



Potential of Power-to-Methane in the EU energy transition to a low carbon system using cost optimization

Herib Blanco^{a,b,*}, Wouter Nijs^{b,1}, Johannes Ruf^c, André Faaij^a

^a Center for Energy and Environmental Sciences, IVEM, University of Groningen, Nijenborgh 6, 9747 AG Groningen, The Netherlands

^b European Commission, Joint Research Centre, Directorate C – Energy, Transport and Climate, Knowledge for the Energy Union, Westerduinweg 3, NL-1755LE Petten, The Netherlands

^c DVGW Research Centre at Engler-Bunte-Institute (EBI) of Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

HIGHLIGHTS

- Scenarios show up to 546 GW PtM capacity with 27 of 55 of them above 40 GW.
- Large PtM capacity (~550 GW) can be deployed with limited impact on system cost.
- System drivers favoring PtM are low CO₂ storage potential and > 60% VRE penetration.
- System drivers exert more influence over PtM potential than technology drivers.

ARTICLE INFO

Keywords:

TIMES
Energy system model
Power-to-gas
Hydrogen
CO₂ utilization
Methanation

ABSTRACT

Power-to-Methane (PtM) can provide flexibility to the electricity grid while aiding decarbonization of other sectors. This study focuses specifically on the methanation component of PtM in 2050. Scenarios with 80–95% CO₂ reduction by 2050 (vs. 1990) are analyzed and barriers and drivers for methanation are identified. PtM arises for scenarios with 95% CO₂ reduction, no CO₂ underground storage and low CAPEX (75 €/kW only for methanation). Capacity deployed across EU is 40 GW (8% of gas demand) for these conditions, which increases to 122 GW when liquefied methane gas (LMG) is used for marine transport. The simultaneous occurrence of all positive drivers for PtM, which include limited biomass potential, low Power-to-Liquid performance, use of PtM waste heat, among others, can increase this capacity to 546 GW (75% of gas demand). Gas demand is reduced to between 3.8 and 14 EJ (compared to ~20 EJ for 2015) with lower values corresponding to scenarios that are more restricted. Annual costs for PtM are between 2.5 and 10 bln€/year with EU28's GDP being 15.3 trillion €/year (2017). Results indicate that direct subsidy of the technology is more effective and specific than taxing the fossil alternative (natural gas) if the objective is to promote the technology. Studies with higher spatial resolution should be done to identify specific local conditions that could make PtM more attractive compared to an EU scale.

1. Introduction

Anthropogenic emissions need to be drastically reduced if the increase in global temperature is to be maintained within 1.5 °C compared to pre-industrial times. Global emissions need to be cut by more than 50% by 2050 (vs. 2010) with developed countries carrying out a larger change [1]. Key components to achieve this target are energy efficiency, renewable energy sources (RES) including biomass and carbon capture and storage (CCS). Wind and solar² are identified as

crucial technologies for the early stages of the transformation. A disadvantage they have is their great variability in time and space. Therefore, there is a need for complementary alternatives to provide flexibility to the system and compensate their fluctuations. Power-to-Gas (PtG) arises as option to satisfy this need. PtG implies the conversion of Power-to-Hydrogen, which can be subsequently used as energy carrier (i.e. hydrogen economy [2–4]) or as reactant for further compounds (e.g. methane, methanol, long chain hydrocarbons). Typical efficiencies (energy output vs. energy input) are 65–75% for Power-to-

* Corresponding author at: Center for Energy and Environmental Sciences, IVEM, University of Groningen, Nijenborgh 6, 9747 AG Groningen, The Netherlands.
E-mail address: H.J.Blanco.Reano@rug.nl (H. Blanco).

¹ The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

² Referred in the rest of the document as VRE = Variable Renewable Energy.

Hydrogen (electrolysis), 75% for hydrogen to methane [5,6] (HHV). The term PtG refers to the conversion of Power-to-Hydrogen and methane (both gases) and for that reason PtM will be used henceforth to refer to methane. Key advantages of PtM are: (1) It allows converting power into a commodity that can be used to reduce CO₂ emissions in other sectors; (2) It uses existing infrastructure; (3) When considered as storage option, it has a high energy density (CH₄ has > 1000 kWh/m³ while hydrogen has 270 kWh/m³ and pumped hydro storage has 0.7 kWh/m³ and [7]) and over 1000 TWh of storage capacity already deployed and operating; (4) It is suitable for long term and large scale storage.

Nevertheless, the technology does not come without challenges. Currently, it is in the early stages of development (Technology Readiness Level – TRL [8–10] 5–7 [11,12]) and more research is needed to de-risk it and promote its large scale deployment. Economically, it needs a low electricity price (< 10 €/MWh [13,14]), low specific CAPEX (currently up to 1500 € per installed kW of synthetic gas [13,15]) and high number of operational hours (> 3000 h to reduce the CAPEX contribution to the cost) to reach a similar price as fossil-derived natural gas including additional costs (e.g. CO₂ certificates). Environmentally, it needs a low electricity CO₂ footprint [16–19] (< 50 gCO₂e/kWh) to represent a better alternative than fossil gas and lead to net CO₂ reduction. These conditions make the use of biogenic CO₂ and power from renewable sources the best sources for its process inputs.

This study aims to explore alternative low CO₂ emission scenarios (reduction targets of > 80%), where it is envisioned that PtM will play a key role and understand better the drivers that promote its use in the energy system. The approach chosen is cost optimization of the entire energy system looking at the longer term (2050) and at a large scale (European level). The reasons for this selection are: (1) PtM is a technology connecting various sectors and there lies the importance of looking beyond power; (2) Only in the long term low carbon scenarios will be achieved; (3) Most previous studies focus on a local or national scale with few considering the dynamics of the entire EU region and (4) Cost optimization is the first step to identify the most economically sustainable routes to meet energy demand. Some of the key insights that can be gained with this approach are: (1) RES fraction (or CO₂ reduction target) that makes PtM necessary (or result in a lower cost system); (2) Amount of PtM used in different scenarios (capacity and energy); (3) Difference in deployment due to different technology parameters (cost and efficiency); (4) Comparison with competing flexibility options (e.g. pumped hydro storage, batteries, demand side management (DSM), grid expansion, excess of installed capacity); (5) Additional system cost for presence/absence of the technology. To explore these issues, an energy system model is used, which allows analyzing the evolution of the capacity mix considering investment and operational components.

The energy model used is JRC-EU-TIMES [20], which covers the EU28 plus Switzerland, Norway and Iceland,³ where each member state (MS) is one region. Its temporal horizon is from 2010 to 2050 (although it can be used beyond this timeframe). To reduce calculation time, it uses hierarchical clustering into representative hours of a year (24 time slices for the power sector and 12 for others), when there are different levels and compositions of supply and demand. Prices for all commodities are endogenous considering the supply and demand options, demand elasticity and consumer and producer surplus. It covers 5 sectors (residential, commercial, industry, transport and agriculture). The approach followed is parametric analysis, where individual parameters are changed and their effect is evaluated on both the entire system and the specific technology.

Key questions that are answered in this study are: (1) What is the PtM capacity deployed in potential future low carbon scenarios for EU; (2) What are the conditions that promote PtM deployment; (3) How

does PtM compare with other flexibility options; (4) What is the effect PtM has on system cost and (5) What are the CO₂ sources that PtM uses when it is deployed in the energy system.

This study is structured in the following manner. Section 2 makes the comparison between the model used in this study and literature. Section 3 explains model topology and structure with focus on PtM. Section 4 is dedicated to the scenario definition. Section 5 discusses the results for the different scenarios and summarizes key outcomes. Finally, Section 6 highlights key conclusions, input for further studies and subsequent work.

2. Literature review and gaps

CO₂ methanation is currently not widely employed, with only a handful of pilot projects, most of them located in Germany (10 projects) and where the largest scale is 6 MW [21,22]. This technological approach has drawn interest in the last couple of years and power conversion to hydrogen only has been more thoroughly discussed [23–27]. Before a major technology rollout, further research, pilot and demonstration plants are required. CO methanation, on the other hand, is deployed in larger scale, however, often with fossil feedstock [21]. A review on PtM was recently done by the authors [28] including 66 studies on PtM and discussing 13 with a special emphasis on energy system models, which is the scope of the current study. Insights from these studies are included in Section 5 to put in perspective results from the current study. It has been identified that there are a set of features each model can cover, but there are trade-offs to be made to limit model complexity and calculation time, where no model includes all features. These are used to compare this study with previous ones and understand the remaining gaps. The different features are:

- *Hourly time step.* This allows better estimating the electricity surplus and hourly choices on options to manage it. It better captures generation flexibility (ramping of power plants) and storage role.
- *Capacity expansion.* Some models [14,29,30] focus on the operational component or use a simulation approach [31] without finding an optimal PtM capacity for a given scenario. Capacity constitutes an exogenous input rather than an output. This could lead to overestimating the role of PtM since the capacity used might not be needed.
- *Energy system coverage.* Some models [30,32–34] focus on the power sector and dealing with power surplus rather than using the surplus for other sectors (e.g. PtX⁴) or finding alternatives routes to deal with the gas demand. Therefore, the coverage should be the entire energy system instead of power only.
- *Grid expansion.* The model should be able to make the trade-off between using (or curtailing) power surplus and investing in the grid to find a sink far enough from the source. For this, the model should have both the investment component and at least a simplified grid representation.
- *Other flexibility options.* With more alternatives to accommodate fluctuations, there is a lower chance of overestimating PtM role. The model should cover as many as possible from: optimal wind/PV ratio (due to its complementary patterns [35–37], DSM, short and long term storage, grid expansion, flexible generation, PtX, to make sure the model has enough outlets for any possible electricity surplus.
- *Endogenous commodity prices.* PtM economic case is directly dependent on the prices for electricity/hydrogen and methane. These are determined by supply/demand dynamics. Models should capture dynamics that determine these prices rather than take them as exogenous assumptions.

³ Referred from this point onwards as “EU28+”.

⁴ PtX = Power-to-X = Power-to-Heat, Hydrogen, Methane, Methanol and other liquids.

Download English Version:

<https://daneshyari.com/en/article/11017558>

Download Persian Version:

<https://daneshyari.com/article/11017558>

[Daneshyari.com](https://daneshyari.com)