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Viability analysis of centralized hydrogen generation plant for use in mobility sector

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ABSTRACT

Nowadays, the use of renewable energy sources is one of the keys to achieve the sustainable development of societies. The intensive use of fossil fuels has caused effects in the environment and the human health. Greenhouse gas emissions and the carcinogenic effect of diesel are widely demonstrated. The production of clean energy based on renewable sources and the use of hydrogen as an energy vector in general and as an alternative fuel in particular represent a technically feasible reality. However, it is necessary to study the economic variables of centralized or distributed production of hydrogen as an alternative fuel. The aim of this paper is to analyze the technical and economic viability of a centralized generation hydrogen plant for mobility use. It was performed a sensitivity analysis of main parameters such as size of hydrogen production plant, operating hours of the plant, investment costs of the main equipment and electricity price. A NPV of 1,272,692 and a 9-year pay-back were obtained for a centralized hydrogen production plant of 2 MW, considering commercial values of the main evaluation parameters. The sensitivity analysis determines that the main variables affecting the NPV are the price of electricity and the operating hours of the plant. With 95% of confidence, the NPV will be positive with an 80.19% of certainty. Therefore, centralized hydrogen production represents a technically viable, environmentally friendly and economically attractive process that can rapidly position hydrogen as an alternative fuel for mobility.

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Introduction

The era of fossil fuels is already coming to an end. The sustainable development of societies requires the development of energy strategies that are technically feasible, economically viable and environmentally friendly. Therefore, the development of the hydrogen energy vector based on a renewable energy production can meet these requirements via water electrolysis [1–3]. Other methods, such as steam reforming, water-gas-shift reaction, pyrolysis, plasma reforming and biomass gasification, have been used for hydrogen production [4–11].

The transport sector is one of the main consumers of diesel; at the same time, this sector is responsible for greenhouse gas emissions (GHG) and problems of air quality of the main cities of the world. Nowadays oil dominates the fuel mix that meets the world's transport needs. Gasoline and diesel account for 96% of the total fuel consumption and 21% of the global carbon emissions. Then, the use of Alternative Fuel Vehicles (AFV) like Fuel Cell Vehicles (FCV) to replace vehicles powered by internal combustion engines is a clear alternative of road transport that may provide security in the energy supply [12,13], reduction in the GHG emissions and improvement of the air quality in cities in the long term [14,15].

Many works have been focused on technical aspects to produce H_2 via alkaline water electrolysis, high pressure polymer electrolyte membrane electrolysis and others [16–19]. Additional economic studies have been reported. To a central production facility with a H_2 capacity of 50,000 kg H_2/d, Genovese et al. [20] reported a price around 3.00 USD/kg H_2. For the same capacity of H_2 production, Ainscough et al. [21] estimated a cost of 5.12 USD/kg H_2. Therefore, the technical aspects of hydrogen production have been consolidated in the last decade; now the main objective is to find a competitive consumer price. Then, the problem is to define how this hydrogen should be produced to deliver the best price. The first option is a centralized hydrogen production plant, transporting the hydrogen up to different Hydrogen Refueling Stations, and the second one is to set different hydrogen production plants in which the hydrogen production is done on-site in the Hydrogen Refueling Station.

The aim of this paper is to analyze the technical and economic viability of a centralized generation hydrogen plant for mobility use. The hydrogen generation technology analyzed will be the polymer electrolysis. It was performed a sensitivity analysis of main parameters such as size of the hydrogen production plant, operating hours of the plant, investment costs of the main equipment and electricity price.

Methods

Hydrogen production plant description

The design considered in this paper is focused on a centralized renewable hydrogen generation plant using the hydrogen generation technology of polymer electrolysis, the storage at generation pressure in large Type-I reservoirs, the compression by membrane compressor and the supply of hydrogen compressed to tube trailers for its distribution to the consumption points. The hydrogen cost obtained from the technical-economic study and the feasibility studies does not include the transport cost; id est, it includes the filling of the tube trailer but not the deployment, as this cost depends directly on the distance to the final consumption point.

The main equipment part of the centralized hydrogen production plant (see Fig. 1) is the following:

- Polymeric electrolyzer. This equipment requires 2.2 MW of electricity, which comes from renewable energies in this case (the stack has a consumption of 2 MW and the remaining 0.2 MW corresponds to the plant balance), and 15 L of raw water per kg of generated hydrogen. The electrolyzer will produce 863 kg of hydrogen per day at 35 bar of pressure and a purity of 99.999%, 3350 kg of oxygen per day at 35 bar and a purity of 99.95% and 21.6 MWday of residual thermal energy with an outlet temperature of 65 C and an inlet temperature of 50 C. Both oxygen and residual heat are byproducts of the polymer electrolysis process that can be evaluated, although they are not considered in the present paper; therefore, the use of these byproducts will improve the obtained results.
- Hydrogen Storage. The generated hydrogen is stored at the generation pressure in order to reduce the CAPEX and OPEX of the storage system and to simplify the installation, as the space is considered to be enough to install the necessary hydrogen tanks. It is considered necessary to have a capacity equivalent to 48 h of full load operation of the polymeric electrolyzer, which allows some flexibility and margin to uncouple the hydrogen generation and the supply of the mentioned hydrogen to the final consumers. The storage system will consist of 4 tanks with a capacity of 150 m^3 of an equivalent volume of water, which can store about 450 kg of hydrogen per tank. All these tanks will be interlinked to the same inlet manifold and the same outlet manifold, so that it can be managed as a single storage.
- Hydrogen Compressor. In order to supply hydrogen to the tube trailers, it is necessary to compress the hydrogen, for which it is also necessary to use a compressor. A membrane compressor has been selected in this case, given that they are the most indicated ones when working with high purity hydrogen. The compressor will have the capacity to compress up to 400 Nm^3/h of hydrogen from 10-bar pressure to 250-bar pressure (a compressor that can reach up to 250 bar must be selected so that it can overcome the load losses and can supply hydrogen to the tube trailer at 200 bar at least). It is necessary to consume 130 kWh of renewable energy to carry out this work, generating 70 kWh of residual thermal energy with an outlet temperature of 65 C and an inlet temperature of 50 C. This residual heat can be used for different applications. In this case, the use of the residual heat is not considered in the study.
- Tube trailers. It is necessary to use tube trailers at 200-bar pressure in order to transport the hydrogen between the centralized generation point and the consumption points. The tube trailers considered for this paper are formed by 4 cages of bottles, each of which is formed by 68 bottles of 85-L capacity. Thus, the tube trailer has a transport capacity of approximately 367 kg of hydrogen.