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Cost assessment and evaluation of various hydrogen delivery scenarios

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ABSTRACT

In this paper, performance and cost assessment studies, including the stages of hydrogen storage, transmission and distribution of three different hydrogen delivery pathways are undertaken comparatively. The produced hydrogen is stored under different temperatures and pressures and then transported to the nearby cities for distribution. In addition, three different methods for the transportation of the produced hydrogen to the distribution centers are studied, which are as transportation for hydrogen by the pressurized tanks, cryogenic liquid hydrogen tanker and the gas pipelines. Moreover, the transmission options from the distribution center to the target consumer are also examined for three different conditions. As a result, the hydrogen production capacity, the levelized cost of energy distribution (in $/kg), the infrastructure costs (truck, tanker number, gas line costs, etc.) for the selected transmission scenario are calculated. Furthermore, the environmental impact (greenhouse gas (GHG) emissions) and some application parameters of the proposed system (e.g., number of hydrogen fuel stations and the distance between the stations, length of the distribution lines, etc.) are also determined. The highest levelized cost of delivery is obtained as 8.02 $/kg H_2 for the first scenario whereas the lowest cost is obtained as 2.73 $/kg H_2 for the third scenario.

Introduction

Hydrogen is considered one of the cleanest energy carrier and potentially chemical feedstock for sectoral, including industrial applications. The absence of the carbon emission throughout the energy production processes in contrast of the conventional fossil fuels makes it viable and environmental friendly choice. Hydrogen is, at the same time, the lightest element in the periodic table with a very low density per unit volume. It has nearly 14 times less dense than the air. Hydrogen is a colorless, unscented, tasteless, and nontoxic gas, under most conditions and changes its phase from gas to liquid state at −252.9 °C under 1 atm pressure. Furthermore, hydrogen is highly diffusive in the surrounding air where it diffuses in the atmosphere rapidly and is able to leak through tiny gaps. All these aforementioned properties of hydrogen cause storage and transmission problems [1].

A crucial factor affecting the hydrogen prices is primarily the transportation and distribution costs. Therefore, developing economically viable and hence feasible options for hydrogen transportation and delivery will help to overcome

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the drawbacks of hydrogen as a fuel due to its relatively higher production costs. The viable development of an H_2 transmission and distribution infrastructure referred to as "hydrogen delivery infrastructure," is one of the most vital issues for an effective penetration of H_2 into the energy system and the commercialization of the hydrogen energy driven automobiles. The required capital investment for the H_2 delivery infrastructure is directly dependent on the size of the construction. There is in fact a relationship between the scale of the transport infrastructure, and the amount of hydrogen demand. The growth of the H_2 market results in the development of the H_2 transport network, and vice versa [2]. Designing the optimum hydrogen transportation pathway depends generally on the specific geographical and market conditions such as population, market penetration of fuel cell vehicles, the amount of refueling stations and city radius [3].

Regarding the hydrogen usage in fuel cells, the delivery process of hydrogen may be classified under two main categories depending on the transportation processes which includes transmission and distribution of hydrogen through designated places. Hydrogen delivery from a centralized H_2 production plant requires both transportation and fueling operations. Three main transportation options are, in this regard, illustrated in Figs. 1a–1c. In these methods, hydrogen is transported in combinations of transmission by liquid tanker, which carries liquefied hydrogen under cryogenic conditions, compressed hydrogen gas transmission by tube trailers, and distribution through pipelines. In addition, a novel approach to the H_2 delivery is illustratively presented in Fig. 1d, which proposes the transportation of the H_2 after employing a chemical reaction or physisorption with a material. This kind of transportation pathway option is still under research and development phase [4].

Other storage forms, such as adsorption of hydrogen on metal hydrides, are currently studied [5–8], but are considered at an early stage of development and are not yet ready to fully commercialize [9].

Optimizing the transportation process of H_2 as regards to the parameters as cost-effectiveness, environmentally friendliness and easy operation is very important for the stakeholders. Thus, there have been many past studies which have focused on transportation and storage of H_2 by several researchers [3,10–18]. Yang and Ogden [3] have developed models in order to obtain delivery distances and to predict transport costs, possible emissions and usage of energy from several sections of the delivery chain. Simbeck and Chang [17] developed an infrastructure cost modules for producing, handling, distributing, and dispensing hydrogen from a centralized production facility and fueling station on-site facility for fuel cell automobile applications. Cost estimation of novel technologies on hydrogen storage and delivery are attracting the attention of the researchers. Moroz et al. [14], investigated the potential applications of the metal hydride based H_2 storage-delivery systems and made a technical and economic comparison to conventional compressed gas H_2 storage and delivery. Weisberg et al. [19], proposed a glass fiber tube trailer based hydrogen transportation system operating at 200 K and 700 bar which results in a synergistic effect on the material properties of glass fiber container and the stored hydrogen. Their results showed that the potential for H_2 delivery costs with their suggested method are less than $1/kg. Kim and Kuby [20], developed and analyzed a mixed-integer linear modeling method which optimized the locations of the refueling stations. Their model considered the limited driving range of automobiles, and necessary deviations that drivers are likely to make from their shortest paths in order to refuel their vehicles when the refueling station network is sparse. Mitz et al. [21] built an analysis model for hydrogen delivery scenarios. The model was built on the economic and engineering cost data with an hydrogen delivery scenario analysis model (HDSAM) which utilized the hydrogen analysis project of United State Department of Energy. Their results indicated that some of the transmission elements were specifically scale dependent. Hence, the transportation and distribution costs are mostly high for rural–Interstate markets and other low-H_2-demand cases. Weinert and Lipman [22], investigated the cost of hydrogen station structures in a variety of scale and types. Seven different hydrogen station were studied based on the size, operating factors, and siting factors. Regarding the performed cost analysis method, it was found in their study that commercial H_2 station building costs largely varied with the size of the station. The structure costs show an increase from around half a million U.S dollar at 30 kg/day of hydrogen capacity to five million U.S dollar at 1000 kg/day of hydrogen. Bellotti et al. [23] investigated a large scale hydrogen and hydro-methane production, storage and distribution systems. They technically considered two different alternatives for the hydrogen storage process. The first one is a more conventional method in which the hydrogen is pressurized into the tanks and trucks are utilized for the delivery process to the refueling stations. Their second selected alternative method suggested a storage and transportation of the hydrogen in hydro-methane form. They also performed a time-dependent thermo-economic optimization of different configurations of the system. Yang and Ogden [24] conducted an optimization study on H_2 infrastructure development in California. A quasi-spatial model was used to develop the infrastructure to supply hydrogen fuel to meet demand in several regions of California. The minimization of the cost was the objective function of their study while the properties of the resources, technology, and the policies were kept set as the constraints for the study.

In the present study, a comprehensive study on the cost and environmental impact assessments of hydrogen delivery pathways, which consist of storage, transmission, and distribution processes, is performed comparatively for various cases and scenarios to help in switching to practical applications. Three different scenarios are considered in which the produced hydrogen is delivered to the end customers in various combinations. The selected scenarios with actual considerations are then evaluated based on their cost and environmental impact. Furthermore, the parameters, which have a significant impact on the cost and GHG emissions, are also obtained and presented in the results section.

Descriptions of scenarios

In this study, an economic analysis of three different hydrogen delivery scenarios is performed with H2A Delivery