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Thermo-economic comparison of hydrogen and hydro-methane produced from hydroelectric energy for land transportation

D. Bellotti, M. Rivarolo*, L. Magistri, A.F. Massardo

TPG, University of Genoa, Italy

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ABSTRACT

This paper aims to investigate a system for large size hydrogen production, storage and distribution to refueling stations for its employment in land transportation.

Hydrogen is produced by pressurized alkaline electrolysers, employing time-dependent renewable electricity produced by a large size hydroelectric plant (100 MW); the hydrogen is stored into pressurized tanks and delivered by trucks to the refueling stations. Since the technologies related to hydrogen vehicles still present high costs, an alternative solution is investigated: the hydrogen produced by water electrolysis is converted into Hydro-methane (a blend of methane and hydrogen, where H_2 maximum volume content is 30%), which is easier to be stored and transported to the refueling stations, considering its higher energy content in volume terms.

Since electricity available from the hydroelectric plant varies widely throughout the year, a time-dependent hierarchical thermo-economic analysis is performed in order to investigate both the optimal size of the whole plant and the management of the alkaline electrolysers. The analysis is carried out for the H_2 and Hydro-methane plant lay-outs, comparing the results from energetic, strategic and economic point of view in a typical European economic scenario (Italy).

For the different plant lay-outs, two energy scenarios are considered: *(i)* to feed the electrolysers only with renewable hydroelectricity during the year, keeping them off when it is not available; *(ii)* to purchase electricity from the national grid in shortage periods, in order to increase the utilization factor of the electrolysers and the production of H_2 and Hydro-methane for the refueling stations.

Introduction

In the last years, the increasing stringency of environmental rules has prompted the research to study innovative fuels with low environmental impact. In this context, hydrogen is becoming more and more interesting: it is a clean fuel with zero CO_2 emissions during its combustion [1]; a worthy option for its generation is represented by water electrolysis employing electricity from renewable generators (i.e. wind

* Corresponding author.
E-mail address: massimo.rivarolo@unige.it (M. Rivarolo).
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Nomenclature

Abbreviation

AEC	Alkaline Electrolytic Cell
DPBP	Discounted Pay Back Period
IRR	Internal Rate of Return
MIUR	Ministero dell'Istruzione dell'Università e della Ricerca
NPV	Net Present Value
PEC	Purchased Equipment Cost
TCI	Total Capital Investment
TPG	Thermochemical Power Group
W-ECoMP	Web-based Economic Poly-generation Modular Program

Symbols

C	Cost [€]
c	Specific cost [€/kg]
M	mass flow [kg/h]

Subscript

f	fuel
fix	fixed
var	variable

turbines, hydraulic turbines, photovoltaic panels). Considering the random nature of the renewable energy, the available electricity amount may be significantly higher than the electrical demand in peak production periods: in this context, a worthy solution is represented by the use of the exceeding energy to produce hydrogen which may become in this way a chemical storage for the electricity.

Considering the Italian scenario, about 25% of the national electrical demand is covered by the electricity produced from renewable sources: 45% of this amount is generated by hydroelectric power plants. In Italy, the hydroelectric yearly production is about 56,000 GWh; the facilities are about 3257: 42 of them have an installed power greater than 100 MW [2]. Since large size hydroelectric plants are affected by water flow availability, which is typically variable on monthly basis, their production is more stable and reliable compared to solar and wind sources, which have an hourly/daily variability. For this reason, hydroelectric plants present the largest number of operating hours per year, as reported in Fig. 1: the data is referred to both large size plants and mini-hydro plants, considering large size plants only, the number of operating hours is increased up to 3000.

Within the framework of the Research Project ***IDRO-RIN TRAN-GENESI***, financed by Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR), the development of technologies for large size hydrogen production from renewable sources (hydroelectric) and its utilization in land and naval transportation is investigated, considering the Italian energy scenario as case study, since the large number of hydroelectric facilities installed there. In the project two large size companies are directly involved together with University of Genoa and National Research Council (CNR). The main activities of the research project are: (i) H_2 generation by water electrolysis from electricity produced by renewable sources (hydroelectric); (ii) development of innovative high temperature electrolysers to improve the efficiency of the low temperature alkaline electrolysers; (iii) H_2 storage with traditional (pressurized tanks) and innovative methods (carbon based nano-materials); (iv) synthesis of hydro-methane starting from H_2 generated by AECs and CO_2 from CCS or biomass gasification; (v) thermo-economic analysis of the systems for hydrogen and hydro-methane production, storage and utilization, taking into proper account the availability over the year of the renewable electricity and the economic scenario. Fig. 2 shows the main activities of the project.

Despite Hydrogen is one of the most promising energy vectors in the near future [3,4], its low energy to volume ratio represents an obstacle towards its large scale diffusion in the transportation sector. Other critical aspects are related to its final use, given the high cost of fuel cells or ICE hydrogen powered vehicles [4,5]. Hydrogen conversion into other fuels or “chemicals”, such as hydro-methane investigated in the IDRO-RIN TRAN-GENESI project, may represent a worthy solution to bypass these energetic and economic limitations. The hydro-methane is produced starting by H_2 and CO_2, according to the well known Sabatier reaction:

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \quad (1)$$

The reaction is highly exothermic ($\Delta H = -165$ kJ/mol) and proceeds in a temperature range between 250 and 400 °C at relatively low pressures (between 2 and 10 bar) on a catalytic bed of Nickel or Ruthenium on Al_2O_3 substrate [6,7].

The gas obtained from the process, after water separation, is composed mainly by methane, plus hydrogen and carbon dioxide not reacted; by definition, hydro-methane (H_2/CH_4) is

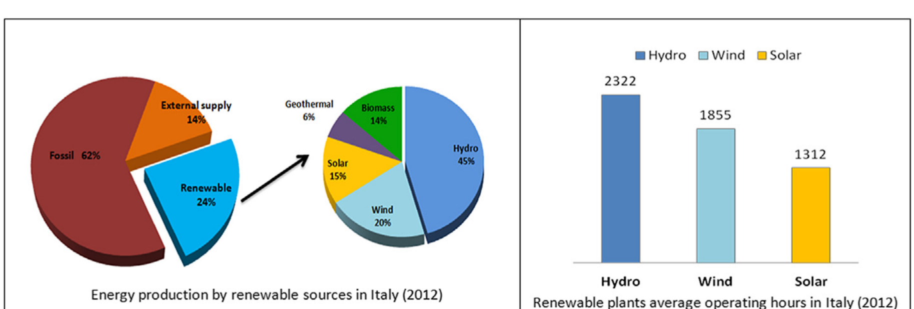

Fig. 1 – Renewable production data in Italy [2].