



Modelling of a power-to-gas system to predict the levelised cost of energy of an advanced renewable gaseous transport fuel



Shane McDonagh^{a,b,c}, Richard O'Shea^{a,b,c}, David M. Wall^{a,b}, J.P. Deane^{a,b}, Jerry D. Murphy^{a,b,*}

^a MaREI Centre, Environmental Research Institute, University College Cork, Ireland

^b School of Engineering, University College Cork, Ireland

^c Gas Networks Ireland, Cork, Ireland

HIGHLIGHTS

- LCOEs of €124/MWh in 2020, €105/MWh in 2030, and €93/MWh in 2040 were found.
- Electricity is by far the largest contributor to the LCOE of a P2G system.
- Zero cost electricity for 6500 h/annum leads to an LCOE of €55/MWh.
- A 20% fall in LCOE requires a drop of 76.2% in CAPEX or 35.9% in electricity costs.
- Integration, secondary incomes, and incentives are essential for competitive P2G.

ARTICLE INFO

Keywords:

Power-to-gas
Sensitivity analysis
LCOE
Energy storage
Hydrogen
Methane

ABSTRACT

Power to gas (P2G) has been mooted as a means of producing advanced renewable gaseous transport fuel, whilst providing ancillary services to the electricity grid through decentralised small scale (10 MW) energy storage. This study uses a discounted cash flow model to determine the levelised cost of energy (LCOE) of the gaseous fuel from non-biological origin in the form of renewable methane for various cost scenarios in 2020, 2030, and 2040. The composition and sensitivity of these costs are investigated as well as the effects of incentives and supplementary incomes. The LCOE was found to be €107–143/MWh (base value €124) in 2020, €89–121/MWh (base value €105) in 2030, and €81–103/MWh (base value €93) in 2040. The costs were found to be dominated by electricity charges in all scenarios (56%), with the total capital expenditure the next largest contributor (33%). Electricity costs and capacity factor were the most sensitive parameters followed by total capital expenditure, project discount rate, and fixed operation and maintenance. For the 2020 base scenario should electricity be available at zero cost the LCOE would fall from €124/MWh to €55/MWh. Valorisation of the produced oxygen (€0.1/Nm³ profit) would generate an LCOE of €105/MWh. A payment for ancillary services to the electricity grid of €15/MW_e for 8500 h p.a would lower the LCOE to €87/MWh. Price parity with diesel, exclusive of sales tax, is achieved with an incentive of €19/MWh.

1. Introduction

The Paris agreement (under COP21) has set a target of limiting the increase in global temperatures to less than 2 °C. To facilitate this, an 80% reduction in greenhouse gas (GHG) emissions by 2050 will most likely be required [1,2]. The reduction in GHG emissions will rely on decarbonisation of the energy sector, and a push for sustainable energy solutions to meet increasing energy demand through leverage of existing and future technologies.

As transmission system operators (TSO) aim to facilitate targets set under the Renewable Energy Directive (RED), renewable technologies

will be prioritised [3]. The ensuing decarbonisation of the energy system will increase the amount of variable renewable electricity (VRE) on the electricity grid. Increasing portions of VRE will pose challenges for the grid with regards to balancing, stability, and periods where supply exceeds demand [4,5]. Thus, the storage, flexibility, and balancing capabilities will need to increase with increased installed capacity of VRE, to ensure the reliability and safe operation of electricity supply [6,7]. Additional flexibility and grid stability requirements to facilitate increasing shares of VRE have been previously discussed in literature [4,5,8]. The task of matching supply with demand can lead to periods of curtailment, inefficient production, and potentially affect

* Corresponding author at: MaREI Centre, Environmental Research Institute, University College Cork, Ireland.
E-mail address: jerry.murphy@ucc.ie (J.D. Murphy).

security of supply [7,9,10]. Large scale and flexible energy storage options are seen as a means of reducing these effects [11].

Storage of otherwise curtailed electricity has typically been achieved through pumped hydroelectric storage (PHS) systems. PHS is a mature technology with a worldwide installed capacity of 143 GW, but is restricted by geography [12–14]. Other technologies such as compressed air energy storage and battery storage have also been mooted as important storage mechanisms in future electricity networks. Power-to-Gas (P2G) is an emerging technology that can utilise otherwise curtailed electricity and convert it to hydrogen (H₂) via electrolysis of water. The hydrogen can then be further combined with carbon dioxide (CO₂) to produce methane (CH₄) via a Sabatier reaction. The ability of P2G to absorb excess electricity and remove the requirement to “turn off” electricity power plants or “spill” renewable electricity facilitates VRE and allows for the provision of ancillary services [15,16]. It has been proposed as a means of storing excess electricity, adding stability to the electricity grid, an alternative to excessive grid expansion, and producing a substitute for natural gas [11,17–19]. Operating ideally, P2G facilitates higher shares of indigenous wind, wave, and solar energy offsetting the need for energy imports and abating GHG emissions [16,20,21]. A significant advantage of P2G as a form of energy storage is the change of the energy carrier from electricity to gas (either hydrogen or methane). Converting electrical energy into chemical energy allows for large-scale storage through existing gas grid infrastructure [6,22].

P2G systems (when the vector is methane) have superior storage capacities and discharge times to that of PHS through use of the natural gas grid [23]. For instance, the French national gas grid alone has a capacity of over 100TWh [24]. P2G does not require favourable geography nor large infrastructural changes in countries with existing gas networks [11]. Notable exceptions include the coupling of existing underground natural gas storage facilities with P2G to create Underground Storage of Hydrogen and Natural Gas (UHNG). In cases such as this, when the favourable geography exists it is taken advantage of [25]. Gaseous fuel from non-biological origin produced by P2G is designated as an advanced third-generation biofuel; such advanced biofuels are heavily promoted within the EU framework due to their low land use change, potentially low carbon intensity, and waste to energy/circular economy characteristics. Transport fuel suppliers are obliged to provide an increasing share of advanced renewable transport (excluding first generation biofuels from food crops), rising from 1.5% in 2021 to 6.8% in 2030. At least 3.6% of this must be from advanced biofuels (including gaseous fuel from non-biological origin) [26]. Gaseous fuel from P2G, injected to the natural gas grid, could thus be used as an advanced transport fuel in natural gas vehicles (NGVs) and in conjunction with guarantees of origin provide the required 70% emissions reduction as compared to the fossil fuel displaced (required by the RED and proposed amendments to ensure sustainability of biofuels beyond 2021) [27–29].

The state of the art in LCOE (Levelised Cost of Energy) of P2G

(methane) systems may be viewed in Table 1. A number of technology reviews of P2G with respect to working principles, relative advantages and disadvantages, and trends in technology have been provided in past literature [7,15,30–33]; estimates of system costs have also been detailed [15,30,34–37]. However, much uncertainty still remains with cost estimates varying substantially [6,32,34,36,38–40] from €75 to €600/MWh CH₄. It is the view of the authors' that anticipated cost reductions in the literature have not materialised to the extent predicted. The concept that electricity that would have been curtailed being available at a low-cost is not reflective of current electricity market data [30,41]. The innovation in this paper is that it advances upon previous cost estimates using a discounted cash flow model of the lifetime of a plant which accounts for maintenance costs and frequency, commissioning/decommissioning, fixed and variable operational expenditure and maintenance (OPEX), and real-world electricity market data. It also uses a plant lifecycle that optimises the replacement schedule of the components and the latest cost estimates for these.

The objectives of the paper are to:

- Assess the most appropriate technologies (electrolysis and methanation), and their associated specifications for use in a P2G system.
- Create a bespoke model that calculates the levelised cost of energy (LCOE) for P2G systems for a range of inputs, scenarios, and time periods.
- Investigate the relationships between various parameters and system LCOE through sensitivity analysis and examination of the cost composition of these.
- Calculate the required incentives to reach price parity with diesel as a transport fuel, and the effect sale of oxygen (produced through electrolysis) or grid services may have on LCOE.

2. Methodology

2.1. The Power-to-Gas (P2G) system

In this study, P2G is defined as the combination of electrolysis, to produce hydrogen, and methanation, to generate methane (by reacting carbon dioxide with hydrogen). In the envisaged system, the methane could be compressed and injected into the natural gas grid. It was also considered that the operation of the P2G plant may require temporary storage of hydrogen. Estimates for the variables outlined in Fig. 1 and used in the model are based upon an extensive literature review and are referenced appropriately. Where several estimates existed, or there were large differences in the quoted values, average figures were calculated and used. Similarly, where estimates were found for time periods outside of those being investigated, figures were extrapolated backward or forward. It is postulated that this method of avoiding the use of a single set of figures minimises the risk of over or under accounting for costs specific to one piece of research, and allows for more accurate approximations of component costs and performance. Values

Table 1
State of the art in LCOE of P2G systems.

LCOE (€/MWh CH ₄)	Assumptions (Year of reference)	Run hours (p.a.)	Electricity cost (€/MWh)	Reference
600	Integration with a lignite power plant. 80MW _e input. (2012)	1200	N/A	Buchholz et al. [42]
190–316	Heat and O ₂ utilisation not included. (2014)	3000	25	E&E Consultants [24]
132–245	Biological methanation as novel upgrading. Compression and grid injection (2016)	N/A	50	Vo et al. [43]
141–236	Heat and O ₂ utilisation not included. (2013)	8600	45	Benjaminsson [30]
210	Coupled with 5 MW biogas production. No heat or O ₂ valorisation. (2014)	3000	50	Graf et al. [41]
185	10 MW _e input. Tax free electricity. Compression and injection included. (2015)	7800	60	ENEA [35]
170	10MW _e input. Tax free electricity. Compression and injection included. (2015)	8600	40	ENEA [35]
143–150	P2G upgrading, biological methanation with and without prior CO ₂ separation. (2016)	7920	100	Vo et al. [44]
92–113	Heat and O ₂ utilisation not included. (2015)	3000	25	E&E Consultants [24]
95	10MW _e input. Tax free electricity. Compression and injection included. (2015)	6100	15	ENEA [35]
75	Revenue of €10/tonne O ₂ included. (2015)	5000	50	Vandewalle et al. [34]

Download English Version:

<https://daneshyari.com/en/article/6680666>

Download Persian Version:

<https://daneshyari.com/article/6680666>

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