



HAL
open science

Review and analysis of demonstration projects on power-to-X pathways in the world

Zaher Chehade, Christine Mansilla, Paul Lucchese, Samantha Hilliard, Joris
Proost

► **To cite this version:**

Zaher Chehade, Christine Mansilla, Paul Lucchese, Samantha Hilliard, Joris Proost. Review and analysis of demonstration projects on power-to-X pathways in the world. International Journal of Hydrogen Energy, 2019, 44 (51), pp.27637-27655. 10.1016/j.ijhydene.2019.08.260 . cea-02558095

HAL Id: cea-02558095

<https://cea.hal.science/cea-02558095v1>

Submitted on 20 Jul 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

Review and analysis of demonstration projects on Power-to-X pathways in the world

Authors: Zaher Chehade¹, Christine Mansilla^{2*}, Paul Lucchese^{1,2,3}, Samantha Hilliard⁴, Joris Proost⁵

Affiliations:

¹ Capenergies, France;

² CEA, Université Paris Saclay, France;

³ IEA Hydrogen, France;

⁴ Clean Horizon, France;

⁵ Université catholique de Louvain, Louvain-la-Neuve, Belgium;

* Corresponding author: christine.mansilla@cea.fr

Abstract

Transforming the energy system towards more sustainability can only be achieved through a combination of low-carbon energy, energy efficiency, and the coupling of energy sectors. In this context, the application of Power-to-Hydrogen concepts for managing demand, providing seasonal storage, and linking elements between different sectors has attracted significant interest during the last decade.

Demonstration is a key first step towards large-scale market introduction. This paper presents the results of a review of 192 Power-to-X demo projects in 32 countries. Results show that the features of demonstrations have evolved significantly over the years: electrolysis capacity has increased, both for PEM and alkaline systems, and the potential for balancing and ancillary services is increasingly investigated via grid-connected demos. The scope of Hydrogen-to-X pathways has also evolved over the years, mainly to include industry applications. This work was carried out under the umbrella of Task 38 of the IEA Hydrogen Technology Collaboration Programme.

Keywords

Power-to-Hydrogen; Hydrogen-to-X; Power-to-Gas; Renewable Energy; demonstration; pilot plant

1. Introduction

Transforming the energy system to a more sustainable system, with a significant reduction of CO₂ emissions in accordance with the Paris COP21 agreement [1], is the guiding principle of the national energy policies. 175 Parties of 197 have ratified the COP21 agreement [1], with the following goals: limit global warming below 2°C above pre-industrial levels and aim to limit the increase to 1.5 °C, set global emissions to peak as soon as possible, reduce emissions in accordance with the best available science. Developing countries shall receive support for adapting to the targets and specific climate actions are developed in Parties. In Europe for instance, the climate goals are threefold [2]: i/ At least 20% (2020), 40% (2030) and 80% (2050) cut in greenhouse gas emissions should be achieved compared to 1990 levels; ii/ At least 20% (2020), 32% (2030) of total energy consumption from renewable energy should be reached, and iii/ At least 20% (2020), 27% (2030) increase in energy efficiency should be gained.

Such a transformation is demanding and all the means need to be leveraged, i.e. a combination of low-carbon energy, energy efficiency, and the coupling of energy sectors [3]. Due to the increasing penetration of renewable energies in the energy mix, balancing generation and demand for grid stability is becoming increasingly challenging. Solutions like creating a transmission super-grid, smart grids and demand management, or back-up capacity implementation could assist in overcoming this

issue; but new measures that go beyond increasing transmission and distribution capacity and flexible generation or consumption will need to be introduced to manage the grid efficiently, as the level of renewable energy sources is increased. In this context, hydrogen systems are included in the global discussion on energy system progression [4]-[5]. The application of Power-to-Hydrogen concepts for managing demand, providing seasonal storage, and the linking element between different sectors (electricity generation, gas grids, transport and industry), has attracted significant interest during the last decade [5].

Power-to-Hydrogen (PtH) can support the integration of fluctuating renewable sources of power generation and convert (surplus) electricity to hydrogen. Power-to-Hydrogen systems can be used on- or off-grid and serve as a measure to avoid curtailment of excess electricity, or adjust the power demand they represent to provide load balancing, stabilization, or other electricity grid services. This is made possible by the characteristics of hydrogen production through water electrolysis to quickly adjust the power consumption: electrolyzers can reach full load operation in a few minutes, even a few seconds [6]. In addition, chemical energy carriers such as hydrogen can also facilitate large-scale long-term storage due to its high specific energy density and the comparatively low storage costs. Further down the value chain the hydrogen can be deployed in a large portfolio of applications – termed as “Hydrogen-to-X” (HtX). Possible applications for hydrogen are: fuel cells in transport (HtF-H₂); other transport pathways include using hydrogen to produce synfuels such as methanol or biofuels (HtF-S), or gas fuels for transport (HtF-G), “green” gas through methanation (PtG-M) or direct blending of hydrogen with natural gas (PtG-H₂) [7], in the industry e.g. refineries (HtI), heat generation (HtQ), production of chemicals (HtCh), and for re-electrification into the electricity grid or remote areas (HtP). Thereby, hydrogen interlinks the power sector to other energy intensive sectors (heat, transport, industry). This leads to consider an integrated energy system with interconnections between the energy carriers [8].

The total value chain from power generation to the usage of hydrogen in diverse applications is commonly termed “Power-to-X”. Note that “Power-to-Gas” can be used in the literature to refer to PtH systems or PtG-M and PtG-H₂ pathways. An attempt at categorizing precisely the different PtH – HtX pathways was presented in Dickinson et al. (2017) [9]. Figure 1 summarizes the different Power-to-X pathways. 6 categories and 9 sub-categories are identified downstream hydrogen production (“Hydrogen-to-X” part).








Category		Acronym	Definition
Power-to-Hydrogen		PtH	Hydrogen production (and storage when requested) from low-carbon electricity either from the grid or off-grid.
Hydrogen-to-Power		HtP	Supply of electricity to the grid from hydrogen with a fuel cell or a gas turbine
Hydrogen-to-Gas		HtG-H2	Hydrogen injection in natural gas grid
		HtG-M	synthetic methane injection in natural gas grid, synthetic methane is obtained from Hydrogen from PtH through methanation processes
Hydrogen-to-Fuel		HtF-H2	Hydrogen in a vehicle to be injected in a fuel cell
		HtF-S	Hydrogen for liquid synfuel applications: liquid biofuels, synthetic liquid fuels, methanol
		HtF-G	Hydrogen for mobility through gas fuels (Hythane®, biogas, synthetic methane)
Hydrogen-to-Industry		HtI	Hydrogen from PtH and for industrial applications (e.g. Refinery)
Hydrogen-to-Heat		HtQ	Hydrogen-to-heat via H2-fired boilers; Hydrogen-to-heat and power via CHPs (fuel cells, turbine etc.)
Hydrogen-to-Chemicals		HtCh	Other pathways to industrial chemical intermediates from hydrogen which we may want to include explicitly: <ol style="list-style-type: none"> 1. H2 to methanol to C2, C3 olefins 2. H2 to syngas to C2, C3 olefins 3. Methanol/syngas to >C1 hydrocarbons and >C1 alcohols 4. H2 to ammonia and formic acid (which could also be used as alternative renewable energy storage)

Figure 1. Power-to-X pathways

In this context, Power-to-X demonstrations are developed throughout the world to explore the potential of Power-to-X by identifying previously established knowledge and remaining concepts which should be further developed, before reaching the market. This work, carried out under the umbrella of Task 38 of the International Energy Agency's Hydrogen Technology Collaboration Programme [10], aims at reviewing all the PtH and HtX demonstrations that have been implemented around the world, to analyse the general trends and coverage, and remaining unknowns. The focus is put on the existing demonstrations, i.e. projects having a purpose of learning about the technology or system. Investigating the commercial plants is beyond the scope of this paper. So is a prospective study on planned projects. Indeed, the ultimate goal is to propose a roadmap depicting the needs for future projects based on what was demonstrated so far (be it in technical, economic or other terms such as regulation), which will be done in collaboration with the IEA.

The following section briefly describes the methodology and selected parameters for a review of 192 demonstration projects in 32 regions (see Appendix 1). Section 3 then provides the analysis of the results, focusing first on the Hydrogen-to-X part, and then on the electrolysis system (Power-to-Hydrogen). The aim is to provide insights about the general trends, and obviously not an in-depth analysis of each demonstration project.

2. Methodology

As stated in the introduction, 192 demonstration projects were reviewed using a methodology developed in several steps.

The demonstration projects were first identified, using the expertise of the Task 38 members. The time coverage started from the oldest demonstration that was identified (in the eighties) up to now.

Over 40 parameters characterizing the demonstrations were identified (see Appendix 2 for the list):

- Overview: Project location, start date, duration of demonstration, investigated pathways, consideration of services to the grid;

- Technical specifications: Type of electrolysis system, installed capacity of electrolyser, power supply scheme (on-grid, off-grid, on-grid + connection to renewable energy source (RES)), in case of renewable connection: type of power supply (e.g. all-in, excess power) and RES capacity, type of hydrogen storage (CHG, MH, CNG, salt cavern, etc.), capacity of hydrogen storage, hydrogen production mode (baseload, flexible), load factor and efficiency;
- Objectives: overall scope and demonstration objective(s); for example, technical, economic, other, and more specifically, when relevant: focus of technical objective (component, system, pathway), type of technical objective (operation validation, efficiency improvement, upscaling, etc.), type of economic objective (e.g. hydrogen production cost optimisation), type of regulatory objective;
- Results and maturity: Major technical results of the demonstrations, major economic results, technology readiness level (TRL) and market readiness level (MRL).
- Legal aspects: Specific regulations taken into account, certification scheme considered, green labeling for hydrogen production, policy support scheme, avoidance of grid fees, maximum hydrogen concentration in the natural gas grid, and incentives if any.
- Future plans: Planned future demonstrations, connection with other demonstrations, links to a roadmap, steps towards the market and messages to policy makers.

To collect the data for all the demonstrations, the demonstration coordinators were contacted directly using a template questionnaire. Also, data was collected from the literature. Over 200 references were consulted, including scientific papers, specific studies on Power-to-Gas projects, articles and news, dedicated platforms (European Power to Gas, DOE global energy storage database, EASE, Dena, etc.) [11]-[230].

The results are detailed and discussed in the following section. Note that the information regarding each demonstration project is not always available; therefore, the demonstration numbers may not always sum up to 192 (and each indicator listed in the Appendix 2 was not used). Moreover, multiple nominations may be allowed on certain indicators (such as the investigated pathways), which explains that, on the contrary, totals higher than 192 may be noticed.

3. Results

3.1 General outlook

192 demonstration projects were examined in 32 different countries, the HYSOLAR project being the first demonstration being identified in 1985, designed by the German Aerospace Center (DLR) and the University of Stuttgart, and implemented in two different countries (Saudi Arabia and Germany). Demonstration projects are implemented in each continent except for Africa (cf. Figure 2), Europe leading the way with 154 projects, and more specifically Germany being far from the other countries with 50 demonstration plants. Demonstration projects have been installed for over twenty years, and we can notice a considerable increase from 2010 onwards. Of these projects, 69% are completed and 31% are still ongoing, which reflects hydrogen being on the current research agenda.

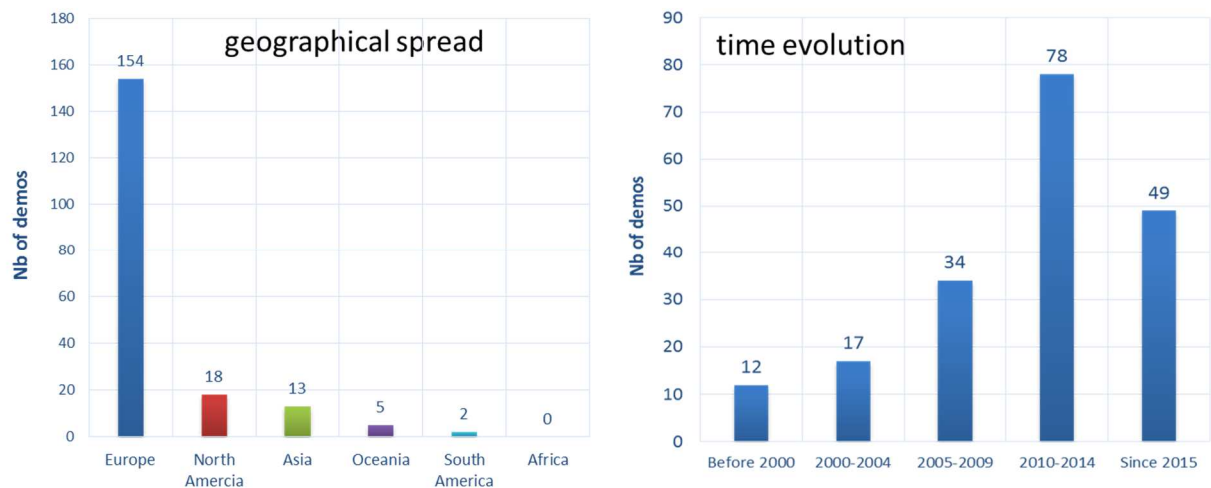


Figure 2. Geographical spread (left) and temporal evolution (right) of the number of demonstration projects

3.2 Pathway trends (“Hydrogen-to-X”)

Hydrogen is versatile. To investigate which pathways are more explored, Figure 3 shows the number of demonstrations for each of the Hydrogen-to-X (HtX) pathways being identified in Figure 1. Since each demonstration project can address more than one pathway, multiple nominations in different categories have been taken into account. Overall, the pathways that have been addressed most extensively are Hydrogen-to-Power (HtP) and Hydrogen-to-Fuel (HtF). As to the first, this is even more so if we take into account that 85% of the Hydrogen-to-heat (HtQ) projects are related to HtP as well through Combined Heat and Power (CHP) concepts. At first glance, hydrogen use for industry or chemical applications seems less investigated, with only 7% of demonstrations covering this pathway.

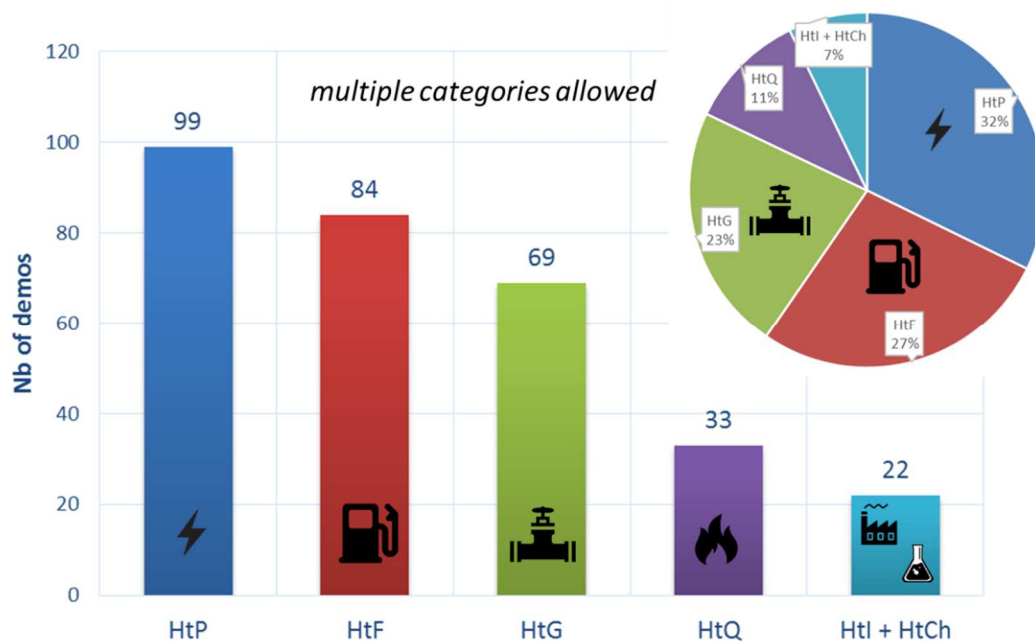


Figure 3. Share of each HtX application of the demonstration projects (multiple nomination allowed)

If we look at the temporal progression of the different pathways (cf. Figure 4), HtP and HtF have also been the pathways that have raised interest first, which contributes to explain that they appear more often among the demonstrations: they have been investigated since the beginning and still are.

Hydrogen-to-Gas (HtG) applications have emerged in the early 2000's and had a boom ten years later. Most recently, the number of demonstrations on Hydrogen-to-Industry (HtI) and Hydrogen-to-Chemicals (HtCh) have risen significantly, and are now close in number to the other pathways. Since they raised interest later, it is quite logical that, overall, there are fewer of them.

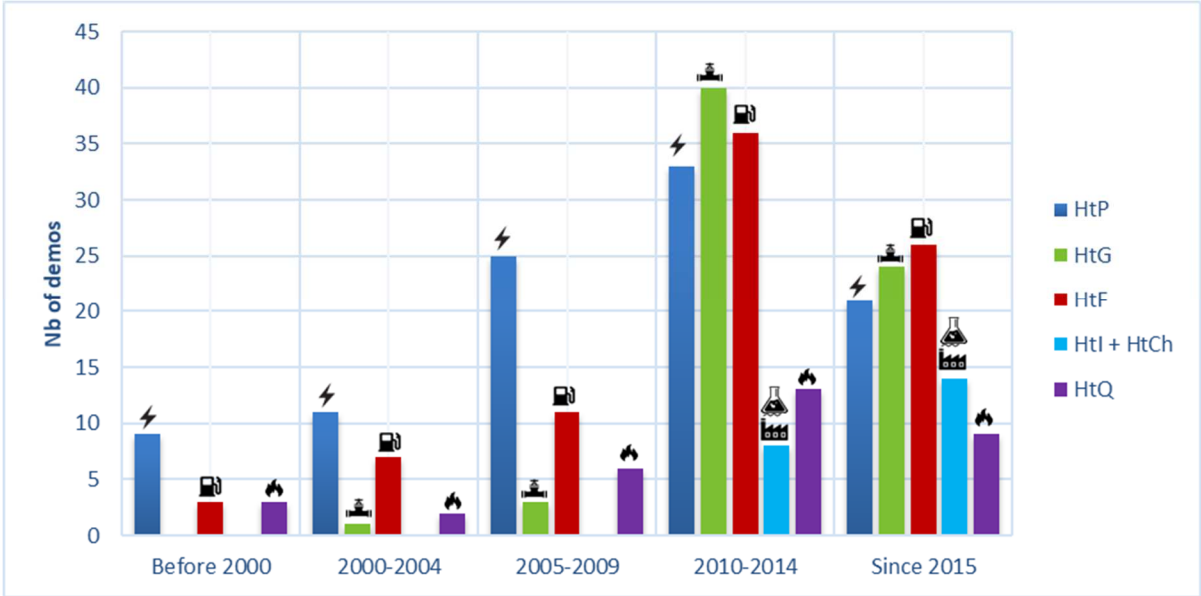


Figure 4. Evolution of HtX applications as a function of time (multiple nominations allowed)

When we consider more specifically the role of H₂ as a fuel (HtF) or a gas (HtG), it can be seen in Figure 5 that pure hydrogen as a fuel is the most investigated pathway, rather than H₂-based mixtures. It should be noted however that demonstrations on liquid synfuels only started in 2010, along with the interest for Hydrogen-to-Industry and Hydrogen-to-Chemicals as in the literature [230], making them as of today a viable alternative to pure H₂ gas for fuelling applications. With respect to Hydrogen-to-Gas, Figure 5 indicates that the injection of synthetic methane is more investigated than the direct injection and blending of pure hydrogen into the natural gas grid. This may be explained by the regulation challenges regarding the latter pathway (the allowed hydrogen concentration in the natural gas network may vary significantly from one region to another) [231]. However, this state of affairs also calls for demonstrations in order to establish the actual technical limits, push them back, and make regulation advance on this topic.

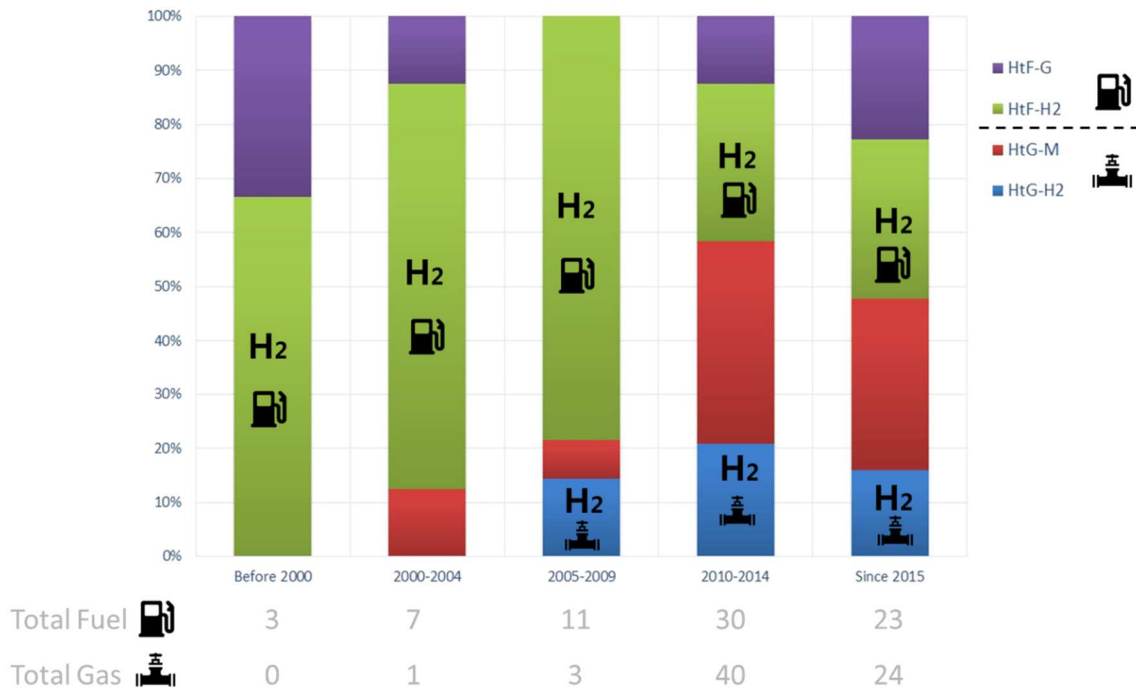


Figure 5. Time evolution of subcategories in Hydrogen-to-Fuel and Hydrogen-to-Gas

Figure 6 illustrates how the different HtX pathways are being spread throughout the world. It is striking that the 2 demo projects identified in South-America are focussing only on HtP. This corroborates in a sense to the fact that HtP has also been the very first HtX pathway being investigated. There have been so far no demonstration project on Hydrogen-to-Industry or Chemicals in America, and none on Hydrogen-to-Heat in Asia. As to the first, Europe is clearly leading the way.

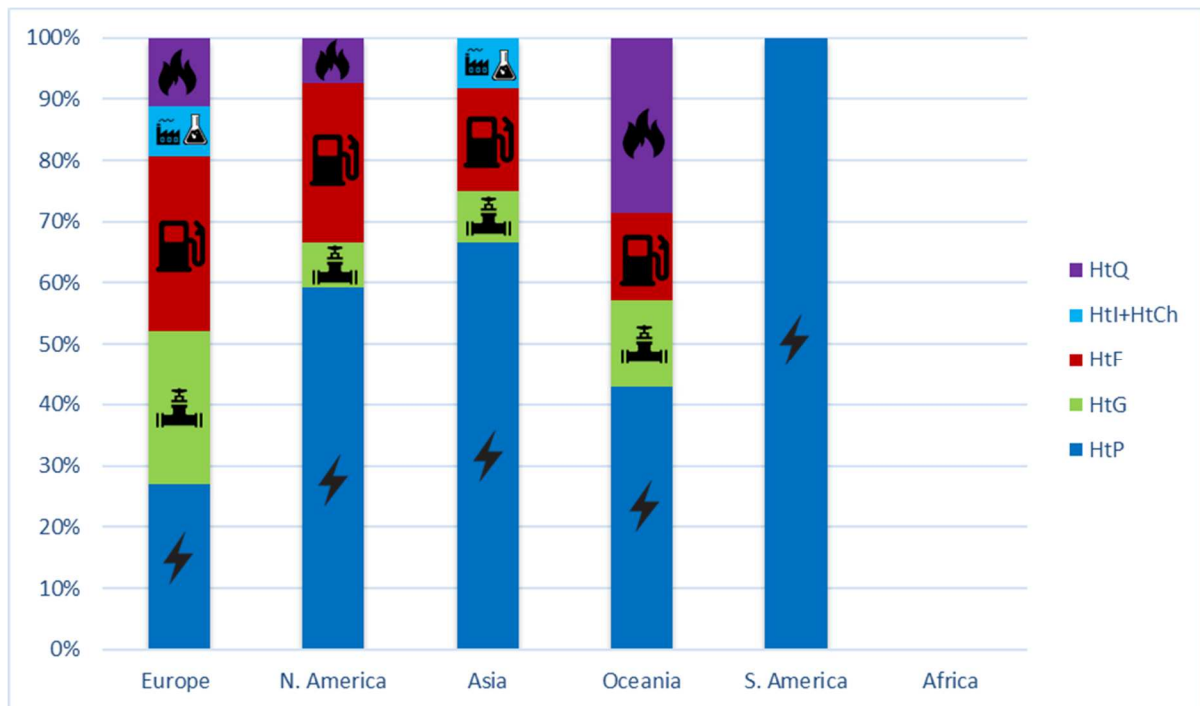


Figure 6. Geographical spread of HtX applications around the world

Finally, with respect to the multiple nominations, it can be seen in Figure 7 that in most cases demonstration projects still focus on one specific application. However, demonstrations have

gradually examined multiple pathways (up to 5) within the same project. In the recent years, the majority of demonstrations are dedicated to two or more applications. This trend reveals an increasing interest in investigating hydrogen versatility in the field.

Investigating a given pathway does not depend on how many applications are considered: all the pathways appear in the demonstrations, whatever how many pathways are being considered. In other words, each pathway seems relevant by itself.

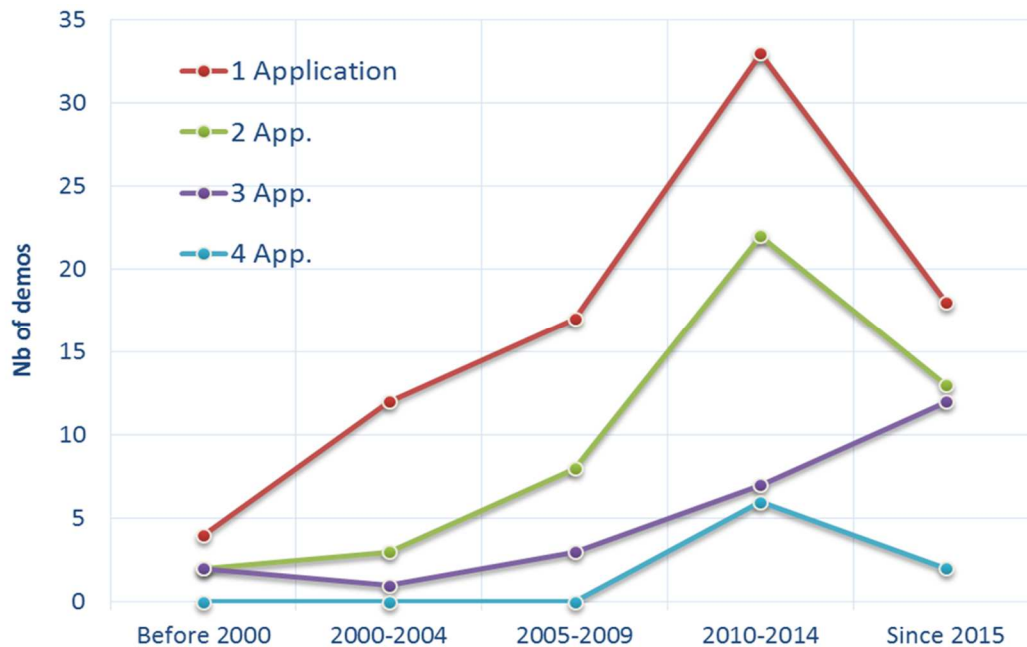


Figure 7. Time evolution of the versatility (number of HtX applications) of demonstrations

3.3 Focus on Power-to-Hydrogen

In this section, the focus is put on the demonstration upstream: the Power-to-Hydrogen part, i.e. the production (and storage when requested) of hydrogen from low-carbon electricity, either from the grid or off-grid. As the power supply scheme is a crucial topic for the production of “green” or low-carbon hydrogen, the power source of the projects was identified and classified in three main categories: on-grid supply (connected to the power grid), off-grid supply (only powered by renewable energy installed nearby or micro-grids isolated from the public power grid), and “on-grid + RES”, meaning that two connections co-exist: a direct connection with a renewable capacity, as well as a grid connection.

As shown in Figure 8 (left), the majority of demonstrations have focused so far on off-grid systems (52% vs. 29% for on-grid demonstrations and 19% for on-grid + RES). Moreover, almost all of the renewables considered were coming from wind power (cf. Fig. 8 right). In recent years however, on-grid systems start to prevail (cf. Figure 9). This may be due to the fact that the pathways may be investigated with a more holistic approach (what could be the contribution of hydrogen to the energy system), including the potential input to help balancing the electric system. Indeed, 41% of the demonstration projects that started after 2015 include grid balancing services, while only 22% in the period 2010-2014, 8% between 2000 and 2010, and zero before 2000.

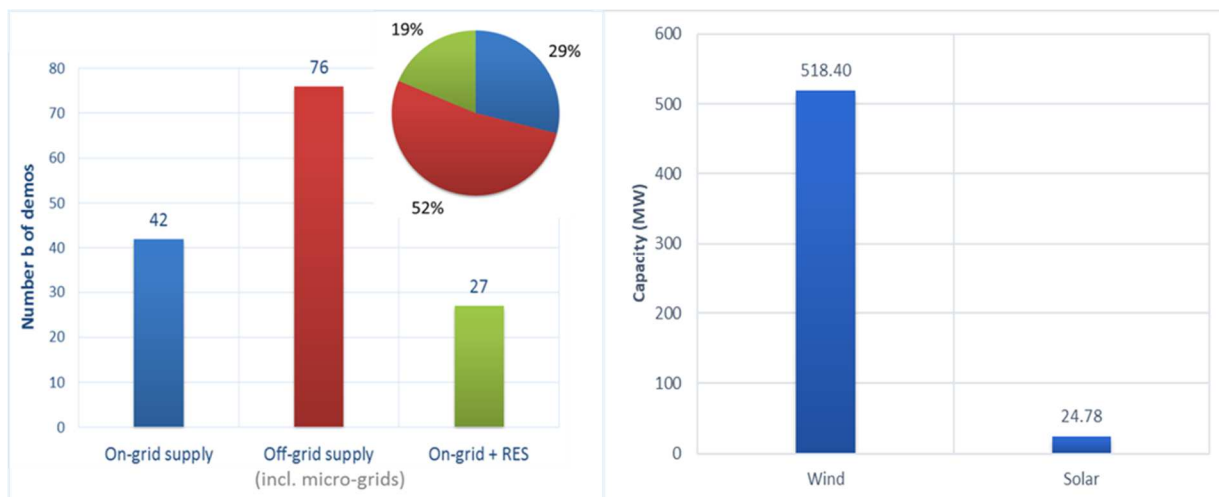


Figure 8. Power supply schemes (left) and origin of green power (right) for the P2H part of the demonstrations

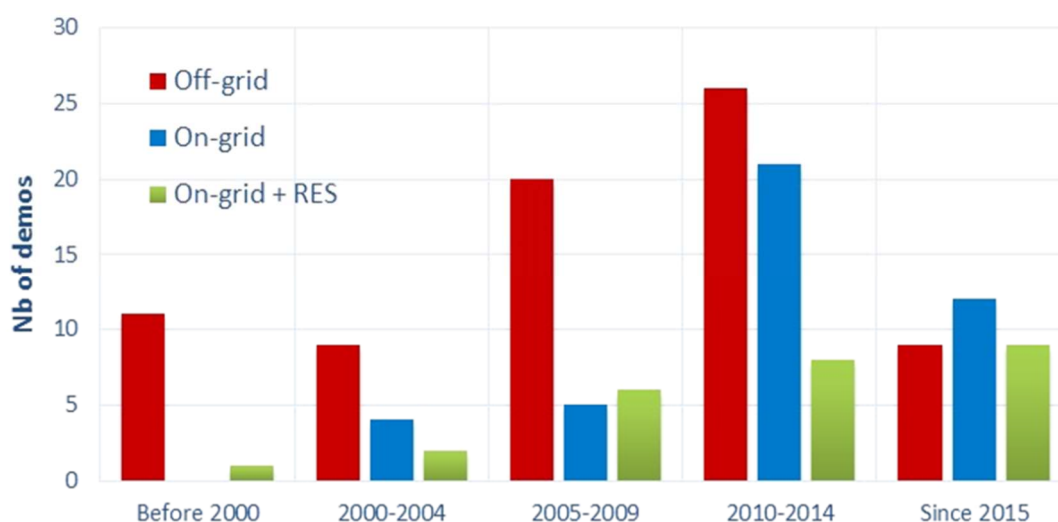


Figure 9. Evolution of the power supply schemes as a function of time

Three electrolyser technologies are considered in general: alkaline electrolysers, PEM (Proton Exchange Membrane) electrolysers, and SOEC (Solid Oxide Electrolysis Cell) electrolysers. PEM electrolysis is the technology often promoted in a context of rising renewable energy shares, due to interesting features: high current densities ($>2 \text{ A/cm}^2$), gas purity, compact system design and dynamic operation [232]. Alkaline electrolysers are commercially-available but less flexible, even though they can still be operated between 20 and 100% of the design capacity, and overload operation up to 150% is possible [16]. By 2030, the capital costs of these technologies are expected to converge [233]. SOEC electrolysers are at an earlier stage of development but may become a key technology in the energy system to come, thanks to specific features such as the potential to work in a reversible mode or to co-electrolyse water and carbon dioxide to produce syngas [234]. All these technologies are investigated by the project demonstrations. It can be seen in Figure 10 that alkaline and PEM electrolysers are almost as often selected (50% of the demonstrations assess alkaline electrolysers; 42% PEM). As a result, the total installed capacity over the years is similar: 45.7 MW of alkaline electrolysis vs. 37.5 MW for PEM. The situation differs greatly for SOEC electrolysers. This technology, even though promising, is much less mature. As a result, demonstrations are still at a different scale: SOEC are investigated in only 8% of the demonstration projects, with a mere 0.55 MW being installed.

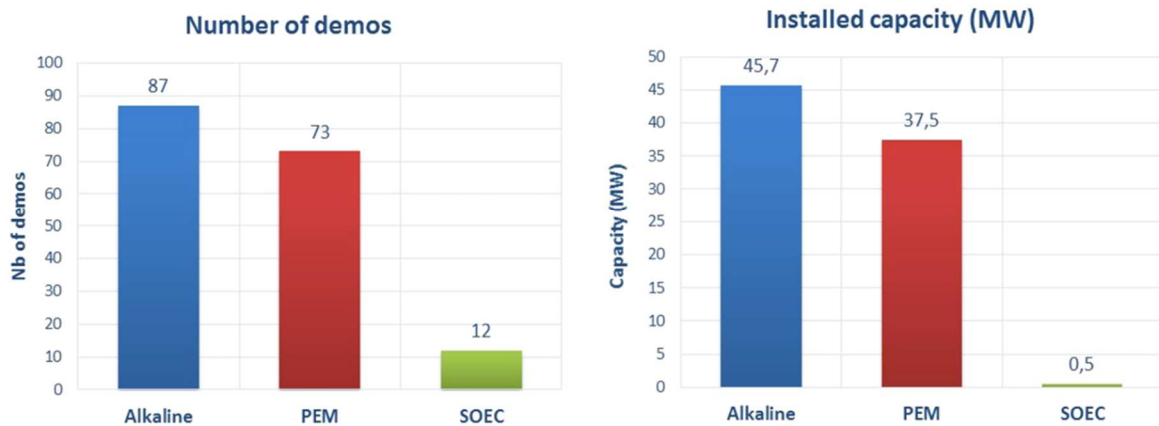


Figure 10. Number of demos (left) and total installed capacity (right) for the 3 types of electrolyser technologies

Figure 11 and 12 consider in more detail the installed PtH electrolyser capacity as a function of starting date, both on a year-to-year basis (Fig. 11) and cumulatively (Fig. 12). Although alkaline is a more mature technology that was also installed first, very similar trends can be observed with a 5-year interval. Moreover, an upscaling phenomenon can be seen, the yearly total installed capacity per demonstration reaching 10 MW in recent years.

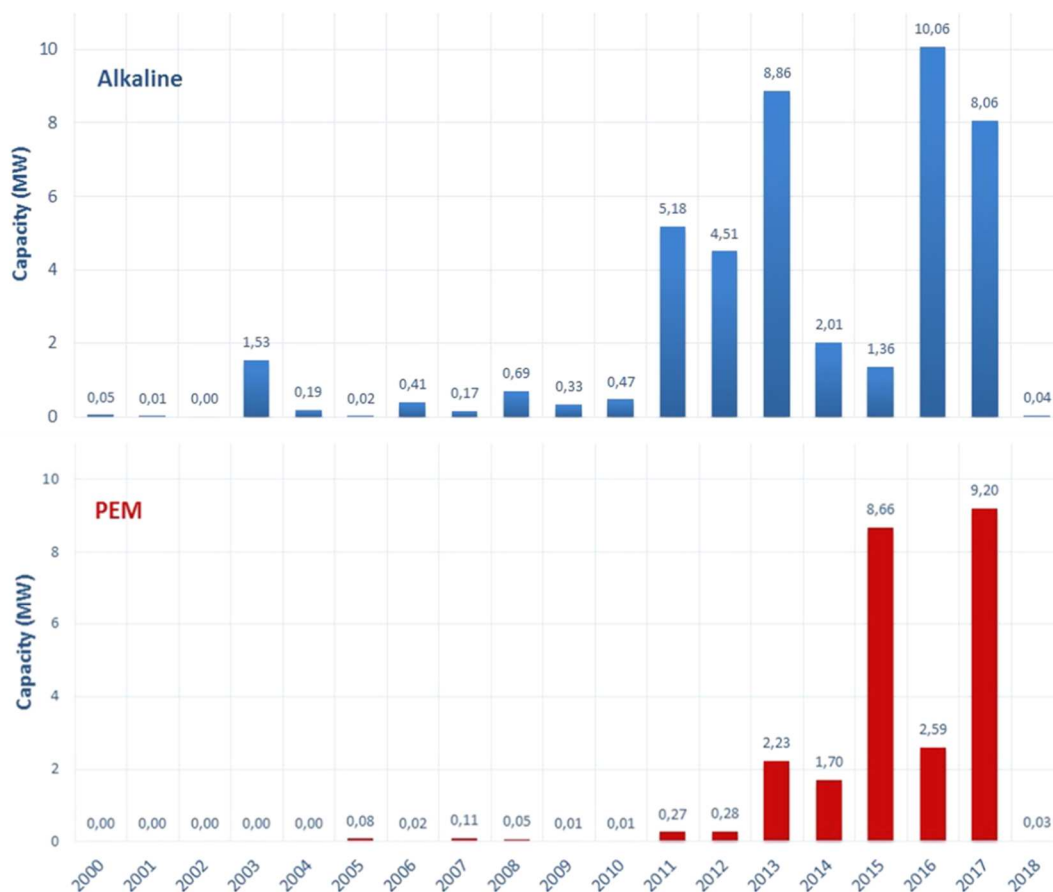


Figure 11. Total installed electrolyser capacity per demonstration project per year

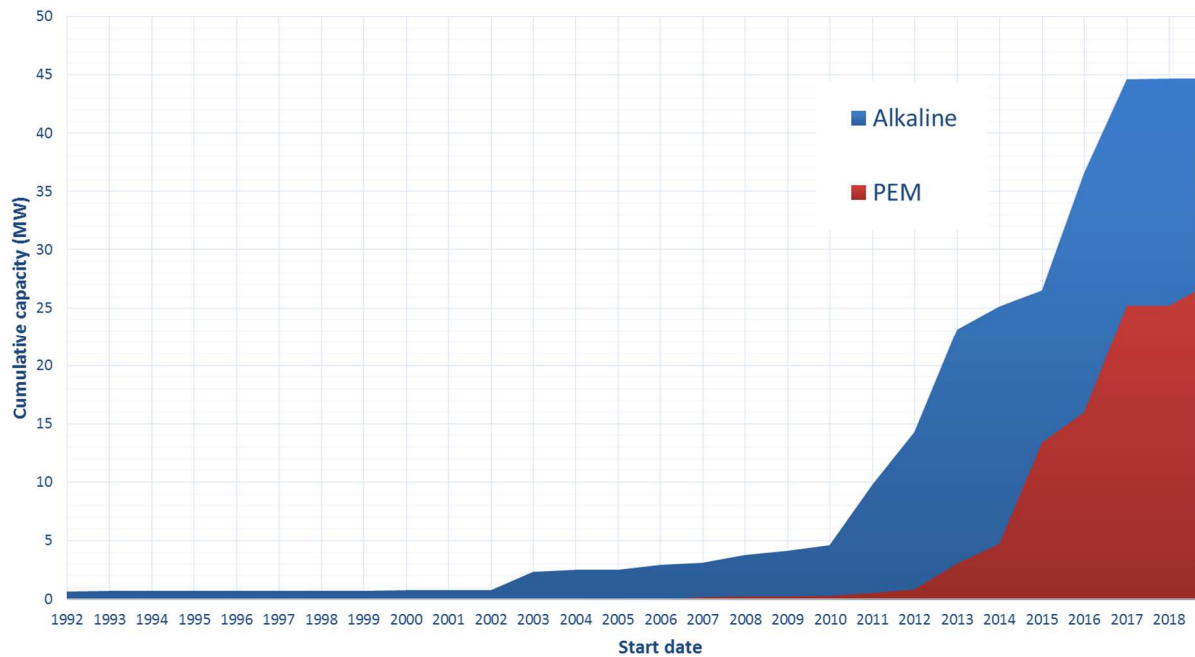


Figure 12. Comparison between the cumulative capacity of the Alkaline and PEM technologies

The electrolysis system efficiency was also assessed from the available data. To this end, the total installed electrolyser capacity (in MW) was plotted as a function of H₂ output (in Nm³/hr), whenever available. The slope of a linear fit through such data is then inversely proportional to the system efficiency. The results are shown in Figure 13. It appears that, contrary to what is often being claimed in the literature, no significant difference can be observed between alkaline and PEM systems. For ≤2 MW systems, the slopes are even identical, resulting in an average efficiency of 73%, based on a slope of 4.9 kWh/Nm³ and a HHV value of 3.54 kWh/Nm³.

Moreover, when looking at the temporal evolution in Figure 14, the efficiency values are quite scattered, and no obvious trend can be observed. Also in the framework of Task 38 of IEA Hydrogen, an international network of experts assessed the techno-economic potential of Power-to-Hydrogen pathways. From their review of 230 internationally-published studies [235], two thirds of the studies assume an average electricity consumption of 45 to 50 kWh/kg_{H2}.

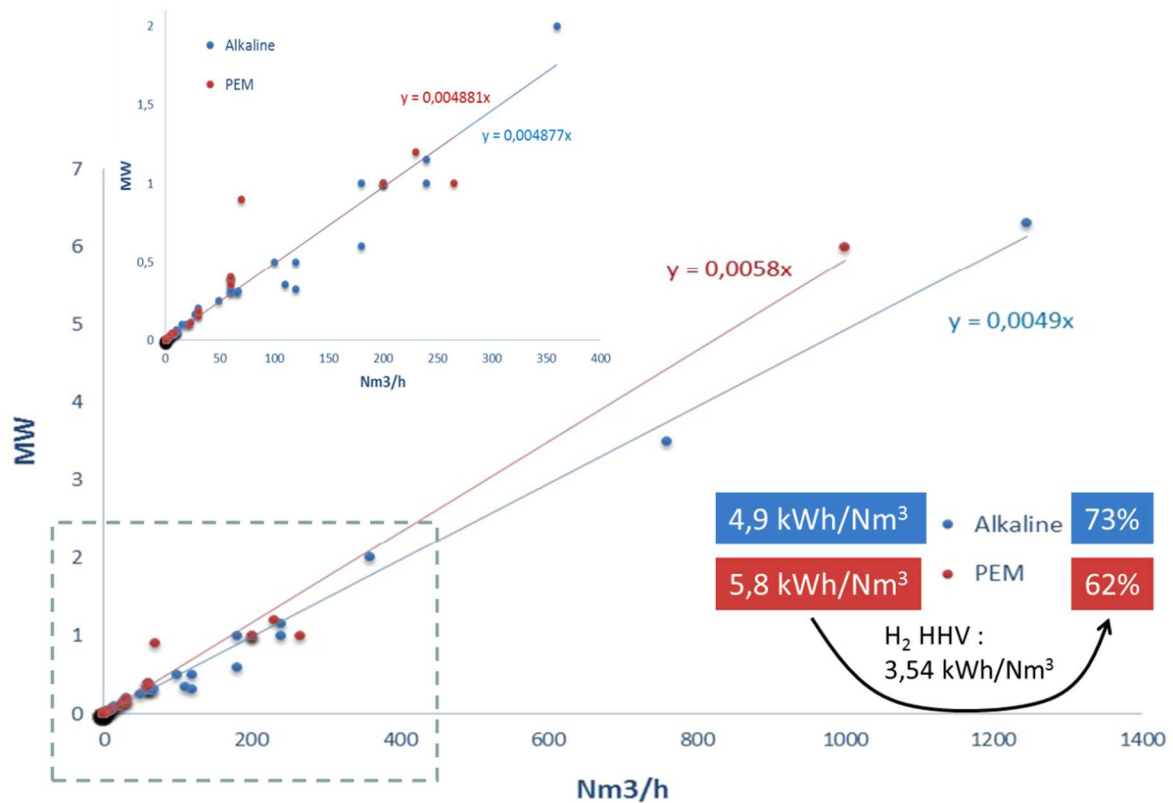


Figure 13. Installed electrolyser capacity (in MW) vs. H₂ output (in Nm³/hr) for each demo project.

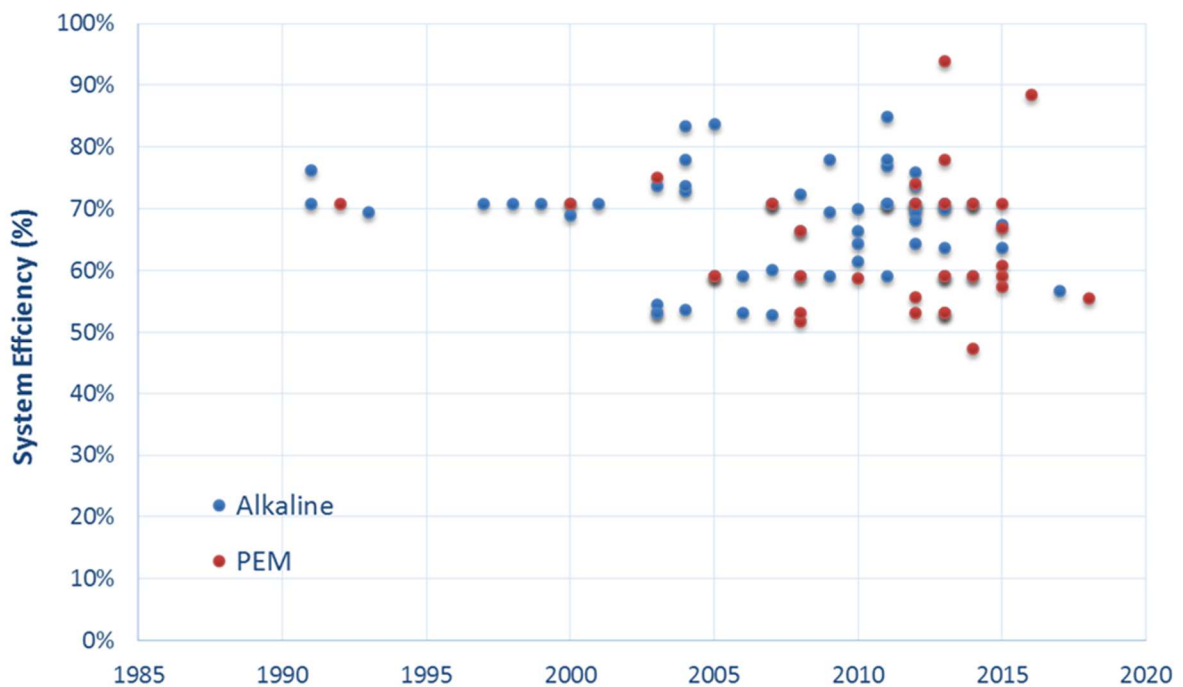


Figure 14. Evolution of Alkaline and PEM efficiencies in function of time, as calculated from Fig. 13

Finally, regarding storage, 79% of the demonstration projects that provide information on this matter, include a storage option. Most of these projects considered a compressed hydrogen gas technology to store the produced hydrogen (cf. Figure 15).

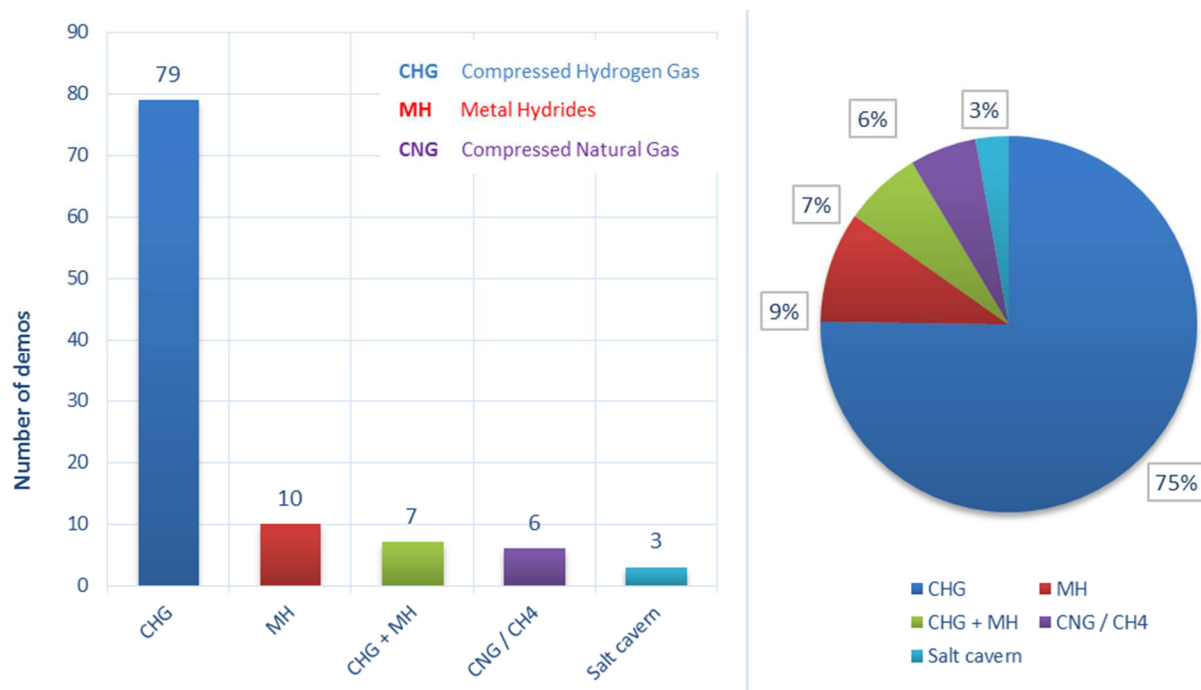


Figure 15. Demonstration storage technology

3.4 Demonstration objectives

156 demonstration projects out of 192 have explicitly mentioned their objectives. In what follows, the percentages are based on these 156 projects.

100 % of demonstrations have technical objectives, with 91% of these projects testing the operational validation, 88% evaluating the efficiency, and a mere 27% considering an upscaling plan. Since 2010, the interest in *only* the technical aspects of the demonstrations has been decreasing. Economic assessments are included in the demonstration objectives as well (cf. Table 1). 42% of the projects have an economic objective, of which only 14% consider the H₂ production cost though.

Table 1. Demonstration objectives

Demonstration start date	Share of demonstrations with technical objective(s) <u>only</u>	Share of demonstrations with economic objective(s)
Before 2000	92%	8%
2000-2004	35%	47%
2005-2009	62%	18%
2010-2014	46%	41%
Since 2015	33%	39%
Total	58% (90 demos out of 156)	42% (66 demos out of 156)

When studying the other targets of the projects, it appeared that most of the direct feedbacks received indicated a regulatory objective, while in the reviewed literature only 2% of the projects highlighted the regulatory aspect. This shows that the regulatory objectives are rather implicit subjects, yet crucial ones, as mentioned previously.

4. Conclusion

'Low-carbon' hydrogen (i.e. H₂ produced through low-carbon pathways) can be used by many energy-consuming services. It has a potential role to play in the electric, gas, transport, and industrial sectors. Demonstrations are a key step towards reaching the market.

A review of the Power-to-X projects in the world was carried out, identifying 192 demonstrations in 32 countries. Results show that the features of demonstrations evolved significantly in the recent years. The investigated pathways diversified, with a recent interest for industry applications. This is happening in the context of a recent and general momentum for industry applications, both at national and international levels [5],[230],[236]-[238]. Also, recent studies showed that only approaches favoring synergies between sectors and acknowledging sector coupling can reveal the full potential of hydrogen to decarbonize the energy system [237]-[241]. Accordingly, demonstrations consider several applications simultaneously, together with an increase of on-grid systems investigating the potential of providing system balancing to the electric grid.

This reviewing work is the first step towards an international roadmap, to be designed with the IEA, in order to better identify what are the demonstrations that are required and focus the effort on the most relevant topics, in order to reach the different markets in the near term. The increasing installed capacities of electrolyzers show that we are on the way.

Acknowledgements

The present work was carried out within the framework of Task 38 of the Hydrogen Technology Collaboration Programme of the International Energy Agency. The task is coordinated by the Institute for techno-economics of energy systems (I-tésé) of the CEA, supported by the ADEME. We would also like to acknowledge the support of Capenergies for this work. One of the authors (JP) wishes to acknowledge financial support from the Public Service of Wallonia – Dept. of Energy and Sustainable Building.

References

- [1] United Nations, "Paris Agreement", 2015
- [2] EU climate action, https://ec.europa.eu/clima/policies/strategies_en . Accessed 30/07/18.
- [3] M. Robinius et al., *Linking the Power and Transport Sectors—Part 1: The Principle of Sector Coupling*. Energies, 2017. 10(7): p. 956.
- [4] C. J. Kikkert, "The effect of power renewables on the grid in 20 years' time", presented to the Electrical Engineering Society of Australia, October 5, 2016.
- [5] IEA, The Future of Hydrogen. Seizing today's opportunities, June 2019.
- [6] A. Godula-Jopek, *Hydrogen production by electrolysis*, Wiley, 2015.
- [7] S. Schiebahn, T. Grube, M. Robinius, V. Tietze, B. Kumar, and D. Stolten, *Power to gas: Technological overview, systems analysis and economic assessment for a case study in Germany*, International Journal of Hydrogen Energy, vol. 40, pp. 4285–4294, Apr. 2015.
- [8] B. Decourt, B. Lajoie, R. Debarre, and O. Soupa, *Leading the energy transition. Factbook. Hydrogen-based energy conversion. More than storage: system flexibility*, SBC Energy Institute, 2014.
- [9] R. Dickinson, F. Dolci, A. Le Duigou, P. Lucchese, Nikolaos Lympieropoulos, C. Mansilla, et al., "Power-to-Hydrogen and Hydrogen-to-X pathways: opportunities for next generation energy systems", 14th International Conference on the European Energy Market (EEM 2017), Dresden, Germany, June 6-9, 2017, Oral presentation.
- [10] P. Lucchese, et al., "Power-to-Hydrogen and Hydrogen-to-X: Midterm appraisal of the IEA HIA Task 38 accomplishments", presented at the 22nd World Hydrogen Energy Conference (WHEC 2018), Rio de Janeiro, Brazil, June 17-22, 2018.
- [11] Energieinstitut an der Johannes Kepler Universität Linz. *Power to Gas – eine Systemanalyse. Markt- und Technologiescouting und –analyse*. Final report. 2014.
- [12] European Power-to-Gas platform, Available from: <http://europeanpowertogas.com/>

- [13] Bailera et al. *Power to Gas projects review: Lab, pilot and demo plants for storing renewable energy and CO₂*. Renewable and Sustainable Energy Reviews 69 (2017) 292-312.
- [14] F. Smeets and D. Thomas. *HyBALANCE: state-of-the-art PEM electrolysis paving the way to multi-MW renewable energy systems*. HyBalance Inauguration Ceremony, Oevel, Belgium, February 13, 2017.
- [15] G. Gahleitner. *Hydrogen from renewable electricity: an international review of power-to-gas pilot plants for stationary applications*. 2013.
- [16] M. Gotz et al. *Renewable Power-to-Gas: A technological and economic review*. 2015.
- [17] V. Vartiainen. *Screening of Power to Gas projects*. Master's Thesis. LUT School of Energy Systems. 2016.
- [18] D. Thomas, Hydrogenics. *Alkaline vs PEM electrolyzers: lessons learnt from Falkenhagen and WindGas Hamburg*. [Presentation] Hydrogen Days, Prague, Czech Republic, April 6, 2016
- [19] H. Iskov, N. B. Rasmussen. *Global screening of projects and technologies for Power-to-Gas and Bio-SNG*. Project report. Danish Gas Technology Centre. November 8, 2013.
- [20] M. Kopp et al. *Energiepark Mainz: Technical and economic analysis of the worldwide largest Power-to-Gas plant with PEM electrolysis*. International Journal of Hydrogen Energy 42 (2017) 13311-13320.
- [21] B. Stefansson. *CO₂-to-methanol: Nordic technology with global application*. [Presentation], November 16, 2017.
- [22] European Power-to-Gas platform. *P2G demo project database*. [Excel spreadsheet] July, 2016.
- [23] F. Geth et al. *Energy Storage Innovation in Europe: A mapping exercise*. GRID+. October 10, 2013
- [24] Aeropila project. Case study article. Axis communications; 2008.
- [25] *U.K.-based Air Fuel Synthesis successfully generates gasoline out of thin air, commercialization planned by 2015*. [Online] Available from: <https://tommytoy.typepad.com/tommy-toy-pbt-consultin/2013/04/scientists-successfully-generate-synthetic-gasoline-out-of-thin-air-a-one-ton-per-day-production-pla.html>
- [26] Ulleberg et al. *Hynor Lillestrøm – A Renewable Hydrogen Station & Technology Test Center*. WHEC 2014.
- [27] K. Thanapalan. *On-board renewable hydrogen production system for hydrogen hybrid vehicles*. Conference paper, May 2012.
- [28] Dr. Thorsten Liese. *Experiences and Results from the RWE Power-to-Gas-Projekt at Niederaußem site*. [Presentation] RWE Power AG, München, November 11, 2013.
- [29] George Olah Renewable Methanol Plant: *First commercial plant*. 2013. Available from: https://web.archive.org/web/20130703233732/http://cri.is/index.php?option=com_content&view=article&id=14&Itemid=8&lang=en
- [30] The George Olah plant. Carbon Recycling International Inc. Available from: https://en.wikipedia.org/wiki/Carbon_Recycling_International#cite_note-13
- [31] *Bio-SNG potential assessment: Denmark 2020*. DGC. November 2010.
- [32] Technical assumptions, technology demonstration and results P2G project. *Power-to-Gas project in Rozenburg, The Netherlands*. Report project. DNV GL. May 31, 2015.
- [33] J. Held. *Small and medium scale technologies for bio-SNG production*. Svenskt Gastekniskt Center report. 2013
- [34] Repotec. *Biomass CHP Plant Güssing*. [Online] Available from: <http://www.repotec.at/index.php/95.html>
- [35] Rob Regan. *Hydrogen Technology Park, 2005 DOE Program Review*. [Presentation] DTE Energy. May 2005.
- [36] R. Regan et al. *Hydrogen Technology Park DTE Energy, Progress report*. 2005.
- [37] Philip Bittner. *Sustainability report 2012/2013*. [Brochure] Julich forschungszentrum. May 2014.
- [38] Energie Speicher. *Reducing the costs with new materials*. [Online] November 10, 2015. Available from: http://forschung-energiespeicher.info/en/wind-to-hydrogen/project-list/project-details//Neue_Materialien_senken_Kosten_bei_PEM_Elektrolyse/
- [39] Dr. Luis Correas. *Elygrid Project*. Foundation for the Development of New Hydrogen Technologies in Aragon (Spain). [Presentation].
- [40] ITM Power. *1 MW sale to ZEAG Energie AG*. [Online] March 31, 2016. Available from: <http://www.itm-power.com/news-item/1mw-sale-to-zeag-energie-ag>
- [41] DLR (German Aerospace Center). *Hydrogen Day Well-established encounter of the industry at DLR Lampoldshausen*. [Online] July 7, 2016. Available from: http://www.dlr.de/ra/en/desktopdefault.aspx/tabid-4058/6636_read-48445/
- [42] DENA Power to Gas platform. *WindGas Falkenhagen*. [Online]. Available from: <http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/windgas-falkenhagen/>
- [43] Store & Go research project. *The German demonstration site at Falkenhagen: May 09th, 2018, Methanation plant in Falkenhagen opens*. [online]. Available from: <https://www.storeandgo.info/demonstration-sites/germany/>

- [44] Dr. Andrei Zschocke. *Experience with the E.ON Power to Gas demo plant*. E.ON Innovation Center Energy Storage. [Presentation] Energy Storage Global Conference, Paris, November 19, 2014.
- [45] A. Ortwein et al. *Bioenergy RES Hybrids in Germany*. IEA Bioenergy. October 5, 2016.
- [46] Maria del Pilar Argumosa, Thomas H. Schucan. *Fuel cell innovative remote energy system for telecom (FIRST)*. INTA, IEA Hydrogen Implementing Agreement. [Online]. Available from: <http://ieahydrogen.org/Activities/Selected-Case-Studies/Fuel-Cell-Innovative-Remote-Energy-System-for-Tele.aspx>
- [47] Dr. Doris Hafenbradl. *Biological methanation processes*. Electrochaea. [Presentation] European PowertoGas Platform: Second Meeting 2016. June 22, 2016.
- [48] Fronius. *Energy self-sufficient Family home*. [Brochure].
- [49] P. Millet et al. *GENHYPEM: A research program on PEM water electrolysis supported by the European commission*. 27-29 October 2007, Ghardaïa – Algeria.
- [50] Karl H. Klug, D. Kwapis. *H2herten Wasserstoffbasiertes Energiekomplementärsystem für die regenerative Vollversorgung des H2-Anwenderzentrums h2herten*. [Presentation] Dena Jahreskonferenz Power to Gas, Berlin, June 18, 2013.
- [51] Energie Park Mainz webpage. [Online]. Available from: <http://www.energiepark-mainz.de/en/technology/technical-data/>
- [52] Chalmers University of Technology. *GoBiGas demonstration – a vital step for a large-scale transition from fossil fuels to advanced biofuels and electrofuels*. [Online]. Available from: https://www.chalmers.se/SiteCollectionDocuments/SEE/News/Popularreport_GoBiGas_results_highres.pdf
- [53] H-TEC Systems. *Power Gap filler project*. [online]. Available from: <https://www.h-tec-systems.com/en/projects/power-gap-filler/>
- [54] NOW GmbH. Establishment of a fully integrated public Hydrogen refuelling station in Schnackenburgallee, Hamburg (CEP). [Online]. Available from: <https://www.now-gmbh.de/en/national-innovation-programme/projektfinder/verkehr/h2-tankstelle-schnackenburgallee-hamburg>
- [55] Dena Power to Gas platform. *H2-Forschungszentrum der BTU Cottbus*. [Online]. Available from: <http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/h2-forschungszentrum-der-btu-cottbus/>
- [56] Hychico project website. [Online]. Available from: <http://www.hychico.com.ar/eng/hydrogen-plant.html>
- [57] FCH JU projects. *Project HyBalance*. [Online]. Available from: <http://www.fch.europa.eu/project/hybalance>
- [58] HyBalance Project website. [Online]. Available from: <http://hybalance.eu/>
- [59] MEFCO2 project website. *Methanol fuel from CO2: Synthesis of methanol from captured carbon dioxide using surplus electricity*. [Online]. Available from: <http://www.mefco2.eu/>
- [60] Cordis, Horizon 2020. *Periodic Reporting for period 2 - MefCO2 (Synthesis of methanol from captured carbon dioxide using surplus electricity)*. [Online]. Available from: https://cordis.europa.eu/result/rcn/190432_en.html
- [61] M. Rey Porto et al. *H2 Production in Sotavento Wind Farm*. 18th World Hydrogen Energy Conference 2010 - WHEC 2010.
- [62] T. Våland et al. *Grimstad renewable energy park*. Agder University College. [Online]. Available from: [http://ieahydrogen.org/Activities/Selected-Case-Studies/Grimstad-Renewable-Energy-Park-\(Norway\).aspx](http://ieahydrogen.org/Activities/Selected-Case-Studies/Grimstad-Renewable-Energy-Park-(Norway).aspx)
- [63] N. Ilhan, A. Ersöz, M. Çubukçu. *A Renewable Energy Based Hydrogen Demonstration Park in Turkey – HYDEPARK*. 18th World Hydrogen Energy Conference 2010 - WHEC 2010.
- [64] Maria del Pilar. Argumosa. *Evaluations of Hydrogen demonstration projects*. IEA HIA Task 18, Feb 2010.
- [65] A. Cruden et al. *Fuel cells as distributed generation*. August 2008.
- [66] H. Iskov. *Lolland Case Study: Micro CHP with integrated electrolyser and gas storage 2005-2007*. Danish Gas Technology Centre. IEA HIA Task 18 Integrated systems. October 2009.
- [67] Fumiuyuki Yamane. *Hydrogen Energy Supply Systems Utilizing Renewable Energy*. Toshiba Energy Systems & Solutions Corporation. [Presentation]. February 27, 2018.
- [68] H2Move project specifications. [Online]. Available from: <https://www.h2move.de/technik-spezifikationen>
- [69] RES-H2 project brochure. H2SusBuild consortium. National Technical University of Athens.
- [70] H2SusBuild project website. [Online]. Available from: <http://www.h2susbuild.ntua.gr/objectives.aspx>
- [71] Maria P. Argumosa, Tomas Cambreleng. *RES2H2 Spanish Site*. INTA, ITC. June 2009.
- [72] Jonathan D. Leaver et al. *Deployment of Hydrogen technologies in New Zealand*. 20th World Hydrogen Energy Conference, WHEC 2014. Gwangju, South Korea, 15-20 June 2014.
- [73] L. Correas, I. Aso. *Task 24: Wind Energy and Hydrogen Integration*. 18th World Hydrogen Energy Conference 2010 - WHEC 2010.

- [74] Vattenfall. *Fuel of the future: HafenCity hydrogen station*. [Presentation].
- [75] D. Hustadt, O. Weinmann. *Hydrogen Refuelling Station Hamburg HafenCity*. 18th World Hydrogen Energy Conference 2010 - WHEC 2010.
- [76] Rupert Gammon. *Measured Demonstration of Low Carbon Success: Demonstration Project of a Carbon-Neutral Energy System*. [Presentation]. November 14, 2007.
- [77] Rupert Gammon. *The integration of hydrogen energy storage with renewable energy systems*. PhD Thesis. Loughborough University Institutional Repository. January 18, 2006.
- [78] Allan Grant. *Hydrogen Assisted Renewable Power (HARP) Project in British Columbia*. Powertech Labs Inc. [Presentation]. Vancouver 2010 Symposium on Microgrids.
- [79] J.D. MacLay et al. *Experimental results for hybrid energy storage systems coupled to photovoltaic generation in residential applications*. International Journal of Hydrogen Energy, 36(19). 2011.
- [80] Michael Wenske. *ENERTRAG- Hybrid Power Plant*. Enertag. [Presentation] International Hydrogen Energy Development Forum 2013 Fukuoka, 30/31.01.2013. Available from: <http://hydrogenius.kyushu-u.ac.jp/cie/event/ihdf2013/pdf/1-2wenske.pdf>
- [81] Frano Barbir. *UNIDO-ICHET's Hydrogen islands initiative, Projects Update*. [Presentation] European Union Sustainable Energy Week 22-26 March 2010.
- [82] Beermann Martin et al. *Hydrogen Powered Fuel Cell Forklifts – Demonstration of Green Warehouse Logistics*. Barcelona, Spain, November 17-20, 2013.
- [83] Fronius Energy Cell. *Storing solar energy as hydrogen*. [Brochure].
- [84] N. Lymperopoulos. *European Developments in Electrolyser Technology, Technical and Economic Outlook*. FCH JU. [Presentation] Power to Gas Conference, Antwerp, June 7, 2018.
- [85] Klaus Stolzenburg et al. *Hydrogen as a means of controlling and integrating wind power into electricity grids, the HyWindBalance project*. International Conference "Hydrogen on Islands", 22-25 October 2008, Bol, Island of Brac, Croatia.
- [86] Massimo Bertoincini. *Power-to-Gas in Italy: INGRID and STORE&GO projects: A first-of-this-kind experience*. Engineering Ingegneria Informatica. [Presentation] Milano, May 28, 2018.
- [87] Alvin P. Bergen. *Integration and Dynamics of a Renewable Regenerative Hydrogen Fuel Cell System*. PhD thesis. University of Victoria. 2008.
- [88] T. Geer, J. F. Manwell, J. G. McGowan. *A Feasibility Study of a Wind/Hydrogen System for Martha's Vineyard, Massachusetts*. University of Massachusetts. American Wind Energy Association Windpower 2005 Conference May 2005.
- [89] ITM Power. *Injection of Hydrogen into the German gas distribution grid*. [Online] December 4, 2013. Available from: <http://www.itm-power.com/news-item/injection-of-hydrogen-into-the-german-gas-distribution-grid>
- [90] Energie Agentur. *Power-to-Gas in Germany and North-Rhine Westphalia (NRW): Ideas, Potential, Projects*. September 2016.
- [91] University of Corsica, Helion, CEA. *Inauguration de la plateforme de Recherche & Développement Solaire et Stockage de l'Energie par les technologies hydrogène – MYRTE*. [Report] January 9, 2012.
- [92] Ulrich Bohn, Florian Lindner. *Power-to-Gas demonstration plant Ibbenbüren: Project description and background information*. RWE Deutschland AG. [Presentation] September 2015.
- [93] Séverine Busquet. *Étude d'un système autonome de production d'énergie couplant un champ photovoltaïque, un électrolyseur et une pile à combustible : réalisation d'un banc d'essai et modélisation*. PhD thesis. Ecole des Mines de Paris. December 15, 2003.
- [94] N. Lymberopoulos. *Hydrogen production from renewables*. September 2005.
- [95] Frédéric Gailly. *Alimentation électrique d'un site isolé à partir d'un générateur photovoltaïque associé à un tandem électrolyseur/pile à combustible (batterie H₂/O₂)*. PhD thesis. University of Toulouse. July 18, 2011.
- [96] Torgeir Nakken et al. *Utsira - Demonstrating the renewable hydrogen society*. WHEC 16 / 13-16 June 2006 – Lyon France.
- [97] P. Millet. *High pressure PEM water electrolysis and corresponding safety issues*. [Presentation] International conference on Hydrogen Safety (ICH3-09) Ajaccio, France, 16-18 September 2009.
- [98] Tapan K. Bose. *Stand-alone Renewable Energy system based on Hydrogen production*. University of Quebec.
- [99] S. Galli. *The Solar-Hydrogen SAPHYS project: Operating results*. ENEA.
- [100] Tauron group. *CCS/CCU in Tauron group*. [Presentation].
- [101] InnoEnergy. *Complete CO₂-SNG installation*. [Online]. Available from: <http://www.innoenergy.com/innovationproject/our-innovation-projects/co2-sng/>
- [102] G. Benjaminsson et al. *Power-to-Gas – A technical review*. SGC report. 2013.

- [103] Hydrogeit. *HYPOS – From Storage to Distribution*. [Online] December 1, 2017. Available from: <https://www.h2-international.com/2017/12/01/hypos-from-storage-to-distribution/>
- [104] HYPOS project website. [Online]. Available from: <http://www.hypos-eastgermany.de/en/>
- [105] McPhy energy. *Innovative H2 Solutions to Move Towards Clean & Smart Territories*. European Commission JRC S3P Energy: Smart Mediterraneo. [Presentation] Bari, 23-24 June 2016.
- [105] Energetica International. *The self-sufficient house: renewable energy with storage systems*. Fronius.
- [106] MeGa-stoRE final report, project no.12006. Aarhus University. 2015.
- [106] Laurent Meillaud. Hydrogen today. *Power-to-gas: inauguration du projet GRHYD à Dunkerque*. [Online] June 12, 2018. Available from: <https://hydrogentoday.info/news/4350>
- [107] Ileana Blanco et al. *Hydrogen and renewable energy sources integrated system for greenhouse heating*. University of Bari. *Journal of Agricultural Engineering* 2013; volume XLIV(s2):e45. 2013.
- [108] A. Shiroudi and S. R. Hosseini Taklimi. *Demonstration project of the solar hydrogen energy system located on Taleghan-Iran: Technical-economic assessments*. World Renewable Energy Congress 2011, Linköping, Sweden, 8-13 May, 2011.
- [109] Erik Christensen. *WELTEMP Water electrolysis at elevated temperatures*. Department of Chemistry, Technical University of Denmark. [Presentation].
- [110] AFHYPAC, Ph. Boucly., Th. Alleau. *Le "Power to Gas"*. Revised by P. Malbrunot on February 2018.
- [111] Dr. Jörg Dehmel. *REFHYNE Project: 10 MW Electrolyser Rhineland Refinery, General Overview*. Shell Rhineland. [Presentation] April 2018.
- [112] Z. Khan et al. *Review on Hydrogen production technologies in Malaysia*. *International Journal of Engineering & Technology IJET-IJENS* Vol: 10 NO: 02. June 2010.
- [113] Øystein Ulleberg et al. *Hydrogen Demonstration Project Evaluations*. Final report for IEA HIA, Task 18, Subtask B. November 2007.
- [114] DOE Global Energy Storage Database website. [Online]. Available from: <http://energystorageexchange.org/projects/1447>
- [115] Wikipedia. *Power-to-Gas*. [Online]. Available from: <https://de.wikipedia.org/wiki/Power-to-Gas>
- [116] Méziane Boudellal. *Power-to-Gas: Renewable Hydrogen Economy for the Energy Transition*. Walter de Gruyter GmbH & Co KG. February 5, 2018 - 226 pages. [Online] E-book. Available from: https://books.google.fr/books?id=3ZNdDwAAQBAJ&pg=SA7-PA40&lpg=SA7PA40&dq=Raglan+Nickel+m%C3%a9ine+canada+power+to+gas+hydrogen+electrolyzer&source=bl&ots=jVKI__oP3w&sig=Nco6uJDGomFyhkOZIIvB1JReULY&hl=fr&sa=X&ved=0ahUKewjy5ZnZy6jcAhUDgVwKHTTWcmwQ6AEIYDAK#v=onepage&q=Raglan%20Nickel%20mine%20canada%20power%20to%20gas%20hydrogen%20electrolyzer&f=false
- [117] Store & Go website. *The Swiss demonstration site at Solothurn*. [Online]. Available from: <https://www.storeandgo.info/demonstration-sites/switzerland/>
- [118] Andy Lutz et al. *Case Study: The Hawaii Hydrogen Power Park Demonstration at Kahua Ranch*. January 22, 2010.
- [119] University of Hawaii. *Final Technical Report: Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems*. September 2008.
- [120] Hycenta. *W2H (01.01.2014-31.12.2017)*. [Online]. Available from: <http://www.hycenta.at/projekte/w2h/>
- [121] Energy innovation Austria. *Hydrogen and fuel cell technology in the energy and transport systems of the future*. February 2015.
- [122] Franz E. Leichtfried. *Wasserstofferzeugung mittels PEM-Elektrolyse: Unterbrechungsfreie Versorgung mit ultrareinem Wasserstoff aus Wasser und Strom*. Biovest GmbH. [Presentation]. 2007.
- [123] *CO2RRECT: Storing electricity while simultaneously capturing CO2*. 2013. Available from: <http://kraftwerkforschung.info/en/co2rrect-storing-electricity-while-simultaneously-capturing-co2/page/0/>
- [124] Johannes Lindorfer. *Research Studio Austria OptFuel 2-stage anaerobic digestion of biowaste combined with power-to-gas*. [Presentation] IEA Bioenergy Task 39. September 29, 2016.
- [125] University of Applied Sciences Hochschule Emden Leer. *POWER-TO-FLEX*. [Online]. Available from: <http://oldweb.hs-emden-leer.de/forschung-transfer/institute/eutec/arbeitsgruppe-umweltverfahrenstechnik/projekte-in-der-ag-umweltverfahrenstechnik/power-to-flex.html>
- [126] HPEM2GAS project website. [Online]. Available from: <http://hpem2gas.eu/results/#WP5>
- [127] AZoCleantech. *Synthetic Natural Gas from Sewage Treatment Plant*. [Online] June 12, 2018. Available from: <https://www.azocleantech.com/news.aspx?newsID=25653>
- [128] B. Simonis, M. Newborough. *Sizing and operating power-to-gas systems to absorb excess renewable electricity*. ITM Power, Sheffield, UK. August 2017.

- [129] Dena Power to Gas platform. *CO2RRECT*. [Online]. Available from: <http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/co2rrect/>
- [130] Christian Buck and Sebastian Webel, Siemens. *Hydrogen from Electrolysis: The Most Versatile Fuel*. [Online] July 2, 2015. Available from: <https://www.siemens.com/innovation/en/home/pictures-of-the-future/energy-and-efficiency/smart-grids-and-energy-storage-electrolyzers-energy-storage-for-the-future.html>
- [131] HELMETH project website. [Online]. Available from: <http://www.helmeth.eu/index.php/project>
- [132] Energiforskning.dk. *El upgraded biogas*. HALDOR TOPSØE A/S. [Online]. Available from: <https://energiforskning.dk/en/node/7155>
- [133] Energiforskning.dk. *El Opgraderet Biogas II*. HALDOR TOPSØE A/S. [Online]. Available from: <https://energiteknologi.dk/node/9160>
- [134] Nvnom. *Power-to-Gas plant for Delfzijl*. [Online] April 15, 2014. Available from: <https://www.nvnom.com/homepage/power-gas-plant-delfzijl/>
- [135] A. Luque et al. *Tenth E.C. Photovoltaic Solar Energy Conference*, Proceedings of the International Conference, held at Lisbon, Portugal, 8–12 April 1991. [Online] E-book. Available from: https://books.google.fr/books?id=CKfnCAAQBAJ&pg=PA476&lpg=PA476&dq=NEMO+project+finland+hydrogen&source=bl&ots=BDZBLEvcyo&sig=YQjG3gev_i-RL2ezD-48wRSMQjY&hl=fr&sa=X&ved=0ahUKewiKtvXM67ncAhXKxoUKHRnMCLYQ6AEIqAG#v=onepage&q=NEMO%20project%20finland%20hydrogen&f=false
- [136] FCH JU. *Project REFHYNE: Clean Refinery Hydrogen for Europe*. [Online]. Available from: <http://www.fch.europa.eu/project/clean-refinery-hydrogen-europe>
- [137] Storengy. *Methycentre: Unité de Power-to-Gas (hydrogène et méthane de synthèse) couplée à une unité de méthanisation*. [Brochure].
- [138] Nel ASA. *Nel ASA: Enters into exclusive NOK 450 million industrial-scale power-to-gas framework agreement with H2V PRODUCT*. [Online] June 13, 2017. Available from: <http://news.cision.com/nel-asa/r/nel-asa--enters-into-exclusive-nok-450-million-industrial-scale-power-to-gas-framework-agreement-wit,c2286835>
- [139] Bjørn Simonsen. *Hydrogen infrastructure for any vehicle types*. Nel ASA. [Presentation].
- [140] HyFLEET: CUTE project website. [Online]. Available from: <https://www.global-hydrogen-bus-platform.com/Home.html>
- [141] Marie-Anne Garigue. *Power-to-Gas : McPhy livre 4 MW d'équipements de génération d'hydrogène au Hebei et conforte sa position sur les projets internationaux multi-MW*. McPhy. [Online]. Available from: https://mcphy.com/fr/mclive/communiqués/power_to_gas_mcphy_hebei_livraison/
- [142] Stephen Crolius. *Renewable Hydrogen in Fukushima and a Bridge to the Future*. Ammonia Energy. [Online] October 19, 2017. Available from: <http://www.ammoniaenergy.org/renewable-hydrogen-in-fukushima-and-a-bridge-to-the-future/>
- [143] RE Hydrogen electrolyzers. [Online]. Available from: <http://rehydrogen.com/OLD2/electrolyzers.html>
- [144] H2orizon project website. [Online]. Available from: <https://www.h2orizon.de/>
- [145] Thorben Andersen. *H2ORIZON: Sector coupling with wind-hydrogen*. German Aerospace Center (DLR). [Online]. Available from: <https://event.dlr.de/en/hmi2018/h2orizon/>
- [146] Jean-Philippe Defawe. *Un démonstrateur « power-to-gas » en service à Nantes*. Le Moniteur. [Online] February 9, 2018. Available from: <https://www.lemoniteur.fr/article/un-demonstrateur-power-to-gas-en-service-a-nantes.1949184>
- [147] Pour la Science journal. *L'Hydrogène au cœur de la transition énergétique*. [Online] March 2018. Available from: https://www.engie.com/wp-content/uploads/2018/05/tap_engie.pdf
- [148] Agence Nationale de la Recherche. *Résumé public du projet*. CHOCHCO project. September 2015.
- [149] Chochco project website. [Online]. Available from: <https://chochco.fr/>
- [150] Energie Innovativ. *MicroPyros GmbH - Power-to-Gas*. [Online]. Available from: <https://www.energie-innovativ.de/service-events/messetour/gestalter-der-energiewende/gestalter-nach-regierungsbezirken/gestalter-in-niederbayern/gestalter-in-niederbayern/gestalter/Gestalter/show/micropyros-gmbh/>
- [151] MicroPyros project website. [Online]. Available from: <https://www.micropyros.de/>
- [152] Nel Hydrogen. *Nel Hydrogen Electrolyser: The world's most efficient and reliable electrolyser*. [Online]. Available from: https://nelhydrogen.com/assets/uploads/2017/01/Nel_Electrolyser_brochure.pdf
- [153] Henning G. Langås. *Large scale Hydrogen production*. Nel Hydrogen. [Presentation] «Renewable Energy and Hydrogen Export» Trondheim, Norway – March 24th 2015.
- [154] M.J. Kippers et al. *Pilot project on Hydrogen injection in natural gas on island of Ameland in the Netherlands*. International Gas Union Research Conference, Seoul, 2011.

- [155] Harm Vlap. *Power-to-Gas Demonstration Project Rozenburg*. [Presentation] Workshop Power2Gas: From Theory2Practice. November 18, 2014.
- [156] FCH JU. *Clean Hydrogen in European Cities project: Presentation of the emerging conclusions*. CHIC project. [Presentation]. June 2016.
- [157] Hydrogen Europe. *Project CHIC: Clean Hydrogen in European Cities*. [Online]. Available from: <https://hydrogeneurope.eu/project/chic>
- [158] Institut Für Energietechnik. *Power-to-Methane Demonstrationsanlage der Schweiz*. [Online]. Available from: <https://www.iet.hsr.ch/index.php?id=13510>
- [159] Hydrogen Europe. *Project NEXPEL: Next-Generation PEM Electrolyser for Sustainable Hydrogen Production*. [Online]. Available from: <https://hydrogeneurope.eu/project/nexpel>
- [160] Sintef. *NEXPEL: Leading the development of highly efficient hydrogen production*. [Online]. Available from: <https://www.sintef.no/projectweb/nexpel/>
- [161] Cordis. *PRessurlzed PEM electrOLYZER*. [Online]. Available from: https://cordis.europa.eu/project/rcn/94279_fr.html
- [162] SET-Plan Information System (SETIS). *Mapping of projects, activities, resources and investments*. PROCON project. [Questionnaire]. January 2011.
- [163] Energie Speicher. *Wasserstoff-Herstellung im Megawatt-Maßstab*. [Online] April 12, 2017. Available from: [http://forschung-energiespeicher.info/projektschau/gesamtliste/projekt-einzelansicht/95/Wasserstoff_Herstellung_im_Megawatt_Massstab/](http://forschung-energiespeicher.info/projektschau/gesamtlste/projekt-einzelansicht/95/Wasserstoff_Herstellung_im_Megawatt_Massstab/)
- [164] *The Hydrogen Centre: The University of Glamorgan Renewable Hydrogen Research and Demonstration Centre*. Baglan Energy Park, University of Glamorgan.
- [165] RESelyser project website. *Hydrogen from RES: pressurised alkaline electrolyser with high efficiency*. [Online]. Available from: <http://www.reselyser.eu/index.html>
- [166] Cordis. *Final Report Summary - RESELYSER (Hydrogen from RES: pressurised alkaline electrolyser with high efficiency and wide operating range)*. [Online]. Available from: https://cordis.europa.eu/result/rcn/176817_en.html
- [167] Greg Jones. *Wind-Hydrogen-Diesel Energy Project*. Nalcor energy. [Presentation] September 15, 2010.
- [168] Catherine Fait. *Data Mining Techniques Applied to a Building-Integrated Hybrid Renewable Energy System*. Bachelor thesis. Ostfalia University of Applied Sciences. [Online] May 25, 2018. Available from: https://www.theseus.fi/bitstream/handle/10024/150448/Fait_Catherine.pdf?sequence=1&isAllowed=y
- [169] *Fuel cells and Hydrogen in Norway*. Fuel Cell Today. Report, January 2013.
- [170] Monika Landgraf. *Regional Generation, Use, and Storage of Power*. Karlsruhe Institute of Technology. [Online] August 31, 2015. Available from: http://www.kit.edu/kit/english/pi_2015_regional-generation-use-and-storage-of-power.php
- [171] Prince Edward Island Energy Corporation. *Canada's green province: Developing, demonstrating and implementing leading-edge renewable energy technologies*. [Presentation].
- [172] Dena Power to Gas platform. *EXYTRON Demonstrationsanlage*. [Online]. Available from: <http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/exytron-demonstrationsanlage/>
- [173] Dena Power to Gas platform. *Exytron Zero-Emission-Wohnpark*. [Online]. Available from: <http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/extyron-zero-emission-wohnpark/>
- [174] EXYTRON. *Une vision devient réalité: Le premier quartier résidentiel ZÉRO ÉMISSION au monde*. [Presentation] Montpellier, December 15, 2016.
- [175] Fabian Reetz. *Das Micro Smart Grid als Baustein einer zukunftsfähigen Energieversorgung*. Innovationszentrum. [Presentation] November 14, 2013.
- [176] Curt Robbins et al. *Small Scale Renewable Energy Power System with Hydrogen Combustion*. Desert Research Institute. [Presentation] NHA Hydrogen Conference, March 31, 2008.
- [177] Desert Research Institute. *Renewable Energy Hydrogen Based System for Off-Grid Applications*. [Online]. Available from: <http://www.dri.edu/editor/rec-projects/213-renewable-energy-hydrogen-based-system-for-off-grid-applications>
- [178] D. Ipsakis et al. *Energy management in a stand-alone power system for the production of electrical energy with long term hydrogen storage*. 2008.
- [179] Hydrogen house project website. *The hydrogen house*. [Online]. Available from: <http://hydrogenhouseproject.org/the-hydrogen-house.html>
- [180] Bright Green Hydrogen. *The Hydrogen Office Project (2008-2014)*. [Online]. Available from: <https://www.brightgreenhydrogen.org.uk/hydrogen-office-project/>
- [181] Invest in Fife. *The Hydrogen Office, Energy Park Fife*. [Brochure].

- [182] Carsten Reekers. *Energy storage in salt domes: IVG Cavern Storage Etzel*. IVG. [Presentation] Challenges in Energy supply - Energy Symposium, Eemshaven, June 3, 2013.
- [183] Isabelle Duffaure-Gallais. *Bâtiment tertiaire Un siège social autonome en énergie*. Le Moniteur. [Online] September 11, 2009. Available from: <https://www.lemoniteur.fr/article/batiment-tertiaire-un-siege-social-autonome-en-energie.509739>
- [184] Peter Focht. *Grüner Wasserstoff für Hanauer Industriepark*. Energie & Management GmbH. [Online] February 20, 2015. Available from: <https://www.energie-und-management.de/nachrichten/detail/gruener-wasserstoff-fuer-hanauer-industriepark-108526>
- [185] H2BZ Initiative Hessen. *Hessischer Elektrolyseur erfolgreich getestet*. [Online]. Available from: <https://www.h2bz-hessen.de/elektrolyseur>
- [186] Andrew Dicks. *Clean Energy Storage: Power-to-Gas*. Griffith University. [Presentation].
- [187] Alan Kneisz. *The Hydrogen Shift is Here, The Future of Power and Mobility*. Hydrogenics. [Presentation] ADB – Clean Energy Forum.
- [188] Agence Nationale de Recherche. *DEMETER project: Technical and economical feasibility of a renewable electricity storage loop on methane by the way of a reversible SOEC*. [Online]. Available from: <http://www.agence-nationale-recherche.fr/Project-ANR-11-SEED-0005>
- [189] K. Pütz and T. Norbeck. *The way ahead for hydrogen in transport in Norway*. OECD, November 30, 2012.
- [190] Icelandic New Energy. *ECTOS Ecological City Transport System*. Second NewsLetter.
- [191] European Commission. *The Hydrogen Fuelling Station, Ecological City Transport System. Demonstration, Evaluation and Research Project of Hydrogen Fuel Cell Bus Transportation System of The Future*. ECTOS – Deliverable 4. May 2003.
- [192] ACTA S.P.A. *Hydrogen generator demonstrated by Abengoa*. [Online]. Available from: <http://www.actaspa.com/hydrogen-generator-demonstrated-by-abengoa/>
- [193] EcoRally. *Carbon neutral liquid fuels - an investment pitch by Air Fuel Synthesis*. [Video] August 31, 2012. Available from: <https://www.youtube.com/watch?v=hafVXGoxb1s>
- [194] Valentine Willman. *Aberdeen Hydrogen Bus Project*. HyER. [Presentation] LowCVP Low Emission Bus Workshop, Glasgow, March 8, 2018.
- [195] HyER. *Hydrogen Bus Project*. [Online]. Available from: <http://hyer.eu/best-practices/hydrogen-bus-project/>
- [196] Bright Green Hydrogen. *Levenmouth Project*. [Online]. Available from: <https://www.brightgreenhydrogen.org.uk/levenmouth-community-energy-project/>
- [197] Bright Green Hydrogen. *Levenmouth Community Energy Project*. [Presentation] APSE Scotland Fleet, Waste & Grounds Seminar 26-29th May 2015.
- [198] Iain Todd. *Levenmouth Community Energy Project: Project update*. [Presentation] All Energy Conference and Exhibition, Glasgow, 5 May 2016 Local Energy Economies event.
- [199] SYNFUEL Project website. [Online]. Available from: <http://www.synfuel.dk/about-the-project>
- [200] S. Kent Hoekman et al. *CO2 recycling by reaction with renewably-generated hydrogen*. International Journal of Greenhouse Gas Control 4 (2010) 44–50.
- [201] Monika Landgraf. *Flexible Methane Production from Electricity and Bio-mass*. Karlsruhe Institute of Technology. [Online] December 17, 2014. Available from: http://www.kit.edu/kit/english/pi_2014_16120.php
- [202] Hitachi Zosen Inova. *Hitachi Zosen Corporation and Hitachi Zosen Inova to Build First Joint Power-To-Gas Plant*. [Online]. Available from: <http://www.hz-inova.com/cms/en/home?p=6276>
- [203] Aujchara Weerawong. *CO2 Conversion to Methane Project*. PTT Exploration and Production PCL.
- [204] Harald Wiederschein. *Schadstofffrei in die Zukunft*. Focus Online. [Online] August 10, 2011. Available from: https://www.focus.de/wissen/technik/mobilitaet/antriebe/tid-23218/wunderkraftstoff-schadstofffrei-in-die-zukunft_aid_652598.html
- [205] Simone Pascuzzi et al. *Electrolyzer Performance Analysis of an Integrated Hydrogen Power System for Greenhouse Heating. A Case Study*. Sustainability, July 5, 2016.
- [206] Engie. *1 MWh with H2 Microgrid in the Atacama Desert*. [Online]. Available from: <http://www.electropowersystems.com/portfolio-item/1mwh-with-h2-microgrid-in-the-atacama-desert-chile/>
- [207] HPEM2GAS project. *High Performance PEM Electrolyzer for Cost-effective Grid Balancing Applications*. [Brochure]. [Online]. Available from: http://hpem2gas.eu/download/project_flyer/UNIRESEARCH_HPEM2GAS_flyer_1718_web.pdf
- [208] Plataforma Tecnológica Española del Hidrógeno y las Pilas de Combustible Grupo de Análisis de Capacidades. *Estado de la Tecnología del Hidrógeno y las Pilas de Combustible en España*. 2005.

- [209] Naturgy. *Gas Natural Fenosa launches pilot project to produce renewable gas in Catalonia*. [Online] Madrid, May 31, 2018. Available from: <http://www.prensa.naturgy.com/en/gas-natural-fenosa-launches-pilot-project-to-produce-renewable-gas-in-catalonia/>
- [210] Jordi Guilera et al. *The COSIN project: synthetic natural gas production from biogas in a waste water treatment plant in Barcelona*. [Online] International Conference on Renewable Energy, April 25-27, 2018. Available from: <http://programme.exordo.com/icren2018/delegates/presentation/38/>
- [211] BALANCE Project website. [Online]. Available from: <https://www.balance-project.org/projects/>
- [212] Power to Flex project website. [Online]. Available from: <https://www.powertoflex.eu/en/>
- [213] FCH JU. *Project RESelyser, Hydrogen from RES: pressurised alkaline electrolyser with high efficiency and wide operating range*. [Online]. Available from: <https://www.fch.europa.eu/project/hydrogen-res-pressurised-alkaline-electrolyser-high-efficiency-and-wide-operating-range>
- [214] Gas Natural Fenosa. *RENOVAGAS Project: Power to Methane*. [Presentation] Western Region Workshop – 28 & 29 Sept 2017 – Lisbon, Portugal.
- [215] Loïc Mangin. *L'hydrogène, accélérateur de la transition énergétique*. ENGIE. March 2018.
- [216] Energy, Oil & Gas. *STORAG ETZEL GmbH*. [Online] July 2016. Available from: <http://www.energy-oil-gas.com/2016/07/15/storag-etz-el-gmbh/>
- [217] Abdol S. Soofi and Mehdi Goodarzi. *The Development of Science and Technology in Iran: Policies and Learning Frameworks*. [Online] E-book, December 7, 2016. Available from: https://books.google.fr/books?id=O5-wDQAAQBAJ&pg=PA192&lpg=PA192&dq=taleghan+hydrogen+project+start+date&source=bl&ots=EiQ2Luu9nS&sig=g80ec_e5-B51sQal8qf0PhmzNS4&hl=fr&sa=X&ved=2ahUKEwivwLrbg5LdAhWLxIUkHX_fAVYQ6AEwAnoECAGQAQ#v=onepage&q=taleghan%20hydrogen%20project%20start%20date&f=false
- [218] Sebastian Becker. *Power-to-Liquids as a new Energy Option, Potentials and Difficulties/Uncertainties*. Sunfire GmbH. [Presentation]. [Online] January 11, 2013. Available from: https://www.umweltbundesamt.de/sites/default/files/medien/377/dokumente/19_session_i_5_becker.pdf
- [219] Aravind PV, Vikrant Venkataraman. *BALANCE Deliverable D5.1, Identification of potentially attractive process chains for reversible solid oxide cell rSOC (systems): power to commodity and vice versa for grid stabilisation*. TU Delft. May 21, 2018.
- [220] Salman, Sartory and Klell. *Wind2Hydrogen – Umwandlung von erneuerbarem Strom in Wasserstoff zur Speicherung und zum Transport im Erdgasnetz*. HyCentA. [Presentation] Symposium Energieinnovation, February 12, 2016.
- [221] Natural Resources Canada. *Glencore RAGLAN Mine Renewable Electricity Smart-Grid Pilot Demonstration*. [Online]. Available from: <https://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/16662>
- [222] VTT. *Demonstration of bio-CO2 products with novel research platform*. bioeconomy+. [Online]. Available from: <https://www.vtt.fi/sites/bioeconomyplus/en/contacts>
- [223] Demo4Grid project website. [Online]. Available from: <https://www.demo4grid.eu/project/>
- [224] FCH JU. *Demo4Grid Demonstration of a 4 MW Large Scale Pressure Alkaline Electrolysis for Grid Balancing Services*. [Presentation]. [Online]. Available from: http://elyntegration.eu/wp-content/uploads/DEMO4GRID_IHT_Session_3.pdf
- [225] W. Stahl, K. Voss, and A. Goetzberger. *The self-sufficient solar house in Freiburg*. Solar Energy Vol. 52, No. 1, pp. 111-125, 1994.
- [226] LNG World News. *Gasunie, Greenpeace Energy Choose Suderburg as Windgas Location, Germany*. [Online] September 28, 2012. Available from: <https://www.lngworldnews.com/gasunie-greenpeace-energy-choose-suderburg-as-windgas-location-germany/>
- [227] Greenpeace Energy. *Neuer schwung für die energiewende: windgas made in Suderburg*. [Online] September 19, 2012. Available from: <https://www.greenpeace-energy.de/presse/artikel/neuer-schwung-fuer-die-energiewende-windgas-made-in-suderburg.html>
- [228] Nick Harmsen. *Hydrogen to be injected into Adelaide's gas grid in 'power-to-gas' trial*. ABC News. [Online] August 7, 2017. Available from: <http://www.abc.net.au/news/2017-08-08/trial-to-inject-hydrogen-into-gas-lines/8782956>
- [229] *El Hidrógeno y las pilas de combustible, el recorrido de la energía*. Junta de Castilla y Leon. 2007.
- [230] C. Philibert, Renewable energy for industry, IEA, 2017.
- [231] F. Dolci, et al., *Incentives and legal barriers for Power-to-Hydrogen pathways: An international snapshot*, Int J Hydrogen Energy, May 2019, 44(23), 11394-11401.
- [232] S. M. Saba, M. Müller, M. Robinius, D. Stolten, "The investment costs of electrolysis—A comparison of cost studies from the past 30 years", Int J Hydrogen Energy 43(2018) 1209-1223.

- [233] J. Proost, "State-of-the art CAPEX data for water electrolyzers, and their impact on renewable hydrogen price settings", *Int J Hydrogen Energy* 44(2019) 4406-4413.
- [234] J. Mougin, Hydrogen production by high-temperature steam electrolysis, In: *Compendium of Hydrogen Energy*, 2015, pp.225-253. [235] M. Robinius et al., *Techno-economic potential of Power-to-Hydrogen pathways: An international literature review*, *Int J Hydrogen Energy*, under review.
- [236] Ministère de la Transition Ecologique et Solidaire, Plan de déploiement de l'hydrogène pour la transition énergétique, 2018.
- [237] NREL, H2 at scale: Deeply Decarbonizing Our Energy System, 2016
- [238] Hydrogen Council, How hydrogen empowers the energy transition, January 2017.
- [239] Hydrogen Council, Hydrogen scaling up, A sustainable pathway for the global energy transition, Nov. 2017
- [240] O. Tlili et al., "Rethinking the way to decarbonize the energy system: prospective study of hydrogen market attractiveness", presented at the 40th IAEE International Conference, Singapore, Malaysia, June 18-21, 2017.
- [241] A. De Vita et al., Sectoral integration- long-term perspective in the EU Energy System, Final report of the ASSET project, 2018.

Appendix 1: list of the reviewed demonstration projects and location

Demo name	Location (country code)
Abalone Energie Nantes	FR
Aberdeen, Hydrogen bus project	UK
Aeropila	ES
Air Fuel Synthesis pilot plant	UK
Alzey, Exytron Null-E	DE
Ameland	NL
Baglan Energy Park Wales	UK
Balance	EU
Bio SNG Güssing	AT
BioPower2Gas, Allendorf, Eder	DE
BOEING (rSOC Demonstrator)	US
Carbazol pilot plant, University of Erlangen-Nürnberg	DE
CEC Denizli Turkey	TR
Cerro Pabellón Microgrid 450 kWh Hydrogen ESS - Enel S.p.A	CL
CHOCHCO	FR
CO2RRECT-Niederaussem	DE
Commercial Plant Svartsengi/George Olah plant	IS
CoSin: Synthetic Natural Gas from Sewage, Barcelona	ES
CUTE and HyFLEET:CUTE, Barcelona	ES
CUTE, Stockholm	SE
Delfzijl	NL
DEMETER	FR
Demo Plant Agricultural University Athens	GR
DEMO4GRID	AT
Demonstration of bio-CO2 products, Bio economy+	FI
Demonstration plant Kuala Terengganu, Malaysia	MY
DNV Kema/DNV GL	NL
Don Quichote	BE
DRI CO2 recycling	US
DTE Energy Hydrogen Technoly Park, Southfield Michigan	US
DVGW-EBI KIT - Demo-SNG	DE
ECTOS	IS
EE-Methan aus CO2	AT
Ekolyser (R&D)	DE
El Tubo	ES
ElectroHgena	FR
ELYGRID (R&D)	EU
Emden I Biogas upgrading	DE
Emden II Upscaling	DE
Enbridge P2G toronto	CA
EnBW H2 station, Stuttgart	DE

Energiepark Mainz	DE
EON PtG plant Falkenhagen	DE
EON PtG plant Hamburg-Reitbrook	DE
ETOGAS, Solar Fuel Alpha-plant 250 kW, ZSW	DE
ETOGAS, Solar Fuel Alpha-plant mobile device, ZSW	DE
ETOGAS, Solar Fuel Beta-plant AUDI, Werlte (Audi e-gas)	DE
Etzel, Salt caverns	DE
Eucolino Schwandorf	DE
Fife, Levenmouth Community Energy Project	UK
FIRST - Showcase II	ES
FIRST project, INTA facility	ES
Foulum Demonstration plant	DK
Freiburg solar house	DE
Fronius Energy Cell, self-sufficient house	AT
Fronius HyLOG-Fleet (Hydrogen powered Logistic System)	AT
Fukushima Power-to-gas Hydrogen Project	JP
GenHyPEM (R&D)	EU
Green Natural Gas	DK
Greenhouse heating, solar-H2	IT
Greenpeace Energy Windgas Suderburg	DE
GRHYD (Hythane)	FR
GRHYD (inj in NG grid)	FR
Grimstad Renewable Energy Park	NO
GrInHy	DE
H2 from the sun, Brunate	IT
H2 research center BTU Cottbus	DE
H2BER (Berlin airport)	DE
H2FUTURE	AT
H2Herten	DE
H2KT - Hydrogen Energy Storage in Nuuk	GL
H2Move, Fraunhofer ISE	DE
H2ORIZON	DE
H2SusBuild / RES-H2	GR
HAEOLUS	NO
Haldor Topsoe - El-Opgraderet Biogas	DK
Haldor Topsoe - El-Opgraderet Biogas II	DK
Hamburg - Schnackenburgallee	DE
Hamburg Hafen City, CEP	DE
Hanau, Wolfgang Industrial Park	DE
HARI project, West Beacon Farm	UK
HARP System, Bella Coola	CA
Hassfurt	DE
Hawaii Hydrogen Power Park (phase 2)	US
Hebei- China	CN
HELMETH	DE

Hidrolica, Tahivilla	ES
Hitachi Zosen/CO2 Conversion to Methane Project	TH
HPEM2GAS (R&D)	DE
HyBALANCE	DK
Hybrid energy storage system NFCRC, California	US
Hybrid Power Plant Enertrag, Prenzlau	DE
Hychico, Comodoro Rivadavia	AR
HyCycle - Center for renewable H2 (R&D)	DK
Hydepark	TR
Hydrogen Island Aitutaki	CK
Hydrogen Island Bozcaada	TR
Hydrogen mini grid system Yorkshire (Rotherham)	UK
Hydrogen village Burgenland	AT
Hydrogen Wind Farm Sotavento	ES
HyFLEET:CUTE, Amesterdam	NL
HyFLEET:CUTE, Hamburg	DE
Hygreen	FR
HYLINK, Totara Valley	NZ
HyNor Lillestrøm, Akershus Energy Park	NO
HYPOS (Leipzig)	DE
HySolar test bed Riyadh (R&D)	SA
HYSOLAR, Stuttgart	DE
HyWindBalance, Oldenburg	DE
INGRID	IT
IRENE System	CA
ITHER	ES
Jupiter 1000	FR
Kidman Park in Adelaide depot	AU
Laboratory Plant HRI Quebec	CA
Laboratory Plant Stralsund	DE
Laboratory System at IFE Kjeller	NO
Lam Takhong Wind Hydrogen Hybrid Project- EGAT	TH
LastEISys (R&D)	DE
MEDLYS, Medium temperature water electrolysis (R&D)	DK
MEFCO2	DE
MeGa-stoRE	DK
MeGa-stoRE Optimising and Upscaling	DK
METHYCENTRE	FR
MicrobEnergy GmbH, Schwandorf	DE
MicroPyros	DE
Minerve, Nantes	FR
MYRTE	FR
NEDO kofu city, Yamanashi Prefecture	JP
NEMO	FI
New zealand Matiu/Somes Island	NZ

NEXPEL (R&D)	NO
OptFuel	AT
P2G plant Erdgas Schwaben	DE
P2G-Biocat	DK
PHOEBUS	DE
Pilot & Demo PtM HSR	CH
Port-Jérôme	FR
PostBus Hydrogen bus, Brugg, aargau CHIC	CH
Power to flex	DE
Primolyzer (R&D)	DK
PROCON (R&D)	DK
PtG-Elektrolyse im MW-Maßstab (R&D)	DE
PURE Project, Unst	UK
PVFCSYS Agrate	IT
PVFCSYS Sophia Antipolis	FR
RABH2	UK
Raglan Nickel mine	CA
Ramea Wind-Hydrogen-Diesel Project	CA
Rapperswil	CH
Reduction and Reuse of CO2: Renewable Fuels for Electricity Production- ZHAW	CH
REFHYNE	DE
REFLEX	IT
Regenerativer Energipark Ostfalia/hybrid renewable energy park (HREP)	DE
RegEnKibo, Kirchheimbolanden	DE
Regio Energie Solothurn/Aarmat hybrid plant	CH
RENOVAGAS	ES
RES2H2 Gran Canaria	ES
RESelyser (R&D)	EU
Reussenköge	DE
RH2 WKA	DE
Rostock, Exytron Demonstrationsanlage	DE
Rozenburg	NL
RWE PtG plant Ibbenbüren	DE
Samsø	DK
SAPHYS, ENEA	IT
Schatz Solar Hydrogen Project	US
SEE / Storage of electric energy	DE
Sir Samuel building Griffith Center, Brisbane, Australia	AU
Small Scale Renewable Power System DRI (Desert Research Institute)	US
SoCalGas/Southern California Gas	US
Solar-H2 Taleghan	IR
SPHYNX, R&D	FR
Stand-alone power system, Neo Olvio of Xanthi	GR
STORE And GO, Troia Italy	IT
Sunfire PtL demo "Fuel1"	DE

SWB Project, Neuburg vorm Wald	DE
SYNFUEL	DK
Tauron CO2-SNG	PL
The Hydrogen house	US
The Hydrogen office	UK
THEUS H2 Energy Storage, Takasago	JP
Thüga PtG plant Frankfurt/Main	DE
Tohoku pilot plant in 2003	JP
Towards the Methane Society	DK
Utsira Island	NO
Vestenskov/ Nakskov Industrial and Environmental Park, Lolland	DK
WELTEMP, Water electrolysis at elevated temperature	EU
Wind2H2 Project NREL	US
Wind2Hydrogen, HyCentA	AT
Wind-H2 stand-alone system ENEA	IT
Wind-H2 Village Prince Edward Island	CA

Appendix 2: List of indicators.

% Av. data provides information about the percentage of demonstrations for which data was available and so the indicator was filled in.

Indicator	% Av. data
Total number of demos	100%
Type of application	99%
Nb of demos completed	73%
Nb of ongoing demos	73%
Nb of demos vs start date	99%
Duration of demo	62%
Nb of demos including services	84%
Alkaline capacity MW	85%
PEM capacity MW	79%
SOEC capacity MW	85%
Nb of Alkaline demos	86%
Nb of PEM demos	86%
Nb of SOEC demos	86%
On-grid supply	76%
Off-grid supply	76%
On-grid + RES supply	76%
Nb of demos with wind supply	63%
Nb of demos with solar supply	60%
Installed wind capacity (MW)	63%
Installed solar capacity (MW)	60%
Supply scheme: All-in	63%
Supply scheme: Excess RES	63%
Demos incl. Storage option	74%
Shares of CHG storage	69%
Shares of MH storage	69%
Shares of CHG + MH storage	69%
Shares of CNG/CH4 storage	69%
Shares of Salt cavern storage	69%
Baseload H2 production	31%
Flexible H2 production	31%
Demos with tech. Obj. only	81%
Demos incl. Econ. Obj.	81%
Operation validation obj	83%
Efficiency obj	83%
Upscaling obj	83%
Pathway focus obj	83%
Regulatory obj	83%
Lobbying obj	83%
H2 production cost obj	81%
Nb of demos with upscaling plan	70%
Nb of demos connected to other demos	78%
Nb of demos connected to a roadmap	71%
TRL	36%
MRL	29%