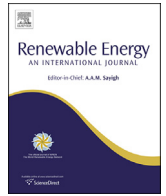




Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Review

Renewable Power-to-Gas: A technological and economic review

Manuel Götz^{a, *}, Jonathan Lefebvre^b, Friedemann Mörs^a, Amy McDaniel Koch^a,
Frank Graf^a, Siegfried Bajohr^b, Rainer Reimert^b, Thomas Kolb^b

^a DVGW Research Center at the Engler-Bunte-Institute of the Karlsruhe Institute of Technology (KIT), Engler-Bunte-Ring 1, 76131 Karlsruhe, Germany

^b Karlsruhe Institute of Technology, Engler-Bunte-Institute, Fuel Technology, Engler-Bunte-Ring 1, 76131 Karlsruhe, Germany

ARTICLE INFO

Article history:

Received 6 March 2015

Received in revised form

15 June 2015

Accepted 24 July 2015

Available online xxx

Keywords:

Power-to-Gas

Electrolysis

Methanation

SNG

Renewable energy

ABSTRACT

The Power-to-Gas (PtG) process chain could play a significant role in the future energy system. Renewable electric energy can be transformed into storable methane via electrolysis and subsequent methanation.

This article compares the available electrolysis and methanation technologies with respect to the stringent requirements of the PtG chain such as low CAPEX, high efficiency, and high flexibility.

Three water electrolysis technologies are considered: alkaline electrolysis, PEM electrolysis, and solid oxide electrolysis. Alkaline electrolysis is currently the cheapest technology; however, in the future PEM electrolysis could be better suited for the PtG process chain. Solid oxide electrolysis could also be an option in future, especially if heat sources are available.

Several different reactor concepts can be used for the methanation reaction. For catalytic methanation, typically fixed-bed reactors are used; however, novel reactor concepts such as three-phase methanation and micro reactors are currently under development. Another approach is the biochemical conversion. The bioprocess takes place in aqueous solutions and close to ambient temperatures.

Finally, the whole process chain is discussed. Critical aspects of the PtG process are the availability of CO₂ sources, the dynamic behaviour of the individual process steps, and especially the economics as well as the efficiency.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

In its Renewable Energy Roadmap 21, the European Commission has proposed a target of 20% renewable energy in the EU's overall energy mix by 2020 [1]. Thereby, wind and solar energy play an important role. In 2013, wind power had already comprised a high share of the electricity supply. In Denmark (34%) and Spain (21%), wind energy has become the largest source of electricity; also Portugal (>20%), Ireland (>16%), and Germany (9%) have reached high shares [2]. The total world installed wind capacity increased from 17,400 MW in 2000 to 318,105 MW in 2013 [3]. However, wind and solar energy are fluctuating and intermittent and have to be balanced for electric grid stability purposes. Consequently, long term and large capacity electricity storage is required, as well as reserve production capacity. In Germany, e.g., the residual power capacity is estimated to be 30–60 GW.

The Power-to-Gas (PtG) technology might contribute to tackling this issue. The PtG process links the power grid with the gas grid by converting surplus power into a grid compatible gas via a two-step process: H₂ production by water electrolysis and H₂ conversion with an external CO or CO₂ source to CH₄ via methanation (Fig. 1). The resulting CH₄, known as substitute natural gas (SNG), can be injected into the existing gas distribution grid or gas storages, used as CNG motor fuel, or it can easily be utilised in all other well-established natural gas facilities. The total world storage capacity of natural gas is > 3600 TWh [4] (total world power production from wind and solar power in 2012: 639 TWh [5]).

The importance of PtG for handling high shares of renewable energies is being discussed at length [6–10]. The scope of this review paper is to describe the technological and economic difficulties, thus the general necessity of PtG will not be the subject of this article. Due to the large number of papers on Power-to-Gas, this review focuses on Power-to-Methane. An alternative would be direct injection of H₂ into the gas grid. However, the amount of H₂ in the gas grid is limited by country specific standards and regulations to a maximum of 0–12 vol.% [11].

* Corresponding author.

E-mail address: goetz@dvgw-ebi.de (M. Götz).

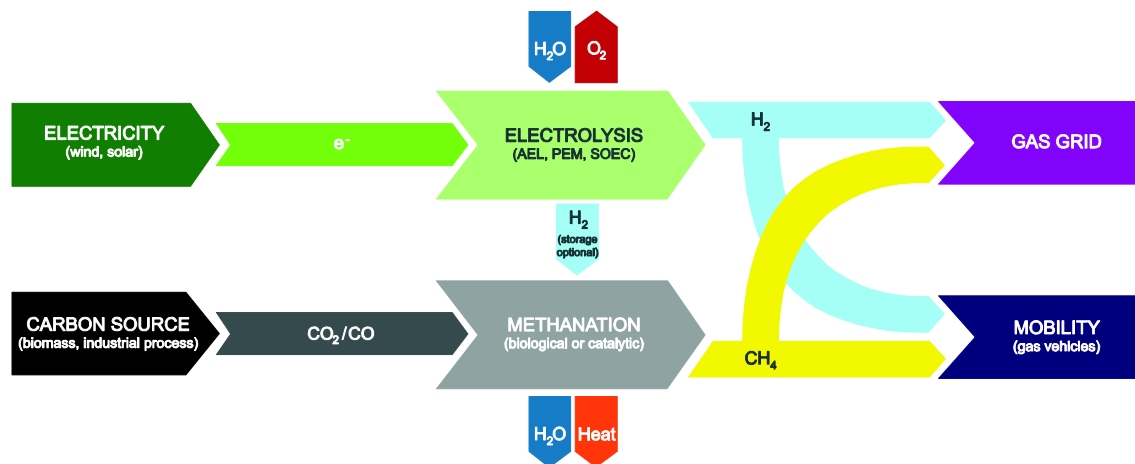


Fig. 1. Exemplary Power-to-Gas process chain.

The main drawbacks of Power-to-Gas are a relatively low efficiency and high costs. These aspects will be discussed in Section 5.

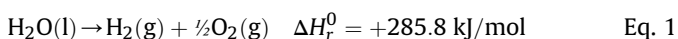
The Power-to-Gas process chain was first proposed in Japan in the 1980s–1990s [7]. Hashimoto et al. proposed a global CO₂ recycling using sea water and built a pilot plant in 2003 [8]. A broader interest in Power-to-Gas has begun to grow (especially in Europe) in recent years driven by the increasing share of wind and solar power [12–17]. In the meantime, there is a significant amount of Power-to-Gas research in different countries. Some examples are Switzerland, Denmark, France, Japan, and Germany where pilot plants are under construction or even in operation (see Sections 3.2 and 5.4).

An alternative to SNG is the production of liquid energy carriers such as methanol, dimethyl ether (DME), and Fischer-Tropsch products or the production of chemicals [18–21]. In the future, the photocatalytic conversion of CO₂ and H₂O to methane or other fuels could be an interesting alternative to the proposed PtG chain [22]. However, this technology is still in an early development stage.

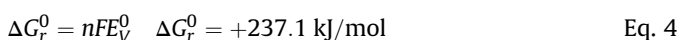
2. Hydrogen supply

2.1. Fundamentals

Water electrolysis to yield H₂ and O₂ (Eq. (1)) is an electrochemical reaction which can be segmented into 2 steps. At the negatively charged cathode the reduction reaction takes place (Eq. (2)), while the oxidation reaction occurs at the positively charged anode (Eq. (3)). Depending on the technology, the charge carrier can be OH⁻, H₃O⁺, or O²⁻ (see Table 1).



For calculating equilibria (Fig. 2), the Gibbs free energy of water electrolysis ΔG_r^0 is expressed by the equilibrium cell voltage (Eq. (4)), where n is the number of transferred electrons counted in moles and F is the Faraday constant, converting electric properties into thermodynamic and vice versa:



As depicted in Fig. 2, temperature has a positive influence on the water electrolysis reaction, while pressure has a negative influence.

The most important parameters of the electrolysis technologies are efficiency, flexibility, and lifetime. The different technologies will be discussed in Section 2.2.

2.2. Water electrolysis

Excess electrical energy can be used to produce hydrogen via water electrolysis. H₂ can be converted into methane with a suitable carbon source or it can be directly injected into the gas grid or used for fuel cell vehicles. Water electrolysis is a well understood technology. Thereby, developments in fuel cell technology also helped to improve water electrolysis technologies. Three different electrolysis technologies are of interest for PtG process chains: alkaline electrolysis (AEL), polymer electrolyte membranes (PEM), and solid oxide electrolysis (SOEC). The key operational parameters of the three electrolysis technologies are summarized in Table 1.

2.2.1. Alkaline electrolysis (AEL)

Of the three types of electrolysis technologies considered for PtG plants, alkaline electrolysis is the most mature and well understood technology (commercially available for decades [23]). In AEL, an aqueous alkaline solution (KOH or NaOH) is used as the electrolyte. AEL works either atmospherically or under elevated pressure. According to Smolinka et al. [24], pressurized alkaline electrolyzers have a lower efficiency and produce a lower purity product than atmospheric AEL. The foremost advantage of pressurized AEL compared to atmospheric AEL is that it produces compressed hydrogen (either for grid injection or further use) with less additional energy input [25]. This is a result of the fact that the reduction in electric efficiency of the electrolysis with increased pressure (see Fig. 2) is lower than the energy needed to compress the produced hydrogen.

According to manufacturers, AEL electrolyzers can be operated between 20 and 100% of the design capacity, and overload operation up to 150% is possible. This operation window makes AEL a good choice for systems such as PtG which are coupled with a fluctuating and intermittent power supply. However, Gahleitner [26] reports problems with intermittent and fluctuating power sources. One problem is that it takes 30–60 min to restart the system following a shutdown [27]. Continuous operation of AEL systems is advised [27]. The biggest disadvantage of AEL is that the utilised electrolytes (alkaline solution, e. g. 20–30 % potassium hydroxide solution) are highly corrosive, thus necessitating high

Download English Version:

<https://daneshyari.com/en/article/6766323>

Download Persian Version:

<https://daneshyari.com/article/6766323>

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