e-HIGHWAY 2050

Modular Development Plan of the Pan-European Transmission System 2050

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WP 3	**Technology portfolio to meet the 2050 scenarios**		

Annex to D3.1 - Technology Assessment

Note on impacts of ICT on the pan-European Power System up to the 2050 Time Horizon

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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CO	Confidential, only for members of the consortium (including the Commission Services)	

Document information

General purpose

This document is an additional note contributing to Task 3.2 of the e-Highway2050 project. It includes the assessment and outlook of the Power-to-Gas technology (P2G) whose description was requested by some of the e-Highway2050 partners.

Change log

Revision	Date	Changes description	Authors
V1	22 December 2015	Creation	Technofi
V2	15 January 2016	Final version	Technofi

Legal disclaimer

The present report reflects the best knowledge of Technofi's experts at the time of writing.

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This note intends to provide a short overview on an additional technology identified by the e-Highway2050 partners in complement to the available technology portfolio.

The note focuses on the description, the main functions with regard to the future energy system, the degree of readiness and the costs of P2G technologies.

1 Introduction

In the general context of the transition towards a cleaner and more sustainable energy system in 2050 in Europe, the challenge of increasing the overall flexibility in the pan-European energy system is a central issue. Among the various solutions such as demand response, dynamic operation of the assets or electricity storage, the power-to-gas (P2G) concepts present several advantages since it allows to transfer energy to other networks (gas) and as a consequence it contributes to the sustainability of other downstream sectors such as industry or mobility.

Power-to-gas is defined as the conversion of electrical power into hydrogen. The concept offers various applications, cf. Figure 1:

- electricity storage (hydrogen can be converted back to electricity with a fuel cell),
- accommodation in the gas infrastructure, by direct injection of hydrogen or by conversion of hydrogen and carbon dioxide into methane (which allows large-scale storage of energy with already existing infrastructures)
- use of hydrogen in industry or as a fuel in the transport sector.

In the particular context of transmission planning in Europe, Power-to-gas can be considered as an alternative solution to overcome problems which could occur more frequently in the electricity sector. The electricity in excess transformed into hydrogen could then be reconverted in electricity, stored, converted into methane, or simply used. P2G appears a suitable future large scale and longtime storage technology.

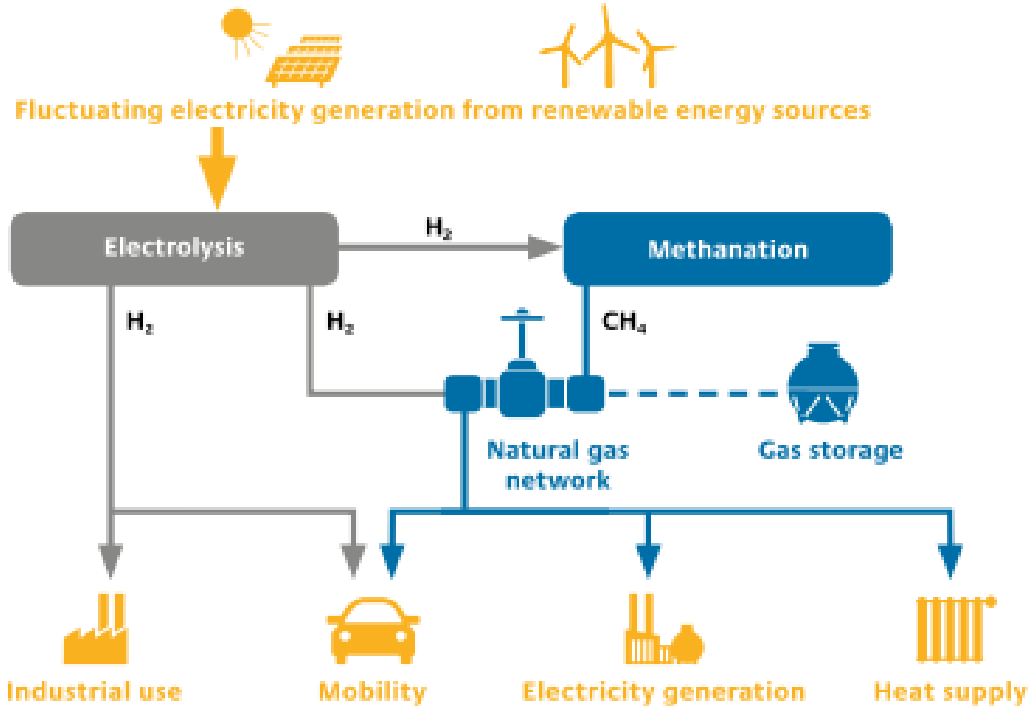

Figure 1 : Power to gas: conversion of renewable energy sources to hydrogen and methane and their uses (source: dena [6])

The implementation of a P2G concept in an energy system requires further analysis of the potential and conditions of implementation leading to case studies in a given energy context.

2 Overview of the technology

P2G refers to the conversion of electrical power into a gaseous energy carrier like hydrogen or methane. The production chain includes electrolysis and possibly methanation:

- Electrolysis is the conversion of electricity into hydrogen from water;
- Methanation refers to the synthesis process of hydrogen and carbon dioxide.

2.1 Water electrolysis

Water hydrolysis is the core process of the P2G concept. Three electrolysis processes are available:

- Alkaline water electrolysis: alkaline liquid electrolyte;
- PEM electrolysis: acidic or polymer electrolyte membrane (PEM) electrolysis with a polymeric solid electrolyte;
- High-temperature steam electrolysis using Solid Oxide Electrolytes.

Alkaline electrolysis is a mature technology well adapted to continuous industrial processes (TRL9) and requires optimization to meet the flexibility needs in terms of ramping up and down created by the intermittency of power resources. The electrolysis manufacturers have redeployed their efforts towards the PEM electrolysis which is better suited to meet the technical flexibility requirements but is at lower maturity level (TRL 5 to 7) [1]: experts consider that there is a need for further research and development to make PEM electrolysers industrially available, particularly with regard to the use of suitable materials and process engineering [dena, 2015]. The Solid Oxide Electrolysis (SOE) alternative has been developed for steady state operations and is thus less suitable for flexible operations: its maturity is the lowest of the three options.

A synopsis of advantages and disadvantages is reported in the table below.

Table 1 : Advantages and disadvantages of relevant electrolysis technologies [1]

Advantage	**Disadvantage**
Commercial technology (high technology readiness level)	Limited cost reduction and efficiency improvement potential
Low investment electrolyser	High maintenance intensity
Large stack size	Modest reactivity, ramp rates and flexibility (minimal load 20 %)
Extremely low hydrogen impurity (0,001 %)	Stacks < 250 kW require unusual AC/DC converters
	Corrosive electrolyte deteriorates when not operating nominally
Proton Exchange Membrane Electrolysis (PEME)	
Advantage	**Disadvantage**
Reliable technology (no kinetics) and simple, compact design	High investment costs (noble metals, membrane)
Very fast response time	Limited lifetime of membranes
Cost reduction potential (modular design)	Requires high water purity
Solid Oxide Electrolysis Cell (SOEC)	
Advantage	**Disadvantage**
Highest electrolysis efficiency	Very low technology readiness level (proof of concept)
Low capital costs	Poor lifetime because of high temperature and affected material stability
Possibilities for integration with chemical methanation (heat recycling)	Limited flexibility; constant load required

Some key techno-economic parameters are provided by dena, 2015 for the two first options. The technology roadmap on power to gas technology built by dena establishes a cost target of the CAPEX of electrolysis to be reduced to a level of 500 €/kW by 2022 resulting from scaling-up effect. In parallel, R&D efforts focus on PEM electrolysis both in terms of materials and process engineering.

Table 2 : Techno-economic parameters of two water electrolysis technology options (dena, 2015) [6]

Properties	Alkaline electrolysis	PEM electrolysis
Investment costs	800 to 1 500 €/ kW	2 000 to 6 000 €/ kW
Efficiency relative to upper calorific value	67 to 82 %	44 to 86 %
Specific energy consumption	4 to 5 kWh /Nm3 H2	4 to 8 kWh /Nm3 H2

2.2 Methanation

In P2G applications, methanation is a downstream process of electrolysis which enables to produce a synthetic natural gas with similar combustion properties as for fossil natural gas. This synthetic natural could meet higher requirements in terms of quality (very relevant for some industries: car, ceramic, glass).

Methanation is the catalytic conversion of hydrogen and carbon dioxide into methane. CO_2 or CO is needed for the catalytic conversion into methane. Capturing CO_2 being an energy intensive process, the capture process impacts the energy efficiency of the methanation process: typical CO_2 sources can be the atmosphere, biomass, biogas, sewage units and fossil fuel driven power plants combined with CCS (carbon capture and storage).

The methanation process can be done chemically or biologically based on the same chemical reaction.

- Chemical methanation is a mature technology widely deployed in different industrial applications. The energy efficiency is in the range of 70% to 85%, (15% - 30% consumed as high temperature heat);
- Biological methanation follows the same reaction at lower temperature ranges. Its maturity is considered as pre-commercial (demonstrations are needed to validate the MW scale-up potential of the technology). Two key advantages are highlighted by manufacturers: the ability to respond within seconds in its full power range and the very high efficiency (over 95%).

Methanation can therefore be considered currently in demonstration phase (TRL 5-7) in the context of hydrogen processes due to the challenging requirement to follow intermittent hydrogen production. For steady industrial processes methanation is a mature technology (TRL 9).

3 Technology readiness and maturity

All in all when considering all P2G technological blocks according to a development curve the following data is available [11].

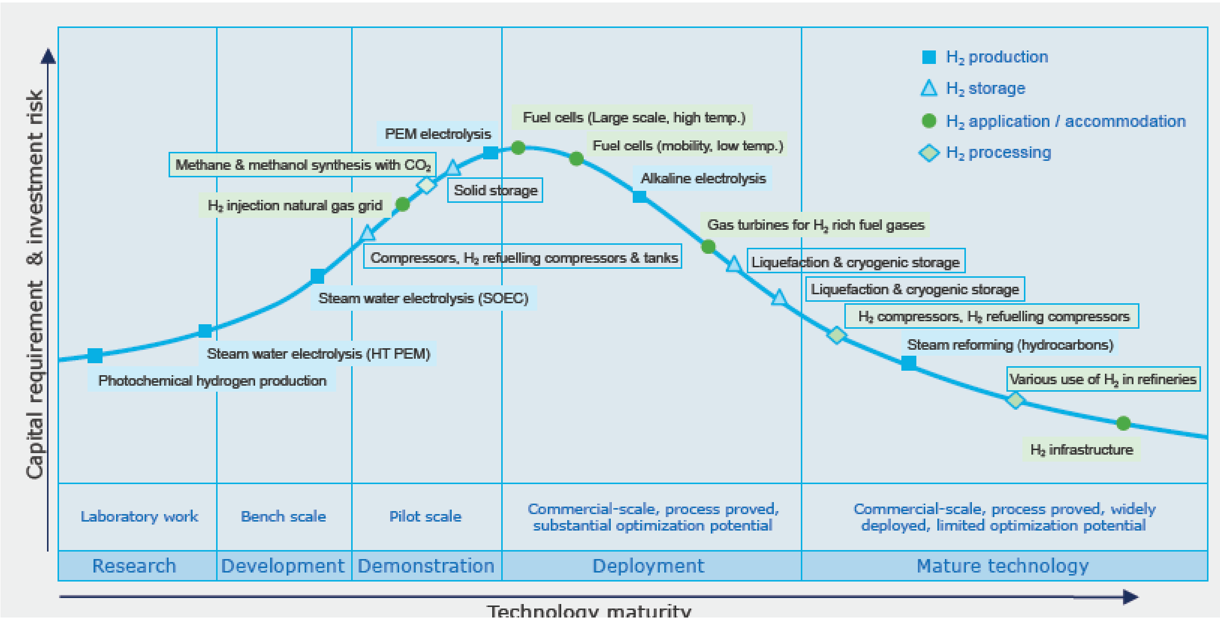

Figure 2 : Development curve of P2G technologies and hydrogen application [11]

A complementary view is proposed by [12].

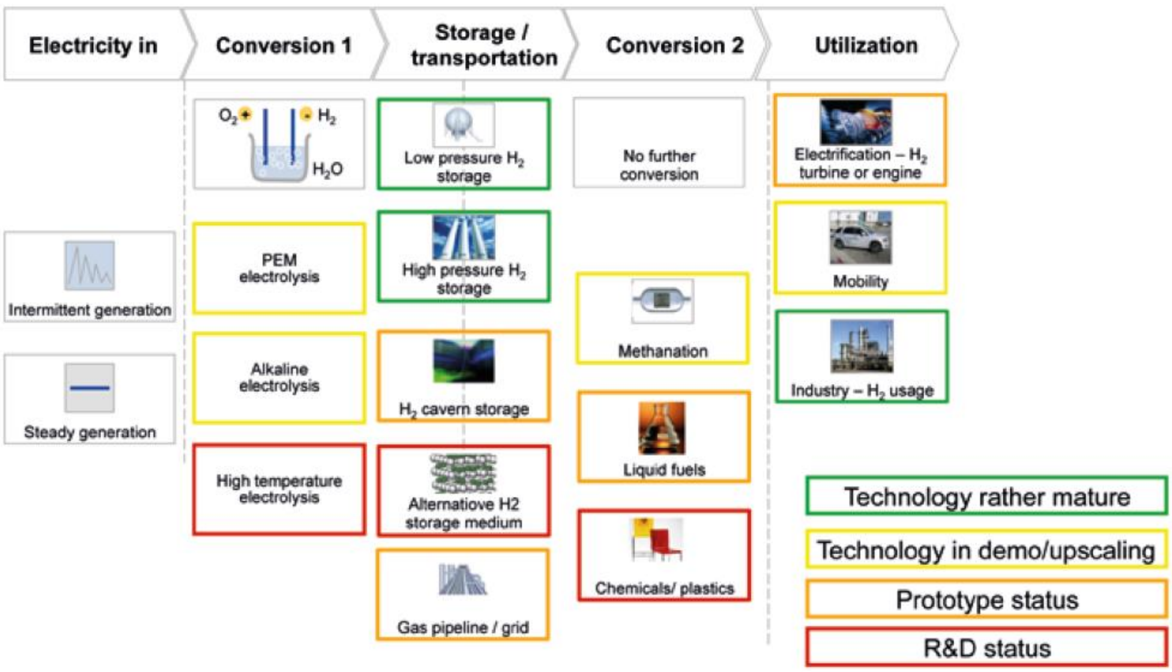

Figure 3 : technical maturity of various parts of the chemical storage components

A particular R&D need identified by manufacturers in the roadmap of P2G is the improvement of the round trip efficiency "electricity-gas-electricity": it depends on the operating method and on the performance variables and is at a maximum of 40% considering the efficiency of:

- The electrolysis process: about 80% of the input energy is converted into hydrogen; (heat losses lower efficiency);
- The methanation process whose efficiency could reach about 80%, provided that waste heat is used as well.

4 Costs

4.1 System economics

4.1.1 Maturity and economy of scale of technology components impact CAPEX and OPEX

Investment costs for P2G units are substantial. Depending on plant size, costs can amount to 2,500 – 3,500 €/kW of electric power (€/kWel) or 1,500 €/kWel for alkaline electrolysis [6]. Both processes are subject to economies of scales as shown in the figures hereafter. It should be noted that for large plant, the share of methanation in the total CAPEX could be relatively small.

Regarding the level of OPEX, it could be lowered for the chemical methanation process if the produced heat produced (200°C-500°C) can be valorized. In general, the valorization of all process by-products could result in improved business cases.

4.1.2 Allowable hydrogen fraction in the natural gas network

Depending on the considered application, this parameter could play a critical role on system economics since it impacts the hydrogen storage potential. Indeed adding hydrogen to the natural gas may have undesirable effects in end-use equipment and on the thermal properties of the resulting fuel.

4.1.3 Efficiency and losses

The system economics is impacted by the level of energy efficiency of each process and by the overall efficiency of the whole cycle “electricity-gas-electricity” reaching about 40%.

4.1.4 Location

Depending of the business model of the P2G plant, location can highly impact the costs. It is driven by the possible access to the electric and gas networks, as well as the sources of reactants. For instance, the proximity of sources of CO2 is critical for a plant including a methanation process.

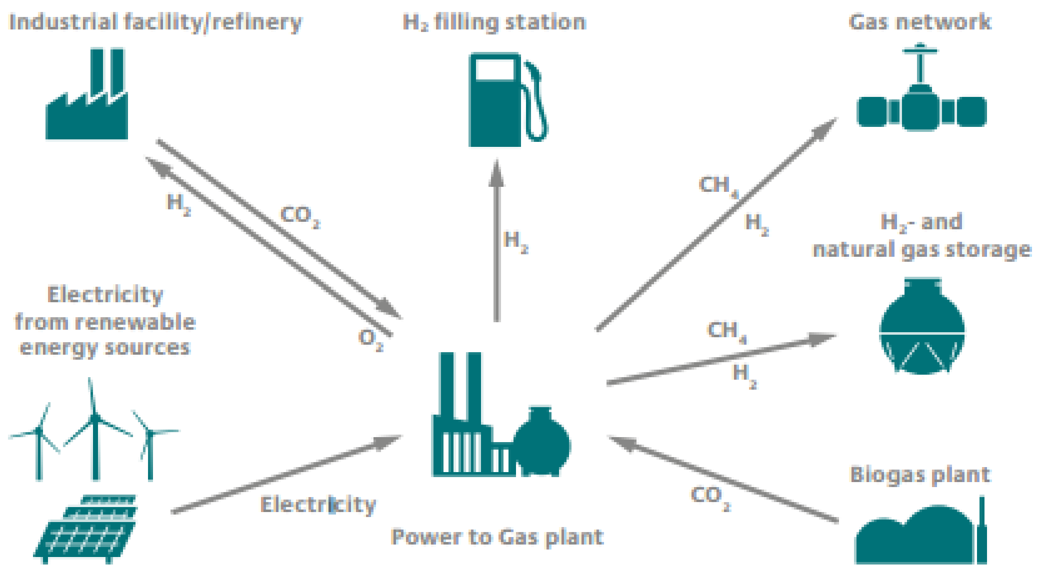

Figure 4 : P2G location factors [6]

4.2 Water electrolysis

The figure below depicts the capital costs of water electrolysis as seen by KEMA in 2013 for the two technological options: alkaline and PEM.

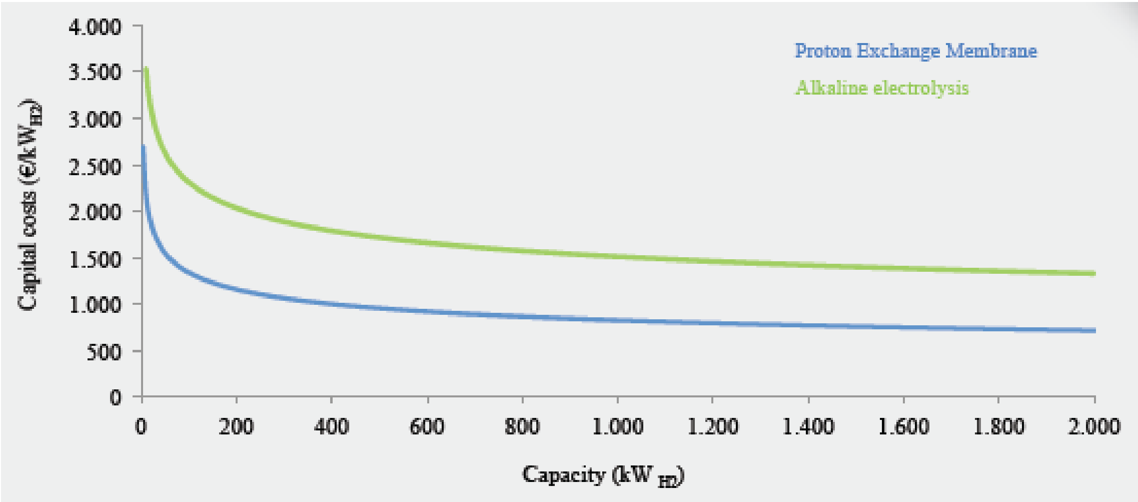

Figure 5 : CAPEX of electrolysis (PEM curve is a prediction of future costs) [1]

4.2.1 Alkaline water electrolysis costs

When focusing on alkaline electrolysis costs (CAPEX and OPEX) the same source has made an appraisal of such costs based on cost data and studies from several authors[1].

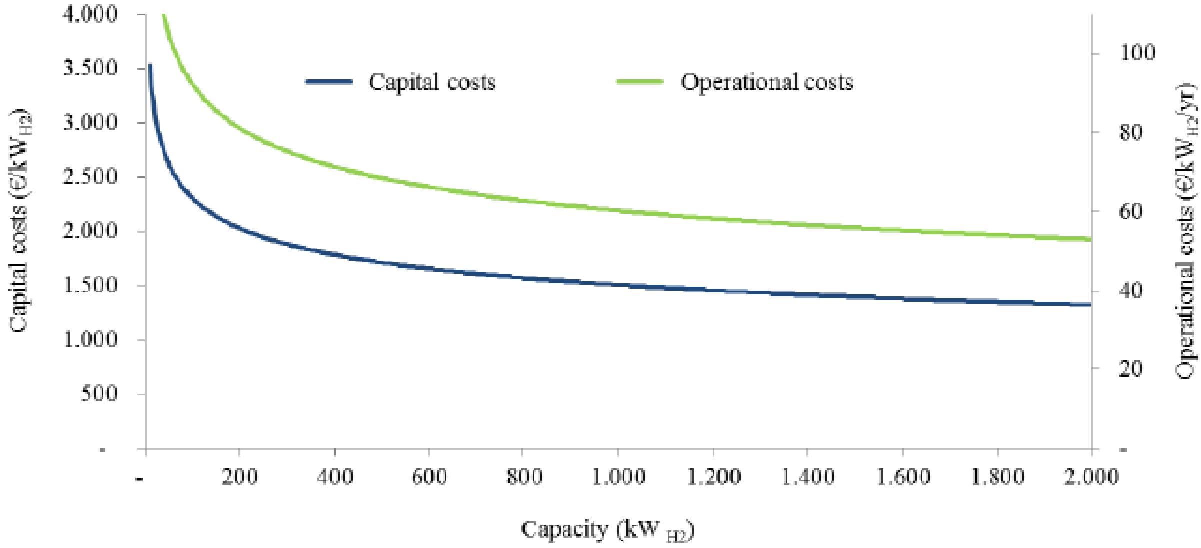

Figure 6 : CAPEX and OPEX of alkaline electrolysis (in €2011) [2]

[1] Weinert, 2005; Greiner et al., 2007; Ewan & Allen, 2005; Hydrogen Technologies, 2011; Angstrom, 2011; Smolinka, 2011 reported in [2]

4.2.2 PEM water electrolysis costs

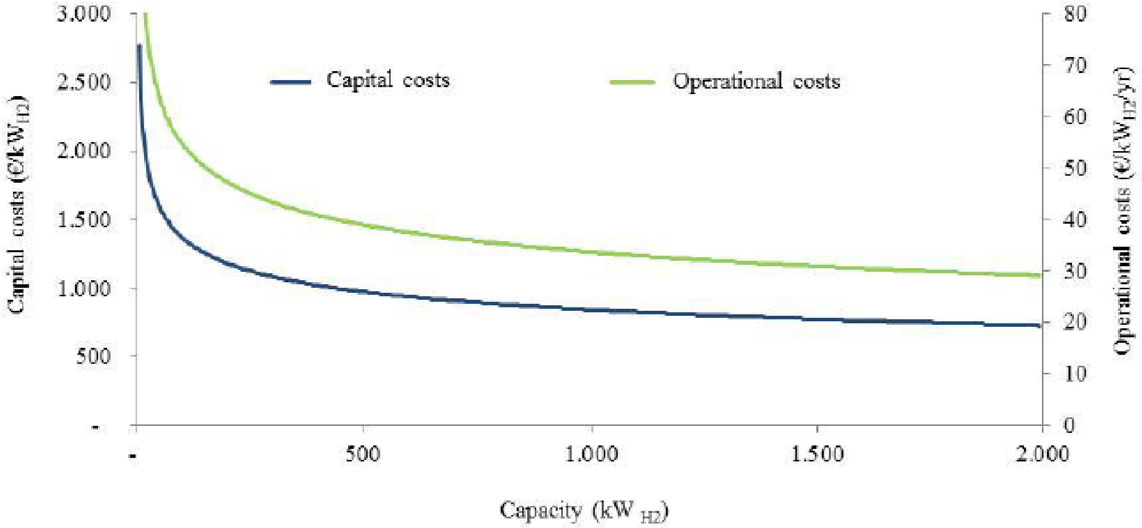

Figure 7 : Future (>2020) projected CAPEX and OPEX of PEM electrolysis (in €$_{2011}$) based on Smolinka 2011, reported in [2]

4.3 Methanation

The CAPEX function of capacity is depicted in the figure below.

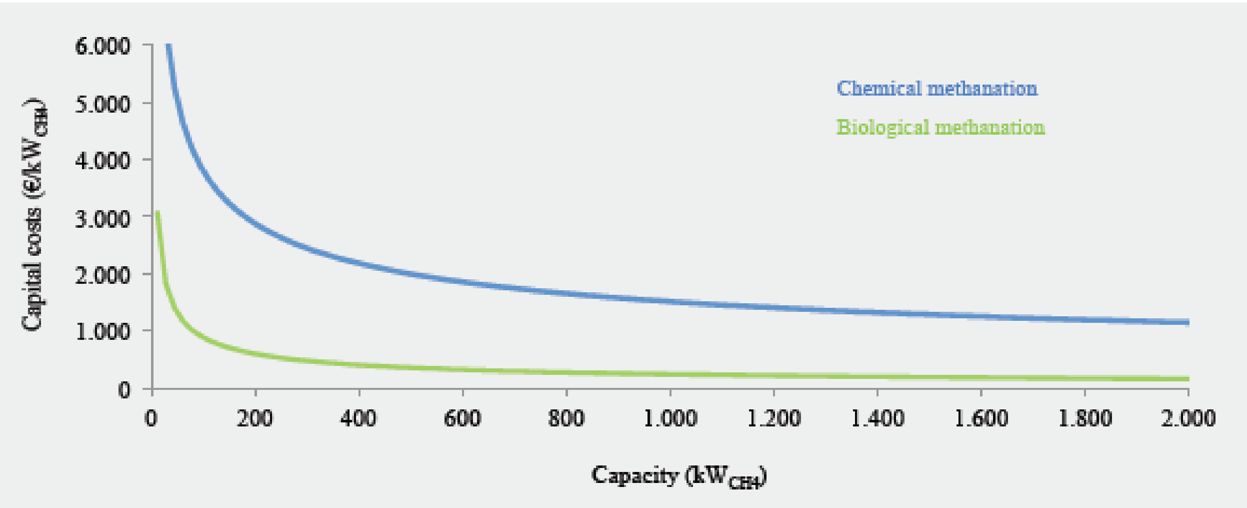

Figure 8 : CAPEX of methanation **[2]**

4.3.1 Chemical methanation costs

When focusing on chemical methanation costs (CAPEX and OPEX) the same source has made an appraisal of such costs

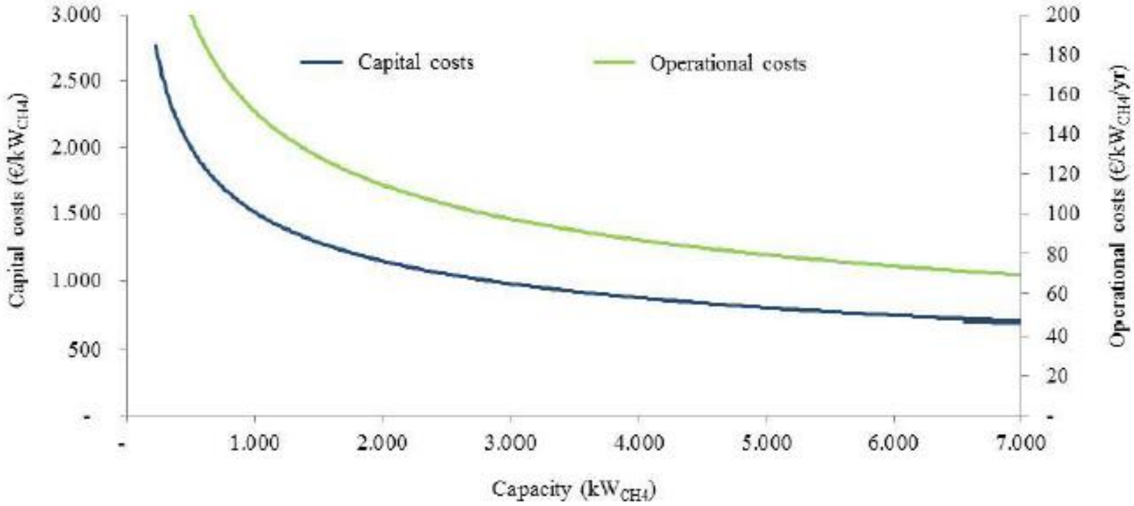

Figure 9 : CAPEX and OPEX of chemical methanation plants ***[2]***

4.3.2 Biological methanation costs

The same authors elaborated the economics of such process (CAPEX and OPEX) based on Krassowski, 2012 [13].

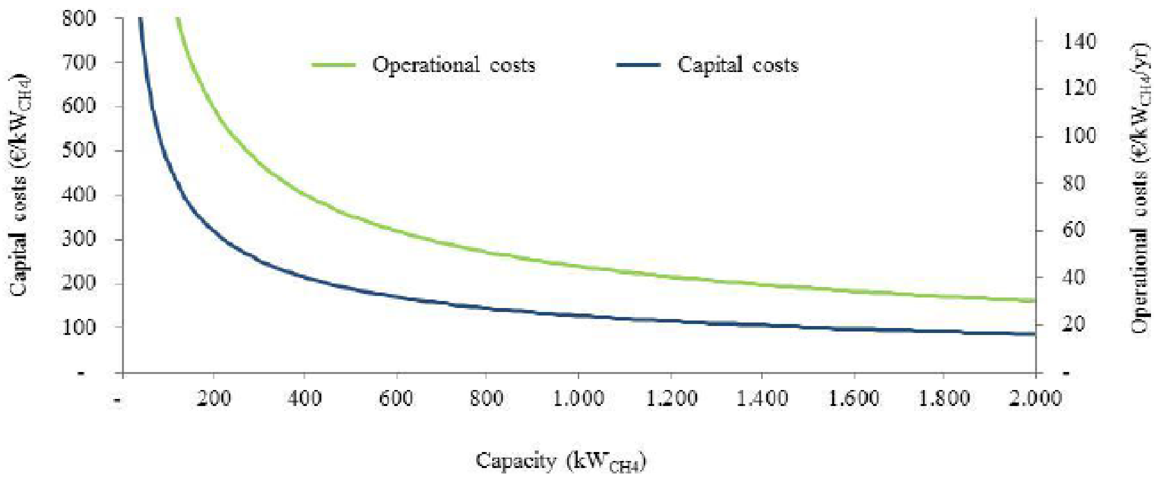

Figure 10 : CAPEX and OPEX of biological methanation plants (€2011) [Krassowski, 2012], reported in [2]

5 Conclusions

Several business cases could be considered based on Power-to-gas plants thanks to the technical flexibility of the above described water electrolysis and methanation technologies.

Some components are still in R&D stage and combined efforts of manufacturers and economies of scale should lead to significant cost reduction and increased efficiency. A regulatory and fiscal debate is also on-going on the issue to consider P2G facilities as non-final customers (and to exempt them from subsequent taxes).

With regard to the e-Highway2050 context, Power-to-Gas should be considered as an option creating additional flexibility for the transmission system in an alternative manner, most likely complementary to the grid architectures resulting from the project by allowing massive storage of energy in the existing hydrogen and natural gas networks (this chemical energy could also be used in various applications including transport and energy production).

A quantitative impact of such influence, especially for some scenarios (e.g. 100% RES) may be the object of further studies[2].

6 References

[1] Lukas Grond and Jojan Holstein. Power-to-gas: climbing the technology readiness ladder. Reports Power to gas. Gas for energy Issue 2/2014.

[2] Grond, L.J.; Holstein, J. and Schulze, P.: DNV KEMA (2013) Systems analysis power-to-gas; Technology Review.

[3] De Joode J.; Daniëls B.; Smekens K.; Van Stralen J.; Dalla Longa F.; Schoots K.; Seebregts A.; Grond, L.J.; Holstein, J Exploring the role for power-to-gas in the future Dutch energy system. Final report of the TKI power-to-gas system analysis project. July 2014. ECN-E-14-026.

[4] NorthSea Power to Gas Platform website: www.northseapowertogas.com

[5] Strategieplatform Power to gas website: www.powertogas.info

[6] Dena. Power to gas system solution. Strategie platform Power to gas. 2015. http://www.powertogas.info/fileadmin/content/Downloads/Broschüren/dena_PowertoGas_2015_engl.pdf

[7] http://europeanpowertogas.com/documents

[8] Commercialisation of Energy Storage in Europe. A fact-based analysis of the implications of projected development of the European electric power system towards 2030 and beyond for the role and commercial viability of energy storage. Final report, March 2015

[9] North Sea Power to Gas Platform. Extended Flexibility Study. Power to gas potential from curtailment in 2025 and 2030. Public version. Thijs Slot, Pieter van der Wijk, DNV-GL. 2014.

[10] Bertuccioli L. (E4tech); Chan A. (Element Energy); Hart D.(E4tech); Lehner F. (E4tech); Madden B. (Element Energy); Standen E. (Element Energy). Fuel cells and hydrogen Joint undertaking. Development of Water Electrolysis in the European Union. Final Report. 7 February 2014.

22 *See for example flexibility studies such as [9]*

[11] SBC Energy Institute (2014) Fact book – Hydrogen based energy conversion. More than storage: system flexibility.
[12] Joint EASE/EERA recommendations for a European Energy Storage Technology Development Roadmap towards 2030. Technical Annex.2013.
[13] Krassowski, J. Power-to-gas Technologien als Baustein in einem regenerativen Energysystem – Ansätze zur Systemintegration in der Altmark, 30 May 2012