ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–14

Available online at www.sciencedirect.com

ScienceDirect

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

Feasibility study of large scale hydrogen power-to-gas applications and cost of the systems evolving with scaling up in Germany, Belgium and Iceland

S. Weidner [a], M. Faltenbacher [a], I. François [b], D. Thomas [c], J.B. Skùlason [d], C. Maggi [e,*]

[a] Thinkstep AG, Germany
[b] WaterstofNet, Belgium
[c] Hydrogenics, Belgium
[d] Icelandic New Energy, Iceland
[e] Federazione delle Associazioni Scientifiche e Tecniche (FAST), Italy

ARTICLE INFO

Article history:
Received 22 December 2017
Received in revised form
16 May 2018
Accepted 27 June 2018
Available online xxx

Keywords:
Hydrogen
Power-to-gas
Levelized cost of hydrogen
Renewable energy

ABSTRACT

The use of hydrogen to store electricity is no longer utopian nor merely theoretical. Hydrogen applications such as Power-to-Gas systems are entering the market and some of them are ready to compete with other options in the near future. This means they have indeed a potential for profitability, especially if seen as large-scale storage solutions for the electricity surplus produced by variable renewable energy sources.

In this study Power-to-Industry, Power-to-Mobility and Power-to-Power applications are chosen to be investigated and compared through levelized cost of hydrogen to identify the main cost drivers and consequently understand the possible solutions to reduce costs. The feasibility of the applications is discussed and analyzed in Germany, Belgium and Iceland, with mid and long-term perspectives, focusing the analysis on the advantage of scaling up.

Introduction

The integration of renewable energy sources (RESs) in the power system has become a relevant issue in Europe, since it is considered one of the solutions to decrease greenhouse gas (GHG) emissions and to increase energy security [1].

The use of hydrogen from RESs as a clean energy carrier could significantly contribute to reach the European Union (EU) mandatory targets of 20% share for renewable energy in final consumption and 10% share in transport by 2020 [2]. The challenge European countries are facing is to keep the electric system reliable and safe through flexible solutions in power production, load management, interconnection and storage, thus embracing at the same time a large amount of variable RES [3].

Hydrogen is a very flexible energy carrier which can store electricity at large scale over long period, mainly to back up intermittent generation from renewables and it is also suitable for mobile applications since it allows larger amounts of energy to be stored under restricted space and weight

* Corresponding author.
E-mail address: cristina.maggi@fast.mi.it (C. Maggi).

https://doi.org/10.1016/j.ijhydene.2018.06.167
0360-3199/

Abbreviations

BE	Belgium
CAPEX	Capital Expenditures
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DE	Germany
DQ	Don Quichote
ETS	Emission Trading System
EU	European Union
GHG	Green House Gas
H_2	Hydrogen
IS	Iceland
LC	Levelized Cost
LCOH	Levelized Cost of Hydrogen
NAHA	North Atlantic Hydrogen Association
NPV	Net Present Value
O_2	Oxygen
OPEX	Operational Expenditures
P2I	Power to Industry
P2M	Power to Mobility
P2P	Power to Power
RESs	Renewable Energy Sources
SMR	Steam Methan Reforming
WACC	Weighted Average Cost of Capital

requirements, thus helping to overcome electricity storage limitations such as in pure battery electric vehicles [4,5]. The increased fluctuation on the generation side due to variability and uncertainty of some energy sources, such as wind and sun, lead to have different prices of electricity during the day [6] that offer opportunities for the development of flexible electric energy-intensive processes and power-to-gas hydrogen processes [7].

On a large-scale right now, pumped hydropower represents the vast majority (99%) of storage in operation worldwide, while other type of electricity storage technologies are not very diffuse [8]. However, there is considerable interest in developing new storage technologies with attractive costs and advanced operating characteristics and power-to-gas represents an interesting storage solution that can help to address grid-stability issues. A power-to-gas system converts electricity generated during periods of overcapacity, into H_2 and O_2 via water electrolysis. The hydrogen produced from renewable power can be used in multiple sectors, a feature that makes hydrogen a very versatile energy carrier.

The potential of power to gas has been already discussed: in [9] hydrogen energy storage is compared to other type of solutions providing the variability of the cost associated and in [10] impacts on other sectors such as gas, electric power and CO_2 are investigated to understand its interactions with these energy sectors. The approach of this study, on the other hand, is to analyze this potential by comparing different types of power-to-gas hydrogen applications in different countries. The study carried out within the Don Quichote[1] Project (Demonstration of new qualitative innovative concept of hydrogen out of wind turbine electricity - DQ) a 5 years project, funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH JU, ref. nr. 303411), assesses the economic potential of large scale implementation of three type of power-to-gas hydrogen applications:

- Power-to-Industry (P2I): H_2 is used for industrial processes such as the production of ammonia, in the petrochemical industry or the food industry.
- Power-to-Mobility (P2M): H_2 can be used in the mobility sector for cars, buses, trucks and forklifts (Fuel Cell Electric Vehicles).
- Power-to-Power (PTP): H_2 produced with excess renewable energy is stored and then repowered via fuel cell system to electricity to be fed into the grid.

The need of such a study was born within the DQ Project, that aims to demonstrate the technical and economic viability of a hydrogen storage system to store renewable electricity for Power-to-Mobility and Power-to-Power applications in realistic conditions. The on-site produced hydrogen via water electrolysis is used mainly as a fuel for hydrogen powered material handling equipment at a Colruyt distribution Center in Halle, Belgium. In order to assess the potentialities of the types of hydrogen applications implemented in the DQ Project, first realistic upscaling scenarios for the implementation in different countries are defined, and second, the assessment of the hydrogen production cost according to the defined scenarios is addressed. A detailed life cycle cost analysis of the deployed system was also carried out in the framework of the DQ project and served as baseline for the upscaling analysis carried out [11].

Methodology

The comparison of scenarios presented and described in the next paragraph, are based on a Net Present Value (NPV) calculation, that allows the evaluation of the profitability of the different solutions in the years and on the levelized cost (LC) of the end-product calculation, that helps to identify main cost drivers. The approach is the same used in [12]; for NPV comparisons, only the revenues coming from selling the end-product have been considered and potential avoided cost for CO_2 emission allowances, revenues from selling O_2, recovery of heat and provision of ancillary services have not been included, furthermore, the levelized cost of the end-product is calculated, using a WACC of 5% and a lifetime of 20 years, not considering taxes.

The end products that come from the power-to-gas applications considered are; the amount of hydrogen produced in terms of kilograms, for P2I and P2M cases, and the electricity generated in terms of MWh, for P2P case.

The base case for the calculation of the LC of the end-product is named 'LC_{max}' and it includes the initial capital investment, fixed and variable maintenance and operating costs. Next to the base case, 'LC_{min}' includes the revenues from the monetized CO_2 by EU ETS scheme, from selling O_2 and from heat valorization and ancillary services, and 'LC_{soc}' additionally includes the avoided societal costs.

[1] http://www.don-quichote.eu/.

Please cite this article in press as: Weidner S, et al., Feasibility study of large scale hydrogen power-to-gas applications and cost of the systems evolving with scaling up in Germany, Belgium and Iceland, International Journal of Hydrogen Energy (2018), https://doi.org/10.1016/j.ijhydene.2018.06.167