Application of Green Hydrogen in Mobility Sector

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At a global level, different studies disclose that transport systems are responsible for 25% of CO_2 emissions. In the context of sustainable mobility, one of the challenges in the short term is associated with the research and improvement of alternative fuels, which should allow a fast decrease in the generation of greenhouse gases due to sustainable transport means. In this sense, green hydrogen can play a fundamental role. Green hydrogen is the basis for producing synthetic fuels, which can replace oil and its derivatives. Synthetic fuels or e-fuel are hydrocarbons produced from carbon dioxide (CO_2) and green hydrogen (H_2) as the only raw materials. H_2 or e-fuel could be used in many sectors (manufacturing, residential, transportation, mining and other industries). In this study, different applications of hydrogen are evaluated by techno-economic analysis. The main variable that affects the production of hydrogen and its derivatives is the cost of electricity. Considering the renewable energy potential of Chile, it is feasible to develop in Chile the green hydrogen production as an energy vector, which would be technically and economically viable, together with the environmental benefits.

1. Introduction

The density of population and scarce territorial planning of big cities historically have excessive use of private transport at the center of mobility. Under COVID-19 pandemic context, the use of private vehicles has increased to the detriment of public transport due to the risk of contagion perception. With more vehicles on the roads, one of the first consequences is the saturation of public streets by private vehicles with a greater use of fossil fuels and, therefore, air and noise pollution problems, which has a negative impact on the health of inhabitants.

The CO_2 emissions are growing continuously at a global level. For example, between 2007 and 2017, the CO_2 emissions have grown approximately 13.3%, from 28,984 million t to 32,840 million t, respectively [1]. Only the transport sector is responsible around 8.04 Gt CO_2 and the same represents about 25.0% of global CO_2 emissions and requires around 29.0% of global final energy consumption [2]. Then, it is necessary to conceptualize a sustainable mobility model considering different types of people, needs and the specific conditions of each city. The new model will allow people to go from one place to another in a more environment friendly, in an accessible, efficient, safe, and equitable way. One approach is to modify the current mobility management model, prioritizing the design of cities for pedestrian, bicycles, major and minor public transport, leaving shared transport in private vehicles and the one-person use of cars and taxis last.

In the context of sustainable mobility, one of the main challenges in the short term is associated with the research and improvement of alternative fuels, which will allow a fast decrease in the generation of greenhouse gases due to sustainable transport means. In this sense, green hydrogen can play a fundamental role. Green hydrogen is the basis for producing synthetic fuels, which can replace oil and its derivatives. Synthetic fuels or e-fuel are hydrocarbons produced from carbon dioxide (CO_2) and green hydrogen (H_2) as the only raw materials [3]. The process requires energy, which must be provided from renewable sources (for example, solar and eolic energies). Synthetic fuels allow a significant reduction of CO_2 emissions compared to the emissions generated using fossil fuels. Based on life cycle analysis, the CO_2 emissions could be reduced by over 70%. Synthetic fuels also have a higher energy density compared to batteries, therefore, they could be offering a solution to those applications where electricity does not yet have an answer, for example, air and maritime transport.

Hydrogen as energy carrier or e-fuel could be used in many sectors (for example, manufacturing, residential, transportation, mining, and other industries). In this study, different applications of green hydrogen are evaluated by techno-economic analysis.

2. Methods

2.1 General technical description, cost estimation and sensitivity analysis

Different study cases are reported in this study. The first case discloses the techno-economic analysis of centralized hydrogen generation plant for use in the mobility sector. The second case analyzes the use of hydrogen obtained via electrolysis in railway transport and, the third case, analyzes the green ammonia production in Chile. All studies consider the production of green hydrogen by renewable energies. The main processes/operational units considered in the production plant evaluated are based on current technologies that were quoted from industrial partners. The main equipments are: Electrolyser, hydrogen storage, hydrogen compressor system, hydrogen dispensers, etc. The cost of these equipments consider prices of the main European manufacturers.

The total estimation of production costs is based on the amount of capital costs (CAPEX) and operating costs (OPEX) for each study case. Capital costs include hydrogen production equipment, storage, compression, ancillary equipment, and civil works. The operational costs include electricity, water, equipment maintenance, staff costs and land leasing costs. The main economic indicators were Net Present Value (NPV), Internal Rate of Return (IRR) and pay-back. These parameters were estimated by standard project evaluation methods [4,5]. Sensitivity analysis was performed with the Oracle Crystal Ball tool to determine the effect of the main variables over the NPV.

3. Results

Chile has a high renewable potential. For example, in the Atacama Desert, the irradiation indexes range from 5 kWh/m^2 to 12 kWh/m^2 in winter and summer, respectively [6]. Then, this renewable potential could support photovoltaic and concentrated solar power technologies. Further, Chile has wind power to develop in-shore and off-shore projects. For example, at the Pacific Ocean the wind could reach average speeds around 10 m/s [6]. Then, this renewable potential will be managed to produce green hydrogen.

Nowadays, many countries have proposed different strategies to produce hydrogen and use it in different applications. The first question is related to how this hydrogen will be produced, in centralized or distributed systems. The first option is required to introduce the hydrogen as new energy vector to meet the demand for captive fleets. The centralized hydrogen production plant requires the transportation of H_2 to different hydrogen refueling stations (HRS). Other option is a distributed hydrogen generation system where the hydrogen is produced on-site in the HRS.

A centralized hydrogen production plant of 2 MW PEM electrolyser requires 2.2 MW of electricity and 15 L of raw water/kg hydrogen produced. The electrolyser will produce 863 kg/day of H_2, 3350 kg/day of oxygen and 21.6 MW/day of residual thermal energy.

The total investment cost of a centralized hydrogen plant is around 3,740,000€ and the economic indicators are: NPV 1,272,692€; IRR 14% and payback 9 years (Fig. 1). The analysis of sensitivity shows that the main variables that affect the Net Present Value (NPV) are the electricity cost and the hydrogen production plant size (Table 1).

The transportation sector is a big responsible of greenhouse gas emissions and the road transportation accounted around 70%. In this sense, new technologies based on hydrogen will play a key role. Then, variables such as technology and environmental awareness, financial status and adequate infrastructure will be studied to evaluate the use of green hydrogen. The environmental awareness and hydrogen availability to consumers (appropriate design of hydrogen production plant and hydrogen refueling stations), produce the acceptation of green hydrogen as environmentally friendly fuel [7].

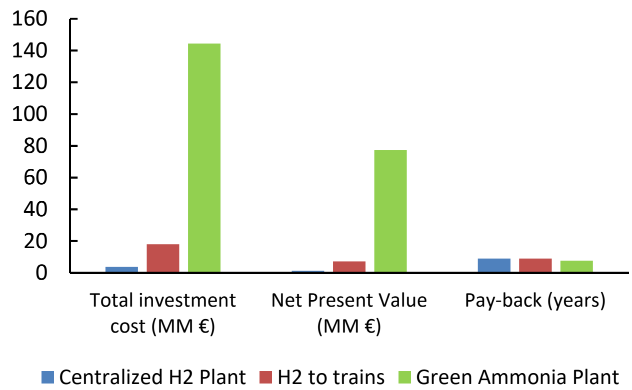

Fig. 1: Total investment and main economic indicators for the different studies cases.

The railway transport sector produces around 4.2% of global CO_2 emissions related to transport sector. The railway transport has social and environmental benefits, since reduces traffic congestion, is safer and the emissions are lower compared to other means of transport [2].

To satisfy the energy demand of a fleet of 20 trains, a 10 MW of polymeric electrolyser system is required. The electrolyser needs 11 MWh of electric energy and 15 L of raw water/kg hydrogen produced. The electrolyser will produce 200 kg/h of H_2, 1600 kg/h of oxygen and 8 MWh of residual thermal energy.

The total investment cost of hydrogen plant to 20 trains is around 17,960,000 € and the economic indicators are: NPV 7,115,391€; IRR 23.5% and payback 9 years (Fig. 1). The sensitivity analysis shows that the main variables that affect the Net Present Value (NPV) are electrolyser capacity or hydrogen refueling station capacity and hydrogen price (Table 1).

Other studies reported in the literature [11-13], show that the hydrogen is an energy vector that contributes to decarbonize with a high energy performance for energy and transport sectors. Particularly, it is possible the use of hydrogen generation and the integration of a hydrogen refueling station for fuel cell hybrid trains, both for passenger and freight trains. These authors reveal a fuel cell efficiency around 50% and a facility efficiency over 50%. Also, attractive financial indicators are disclosed (for example, IRR 19%). These results confirm that the technical and economic opportunity to use green hydrogen in passenger and heavy-duty transportation.

Table 1: Sensitivity analysis of different study cases (adapted from [8-10]).

Study Case	Centralized H_2 Plant	H_2 to trains	Green Ammonia Plant
Variables	**Contribution to variance (%)**		
Electricity Cost	62.9	-10.0	96.4
Hydrogen Production plant size	36.7	--	--
Electrolyser Cost	0.30	--	0.9
Operational hours/year	0.00	5.5	1.0
Hydrogen price	--	38.8	--
Electrolyser size	--	44.3	0.4
Haber-Bosch cycle cost	--	--	1.4
Ammonia price	--	--	0.0

Considering an energy transition, other clean fuels must be evaluated, while the hydrogen economy continues to develop. Recently, ammonia has been regarded as a hydrogen storage medium and it could be used as an energy vector. Ammonia is also used as a fertilizer, a chemical feedstock, a clean-burning fuel for transportation, a refrigerant fluid, and a power generator [10].

To produce green ammonia from green hydrogen a 150 MW PEM electrolyser is needed. In this case, the standard Haber-Bosch process is applied. The electrolyser needs 160 MW of electric energy and 15 L of raw water/kg hydrogen produced. The electrolyser will produce 2687 kg/h of H_2, 21582 kg/h of oxygen and 60 MWh of residual thermal energy.

The total investment cost of green ammonia production is around € 144,375,000 and the economic indicators are: NPV € 77,414,525; IRR 17.0% and payback 7.6 years (Fig. 1). The analysis of sensitivity shows that the main variable that affect the Net Present Value (NPV) is the electricity price (Table 1). Considering the latest energy tenders in Chile, renewable energies (mainly, solar and eolic) show the lowest prices. Then, with a low energy price of renewables, the green ammonia production in Chile is feasible with good economic indicators.

The above business cases show the role of hydrogen in the decarbonization in the mobility sector. Notwithstanding the above, the green hydrogen as energy vector could play a different role in many economic sectors. For example, it could contribute to integrate large-scale renewable plants, as carrier of energy, decarbonize industry, transport and building heating and serve as feedstock to chemical and other industries [13].

4. Conclusions

The main findings are:

- The transportation sector is responsible for around 8.04 Gt CO_2 and the same represents about 25.0% of global CO_2 emissions and requires around 29.0% of global final energy consumption.
- Hydrogen has the potential to be a powerful enabler to different energy requirements because it offers a clean, sustainable, reliable, and flexible option.
- The business cases show that green hydrogen is an energy vector that could play a key role in the mobility sector. From a technical point of view, the green hydrogen is safe, is an efficient energy vector, the infrastructure is growing worldwide, is sustainable with environmental and social benefits. On the other hand, from an economic point of view, the projects of hydrogen production show acceptable economic indicators, such as, Net Present Value (NPV), Internal Rate of Return (IRR) and pay-back.

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