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Economic assessment of a power-to-substitute-natural-gas process including high-temperature steam electrolysis

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ABSTRACT

Power-to-Substitute-Natural-Gas (SNG) processes are studied since they can offer solutions for renewable energy storage and transportation. In the present study, an original Power-to-SNG process combining high-temperature steam electrolysis and CO_2 methanation is economically assessed. This evaluation is based on experimental data describing the electrolyser performance and its degradation during long-term operation. These data are obtained on a commercial single cell. Tests are originally conducted by imposing voltage and steam conversion rate. The main conclusions of this experimental work are that two fields of current density evolution are evidenced in the tested conditions: a first transient one where the current density absolute value decreases very quickly, followed by a second field where the evolution of current density achieves a steady state. The influence of the operating point seems not significant once this state is achieved.

The process assessed here has been developed in a previous work where a precise framework matching with a wide range of applications was defined. The design of the process main units and the calculation of matter and energy fluxes are based on this work. To go further, the economic assessment of this process is proposed. In this study, various scenarios of initial performance of the electrolyser are considered and integrate the performance degradation associated. The SNG production cost is estimated between 211 and 570 €/MWh_{HHV} according to the scenario and the hypotheses considered. The two major items accounting for this high cost are the purchase cost of the electrolyser and its performance degradation. It also evidenced that none of the other items can be neglected. Through a sensitivity analysis, it is shown that an increase of plant annual availability and capacity makes the SNG production cost decrease.

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Introduction

Power-to-Gas processes are considered as a possible and interesting solution to integrate efficiently wind and solar renewable resources into the current energy mix. This solution aims at using power to convert water into hydrogen *via* electrolysis [1], and storing the obtained fuel until having a high power consumption period when it would be reconverted into electricity. A further step could be considered with the conversion of the electrochemical hydrogen into methane thanks to the Sabatier reaction. This allows to produce Substitute Natural Gas (SNG) and then, it becomes possible to store the obtained fuel by injection into the natural gas grid [2,3]. Methane, which is the main compound of SNG, has several advantages over hydrogen which deal with volumetric energy content and safety concerns. In addition to these physical data, there is no limit for SNG injection into the gas grid whereas if hydrogen is produced, it can be injected into the grid in the limit of 6_{vol}% for instance in the French grid [4], the current factual fraction being under 2_{vol}%. Grid for transportation and distribution already exists in Europe, allowing to store and deliver natural gas and its substitute. Producing SNG is chosen here since, on top of the advantage of accessing the grid, it is a versatile compound, which can be used to generate thermal energy, chemicals, fuels for mobility and finally electrical energy, as illustrated in Fig. 1. Added to the social acceptability of natural gas currently observed, these arguments make the solution of Power-to-SNG interesting and relevant for further investigations.

Units required to produce SNG were previously defined and modelled [3,5]. They consist of High-Temperature Steam Electrolysis (HTSE), methanation with the Sabatier reaction and finally gas purification. The original Power-to-SNG process including these units were simulated and results are presented elsewhere. This previous work allowed to calculate matter and energy fluxes of the process in an accurate framework matching to a wide range of applications. Components as electrolyser and methanation reactors were also designed in this work.

As a following study of Power-to-SNG modelling and simulation, the present work focuses on the economic assessment of such a process. As no other detailed Power-to-SNG process simulation has been conducted, no economic assessment could have been done on this detailed basis. However, in Ref. [6], several Power-to-SNG processes from literature including low temperature electrolysis technologies are described and economically compared. Authors made hypotheses when data were missing, particularly concerning the electrolyser lifespan. In the same way, a German study concerning a Power-to-SNG process including low temperature electrolysis is carried out in Ref. [7] but it mainly focuses on the economic aspect and does integrate neither detailed technology specifications nor process behaviours. As a result of this study, low-temperature Power-to-Gas processes are difficult to be economically profitable under the German current regulations. To determine if high-temperature Power-to-SNG processes are economically profitable, it is important to rely on detailed data of design and architecture and to consider, in a first step, the energy consumption and the SNG production observed for a given process, to evaluate in a second step, the production cost of SNG.

Concerning the electrolyser, no data were found in literature reporting performance and evolution during long-term operation for electrolysis cells operating under conditions describing the Power-to-SNG process; that is to say at high steam-conversion rate at the thermoneutral voltage, these two parameters being constant during operation. However, data of performance and ageing must be integrated into the economic assessment. The performance is linked to the hydrogen production per surface area, and to the plant investment cost, whereas the time evolution of performance describes cells ageing and has to be included in the calculation of the plant operating cost.

Experimental work is carried out to obtain data qualifying the electrolyser performance and its degradation under various working points in terms of temperature and steam conversion rate at the thermoneutral voltage. Experiments are conducted on commercial single cells. Results from long-term tests are used to propose mathematical

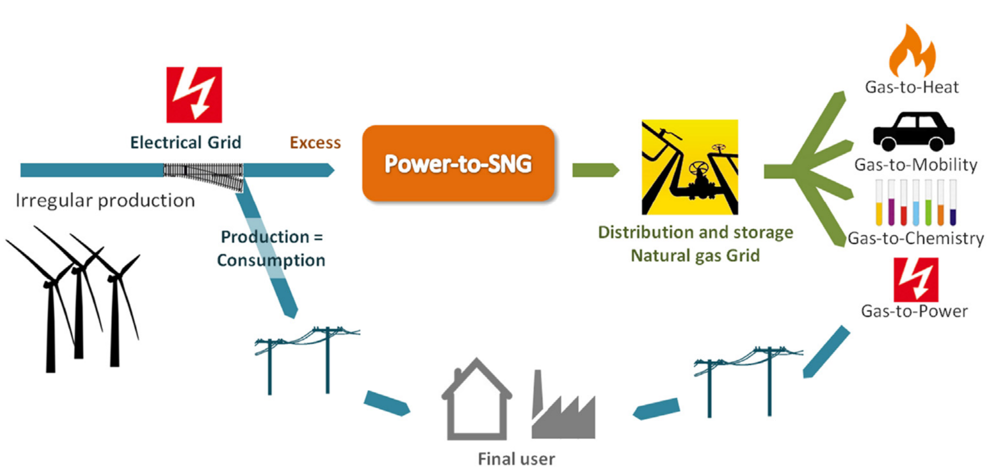

Fig. 1 – Power-to-SNG concept as a solution for electrical energy storage and transportation, [3].

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