INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–13

Available online at www.sciencedirect.com

ScienceDirect

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

CO_2 valorization through direct methanation of flue gas and renewable hydrogen: A technical and economic assessment

G. Iaquaniello [a], S. Setini [b], A. Salladini [c,*], M. De Falco [d]

[a] KT – Kinetics Technology SpA, Viale Castello Della Magliana 27, 00148 Rome, Italy
[b] University of Rome "La Sapienza", Via Eudossiana 18, 00184, Rome, Italy
[c] Processi Innovativi Srl, Via di Vannina 88/94, 00156 Rome, Italy
[d] Unit of Process Engineering, Faculty of Engineering, University "Campus Bio-Medico" di Roma, Via Alvaro Del Portillo 21, 00128, Rome, Italy

ARTICLE INFO

Article history:
Received 11 December 2017
Received in revised form
5 June 2018
Accepted 13 July 2018
Available online xxx

Keywords:
Power to gas technology
CO_2 methanation
Flue gas
Renewable hydrogen
Chemical storage

ABSTRACT

Under the scenario of an increasing sharing of renewable energy, Power to Gas technology may offer an effective and valuable solution for surplus energy management, accounting for a large and long-term chemical storage. In the present study an innovative Power to Synthetic Natural Gas (SNG) process has been described and investigated from a techno-economic and environmental point of view. The configuration is based on a methanation process, directly applied on flue gas stream thus acting both as a CO_2 capture and sequestration technology and as renewable energy storage mechanism. Reacting hydrogen is produced via water electrolysis powered by surplus of renewable energy, normally low-priced otherwise wasted. With a reference capacity factor around 4000 h/y, the resulting SNG cost is 0.34 €/Nm^3 based on a carbon tax equal to 30 €/t CO_2. The obtained results are attractive and consistent with the fact that future investment cost for water electrolysis is decreasing accordingly.

Introduction

The growing concern for global climate changes continuously drives the international community looking for more cost-efficient solutions promoting a less energy-consuming and more climate-friendly economy. Considerable policy efforts have been achieved in the last few years aiming to increase renewables penetration in all sectors responsible for GHG emissions. On this regards, the EU low-carbon economy roadmap suggested that by 2050 the EU should cut GHG emissions to 80% respect to 1990 levels. The achievement of this goal should be realized through a 40% reduction by 2030 and 60% reduction by 2040. Among main sectors, power industry is depicted to have the biggest potential for cutting emissions by 2050 [1].

Contribution of renewables in electric energy production continuously raises accounting for a global generation capacity of about 2000 GWh at the end of 2016; wind and solar grew more rapidly respect to other renewable technologies achieving an installed capacity of 467 GWh and 269 GWh respectively [2]. However, the fluctuating and intermittent

* Corresponding author. Via di Vannina 88/94, Rome 00156, Italy.
E-mail address: salladini.a@processiinnovativi.it (A. Salladini).

https://doi.org/10.1016/j.ijhydene.2018.07.099
0360-3199/© 2018 Published by Elsevier Ltd on behalf of Hydrogen Energy Publications LLC.

nature of these energy sources accounts for an unbalancing of the grid, making the sharing of large amount of renewable electricity quite challenging. In order to assure security and stability of the grid, under a surplus electric energy production a common practice is to technically reduce the power output below the maximum availability. This reduction is called "*curtailment*". In some countries such as China and Italy for example, curtailment levels have exceeded 10% of renewable generation capacity [3] while up to 4 TWh of wind energy is lost in Germany [4]. It is quite clear that to assure safe grid operation, a different approach has to be adopted considering that last EU directive asked that curtailment of renewables should be done last in order to avoid any clean energy lost [5].

Electric Energy Storage (EES) could be a strategic solution able to smooth power production thus avoiding the mismatch between supply and demand generally responsible for damages in power supply stability and quality. Different kinds of EES systems are available in the market and deeply investigated in the literature [6,7]. According to the form of energy used, EES systems may be classified into mechanical, electrochemical, chemical and electrical. The most common mechanical storage devices are pumped hydro-storage system covering about 90% of the global installed storage capacity [8]. For what concern electrochemical sector, battery storage systems are widely available on the market, although the cost for stationary applications is still too high.

Chemical storage may provide an interesting opportunity allowing to store surplus of low-priced energy or otherwise wasted, into chemical energy bond. This kind of storage is considered to be the most promising one due to the high storage capacity potential and the high charge/discharge periods [9].

Hydrogen and Synthetic Natural Gas (SNG) are the two main secondary energy carriers suitable for a chemical storage [10]. In medium to long term, electrolyser technology for hydrogen production is depicted as a potential significant development in the global energy system. Installing electrolysers in conjunction with renewable will allow for a larger share of green energy into the electrical grid network. This would in turn provide a mean to convert substantial amount of excess green energy into hydrogen [11]. In this regards extensive review in the literature showed that the number of power to gas pilot plants producing hydrogen from fluctuating renewable power sources is increasing all over the world [12].

Conversion of power into H_2 via electrolysis and afterwards into SNG through methanation reaction, allows to transfer the stored energy from a low energy density molecule into another one having higher chemical density namely methane CH_4. Production of SNG gained popularity due to the flexible use of methane as fuel for mobility and residential buildings. The SNG can also be used as raw material for chemical production as well as in industry for power and heat generation. Moreover storing energy into methane can take advantages in using existing natural gas infrastructures for its storage and transportation.

The Power to SNG process has been widely investigated in the literature and depicted as a promising solution for renewable energy storing and transportation. Biogas, flue gas stream or emissions from cement and metallurgical industry are considered potential sources of CO_2 for methanation reaction.

De Saint Jean et al. (2014) [13] simulated a Power-to-SNG process combining a high temperature steam electrolysis with methanation reaction assuming CO_2 coming from an industrial capture process. Without considering consumption associated to CO_2 capture, authors estimated an energy consumption of 14.4 $kWh_e/Nm^3{}_{SNG}$ where 90% is associated to the electrolysis step. The economic assessment reported SNG production cost ranging from a maximum value of 567 €/MWh $_{HHV}$ in the case of the risky scenario, down to a minimum one of 304 €/MWh $_{HHV}$ for the ideal prospective one. Current scenario brought to an intermediate condition equal to 494 €/MWh $_{HHV}$ [14]. Chiuta et al., (2016) [15] investigated the technical and economic feasibility of power to gas plant where hydrogen was produced via alkaline water electrolyzer and CO_2 assumed available for free as a waste product from an existing syngas plant.

Vo et al., (2017) [16] moving from forecasted wind energy curtailment in Ireland in 2020, evaluated the potential SNG production deriving from biogas upgrading. They showed that 1 GWh_e of curtailed wind derived energy once used to produce H_2 for biogas upgrading can save about 97 tonn CO_2. Bailera et al., (2017) [17] depicted a detailed worldwide power to gas project reviewing CO_2 methanation plant as well as biogas and syngas upgrading systems. Collected data showed Germany is the leader in developing Power to Gas system mainly based on CO_2 catalytic methanation.

Simonis and Newborough (2017) [18] investigated different power-to-gas configurations for capturing excess wind power on the German's North Sea Coastline. Prediction for wind generation and electricity demand indicates growing excess of renewable electricity level. Authors evaluated different solutions based on production and injection of low concentration hydrogen admixture, SNG or hydrogen/SNG mixture.

Esterman et al., (2016) [19] studied the feasibility of implementing power-to-gas systems, to absorb surplus solar power from electricity distribution networks and carbon dioxide from biomass anaerobic digestion plant, in order to produce synthetic methane. The study was tailored for the Bavaria Region in the Southern region of Germany considering that is characterized by a high solar power penetration and by a large number of anaerobic digesters for biogas and bio-methane production. Based on this high renewable penetration in the South of Germany, a suitable electrolyzer capacity was modeled aiming at reducing solar energy curtailment. Remaining in the German context, Schiebahn et al., (2015) [20] evaluated different scenario for power to gas application, in particular the injection of hydrogen or SNG into the natural gas grid as well as the utilization of hydrogen in a dedicated infrastructure for directly use in road transport. Analysis was based on forecasted power generation deriving from onshore and offshore wind derived energy.

Given the large capacity of wind generation expected to be installed in Scotland and in the northern parts of England and Wales, Qadrdan et al., (2015) [21] investigated the potential impact of integrating Grain Britain gas and electricity networks operation using power-to-gas systems. Obtained results showed that producing hydrogen from excess electricity can significantly reduce wind curtailment under intensive wind periods.

The economic viability of SNG production from power and CO_2 was analyzed by Guilera et al., (2018) [22] considering as