better than the PSA reference case for all indicators
- HyGrid's impacts show large variability (error bars) depending on the chosen scenario parameters:
 - Amount of electricity & heat consumption (depends on T [°C] and H₂%)
 - · Lifetime of components
 - Number of EHP membranes
 - End of Life (EOL) recycling or not

27/10/2021 Page 20

(Disclosure or reproduction without prior permission of HyGrid is prohibited).

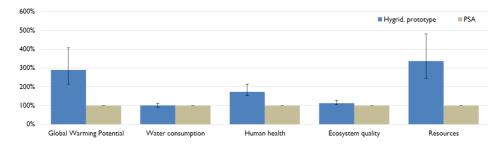


Hy Grid

LCA - Comparison HyGrid vs. PSA



Wind Power



- When using a low-impact electricity source (wind power), HyGrid does not perform better than PSA for any indicator.
- · Reason is the fossil heat source (natural gas) used in the HyGrid prototype
- HyGrid's impacts show large variability (error bars) depending on the chosen scenario parameters.





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

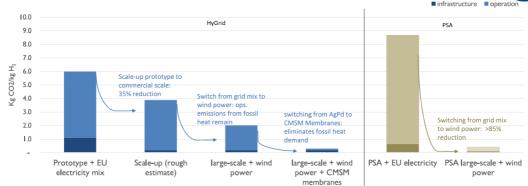
v01.docx

Date: 27/10/2021 Page No: 81 of 98

HyGrid

Carbon Reduction Pathway





- Carbon intensity of current prototype high, but significant reduction potential with
 - · Scale-up
 - · Low-impact electricity sources
 - · Reduction of (fossil) energy demand by choice of membrane
- No major trade-offs expected regarding other indicators

27/10/2021 Page 22

(Disclosure or reproduction without prior permission of HyGrid is prohibited).



04

LIFE CYCLE COSTING



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 82 of 98



System boundaries & LCC data



Life cycle cost data used

- · Electricity price, EU average:
- Premium renewable el., GoO 2020:
- Premium renewable el., GoO 2030:
- · Natural gas price:
- · Carbon Price 2020
- · Carbon Price 2030, estimate
- 0.125 €/kWh (Eurostat, everage 2015-2020)
- + 0.001 €/kWh (GoO 2020 of I€/MWh)
- + 0.0025 €/kWh (GoO 2030 of 2.5€/MWh)
- 0.04 €/kWh (Eurostat, everage 2015-2020)
- **45€/tonne** (EU ETS May 2020)
- 100€/tonne (estimate, reuters: >55€/MWh)
- Other pirces not provided by Tecnalia, HyET, HyGear: taken from ecoinvent v3.6 database
- GoO = Guarantees of Origin

27/10/2021 Page 26

 $({\it Disclosure}\ or\ reproduction\ without\ prior\ permission\ of\ HyGrid\ is\ prohibited).$





LCC - Results & Scenarios



HyGrid System at large-scale (200kg H_2 /day)

Expected default scenario

	€/kg H ₂	%		
CAPEX	0.57 €	36%		
OPEX	I.03 €	64%		
Total	I.60 €			



Average heat, electricity & CO₂ price Operation scenario: expected scale-up

Lower estimate

€/kg H ₂	%
0.57 €	48%
0.62 €	52%
1 10 £	



- Renewable electricity, average heat
 2020 CO₂ price
- Operation scenario: low heat & electricit

Upper estimate

oppor oscimilato		
€/kg H ₂	%	
0.57 €	23%	
1.87 €	77%	
2.44 €		



Average heat, electricity price Upper estimate of 2030 CO₂ price Operation scenario: high heat & electricit demand





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 83 of 98



LCC – Results & Scenarios



HyGrid System at large-scale (200kg H₂/day)

- Hot-Spots: OPEX (52% 77%)
 - Electricity cost
 - Heat/natural gas cost
 - Carbon cost (CO₂ emissions)
 - Carbon emissions mostly stem from heat and electricity and heat generation. Hence using low-carbon energy sources
 will reduce this cost factor. The higher price for low-carbon energy sources (e.g. renewable electricity) is lower than
 and thus does not outweigh the higher energy price.
- Variability of OPEX
 - · Natural gas, electricity & carbon prices
 - → High temporal volatility
 - → Location dependent
 - → Variability of life cycle costs is high!

27/10/2021 Page 29

(Disclosure or reproduction without prior permission of HyGrid is prohibited).





LCC – Comparison to PSA & H₂ production



HyGrid System at large-scale (200 kg H₂/day)

Life cycle costs: put in perspective

	Min [€/kg H ₂]	Max[€/kg H ₂]
HyGrid	1.2	2.4
PSA at natural gas distribution pipleline, 10% H ₂ conc., 80% recov. rate, 100-1000kg H ₂ /day, USA ^[1]	1.7	6.3
H2 production (Min = from natural gas via steam reforming, USA; Max = green H2) [2][3]	1.06	6.0

Sources: [1] NREL, 2010, https://www.nrel.gov/docs/fy13osti/51995.pdf; [2] https://www.sciencedirect.com/science/article/pii/B9780128120361000020; [3] https://en.wikibedia.org/wiki/Hydrogen_economy#Costs





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 84 of 98





Conclusions & Recommendations



Environmental hot-spots → improvement potential

Recommendations to improve environmental performance	expected impact on life cycle costs
Reduce energy consumption: largest improvement potential	1
Reduce heat demand: Investigate CMSM membrane option	?
Material efficiency of infrastructure: scale-up & recycling	>
System operation: low-impact electricity sources	→





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 85 of 98





Flexible Hybrid separation system for H₂ recovery from NG Grids



Environmental LCA & Economic Assessment

Thank you for your attention

Contacts:

florentine.brunner@quantis-intl.com
mireille.faist@quantis-intl.com

Quantis



 $({\it Disclosure}\ or\ reproduction\ without\ prior\ permission\ of\ HyGrid\ is\ prohibited).$





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 86 of 98

11 Engie - GRHYD : a successful demonstration for the new gas H2NG



Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 87 of 98









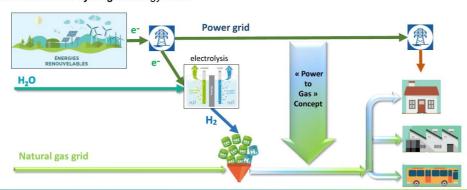
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 88 of 98

The aim: store and valorize renewable energies in existing gas networks thanks to hydrogen vector

Power-to-gas is a solution of flexibility and arbitration for the coupling between power grid and gas
grid thanks to the hydrogen energy vector



GRHYD

French Investment for the Future Program: The GRHYD 'Power-to-Gas-to Grid' project

- Selected mid-2011 by the French Government, as part of the 'Investment for the Future' pilot and technology platform for renewable and low carbon energy: hydrogen and fuel cells
- French first ever "Power-to-Gas-to-Grid" project in France and a significant step towards the development of hydrogen at urban level
- The GRHYD project also addresses the theme of "Hydrogen for a Sustainable City" bringing more renewables in urban energy uses







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

27/10/2021 Date: Page No: 89 of 98

An Experts Partnership to build a new supply chain based on Hydrogen-enriched natural gas





















- **Dunkirk municipality**
- Local operator of urban buses, DK'BUS Marine
- Leading energy company ENGIE and 3 subsidiaries:
 - ENGIE Solutions (Ineo Normandie) (energy management for the H2 production & storage
 - with GRDF (GN-H2 mix injection and distribution in the gas grid),
 - and ENGIE Solutions (NG fuels) for the Hythane® refueling station for buses.
- OEMs: AREVA H2Gen for H2 production, and McPhy Energy for H2 storage
- R&D and technical centers: CEA, INERIS, CETIAT

Budget: 15.3 M€







The gas uses staged and evaluated by means of operational demonstration





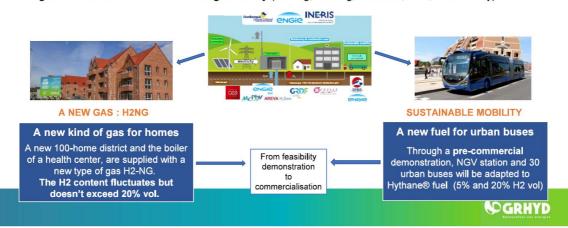
Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 90 of 98

Two pilots based on Hydrogen to assess the relevance of H2NG chain for sustainable cities

 GRHYD objective: produce H2 from renewable electricity, inject this H2 into the gas distribution grid and consume the new H2-NG gas locally (heating, cooking, hot water, CHP, and mobility)









Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 91 of 98



1st Power-to-Gas H2 demonstror in France : Mission accomplished !

Successfull operation of the R&D pilot :



✓ Evaluate in actual conditions: the technical, environmental, regulatory and societal aspects of a sector using new H2NG energy for usual gas uses at home







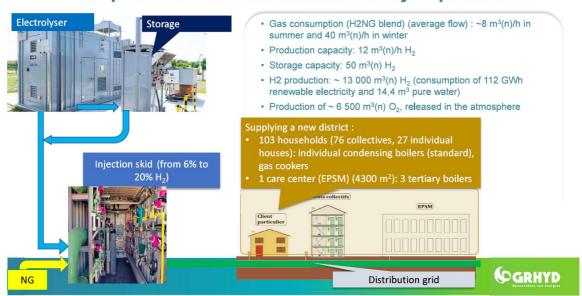


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 92 of 98

A complex technical chain successfully implemented



The demonstration lasted 22 months, and applied the fluctuating H₂ content in gas during the winter 2019-2020





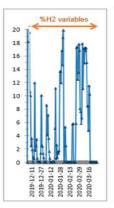


Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

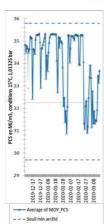
v01.docx

Date: 27/10/2021 Page N°: 93 of 98

H2NG gas quality

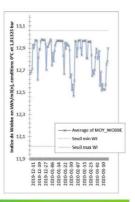


 The fluctuating H2 % run during the winter times (Dec-March)



Seuil bas PCS pres

- The delivered H2NG fulfilled the DSO requirements in France (L-gas), except:
 - ➤ Content of H2 in NG
 - ➤ Calorific value (PCS):
 - ❖ GCV is out of the legal range above 12% H2 in L-gas
 - Large fluctuations will lead to development of Smart Gas Grid (billing purpose)
- The Wobbe index shows rapid instantaneous variations which may impact some sensitive end-uses, other than domestic gas appliances











D10.17

Final conference / workshop

Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 94 of 98

Confirmed adaptability of equipment, network and downstream meter facilities (gas appliances) to hydrogen/natural gas mixtures

Complex technical chain successfully implemented

Laboratory testing confirmed by field experimentation:

- Fragilization of materials √
- Tightness of equipment √
- Permeation / leaks ✓
- Odorization ✓
- Meters compatibility
- Non-stratification (no over-concentration of H2) ✓

Tests of innovative equipment:

- New injection skid with H2/NG mixer
- Gas analyser

Indoor installations

Laboratory testing confirmed by field experimentation:

- Fragilization of materials (copper) √
- Tightness of the equipment ✓

Gas appliances

Laboratory testing confirmed by field experimentation:

- Individual new condensing boilers (Saunier-Duval)
- New and existing boilers from the boiler room of the care center

Laboratory tests only:

- Existing individual boilers and gas
- New gas cookers √



The technical feedback makes it possible to validate the feasibility of the injection of 20% vol. H2 in a new gas distribution network, supplying new homes

MAIN ELEMENTS OF REX ON THE DISTRIBUTION NETWORK:

- ✓ No security incident including during the adjustment periods of the demonstrator equipment
- No incident recorded during operations to operate the network at increased frequency (systematic search for leaks, inspection of valves, inspection of interior pipes and risers)
- Very good quality of the hydrogen produced: <5 ppm H2O and <5 ppm O2 => compliance with technical requirements for the gas distributed
- \checkmark **Derogations** from regulatory thresholds have been given for H2 content, PCS and Wobbe index

DOWNSTREAM THE GAS METER:

- Campaigns on domestic gas appliances (volunteer residents) and on the tertiary boilers confirm the trends observed in laboratories:
 - ✓ Improved useful efficiency of domestic boilers (evaluated at + 4% in the laboratory)
 - ✓ Reduction of CO2, CO, NOx emissions (in the exhaust fumes)





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 95 of 98





A success of the injection demonstration plant that reinforces the technical feasibility of the new sector

Technical success in setting up a complex Power-to-Gas chain (hydrogen production by electrolysis - H2 storage - injection of H2 in mixture up to 20% (vol.) with variable rates): 22 months of field demonstration, design testing of innovative equipment (PEM electrolyser, solid H2 storage, injection station, gas analyzer)

A new gas distribution network and residential-tertiary natural gas uses that work well with the H2/natural gas mixture, under industrial safety conditions equivalent to the natural gas ones

Constructive technical dialogue with the French administration

Good social acceptability among users, their main concern being the management of the energy bill

A confirmed environmental benefit of hydrogen injection: -6% CO2eq vs natural gas or 20 tons of CO2eq avoided on the neighborhood per year, reduction in CO emissions (-63%) and NOx (-42%) at the stack (exhaust system) of domestic boilers





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 96 of 98

A demonstrator that guides future work

Continue to optimize the Power-to-Gas chain by relying on improved solutions for operation and monitoring of the equipment

Develop equipment and operationmaintenance procedures adapted to the new composition of the gas supplied (inspection method and frequency, leak detectors adapted to the mixture, etc.) Work on European regulations, standardization & certification with consideration of hydrogen in gas infrastructures and gas uses to prepare for industrial deployment (network equipment, gas analyzer and meter, equipment and installations downstream meters, gas appliances, etc.)

Extend the compatibility analysis of the natural gas chain by carrying out tests on the existing devices (distribution network, indoor installations, downstream meter equipment in the residential, tertiary and industrial sectors) Continue R&D work on protection solutions for sensitive network installations or customers (e.g. membranes separating H2 from natural gas)

As a conclusion

- In France, Territorial Communities have an interest in this new green gas
- The GRHYD project is preparing the ground for the pre-industrialization and deployment of the new H2NG gas: the next project will increase in size!







Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page N°: 97 of 98





Proj. Ref.: HYGRID-700355 Doc. Ref.: HYGRID-WP10-D1017-DLR-HyGear-27102021-

v01.docx

Date: 27/10/2021 Page No: 98 of 98