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Review

# Perspective on hydrogen energy carrier and its automotive applications

*Giovanni Cipriani* [a], *Vincenzo Di Dio* [a], *Fabio Genduso* [a,*], *Diego La Cascia* [b], *Rosario Liga* [a], *Rosario Miceli* [a], *Giuseppe Ricco Galluzzo* [a]

[a] *DEIM, Department of Energy Information Technology and Mathematical Modeling, University of Palermo, Viale delle Scienze, 90128, Block 9, Palermo 90128, Italy*

[b] *DICGIM, Department of Chemistry, Industrial Management, Informatics, and Mechanical Engineering, University of Palermo, Italy*

ARTICLE INFO

*Article history:*
Received 8 January 2014
Received in revised form
19 March 2014
Accepted 23 March 2014
Available online xxx

*Keywords:*
Energy carrier
Hydrogen
Storage
Transportation

ABSTRACT

The paper outlines the concept of energy carrier with a particular reference to hydrogen, in view of a more disseminated employment in the field of automotive applications. In particular hydrogen production is analyzed considering the actual state of the art and recent technologies applied in production from the primary sources (fossil fuels, renewable energies, and water electrolysis). Then the problem of hydrogen storage is considered both from technical and economical point of views. In particular, differences between physical and chemical storage are here considered with a particular glance to the most innovative technologies including carbon nanostructures. A review on the main problems in storage and transportation is then shown with a particular attention given to infrastructures costs that perhaps will address particular choices for the technologies of the next future. Automotive applications are called out, accounting the main current technologies and notes on fueling station for hydrogen fed vehicle. The discussion of hydrogen safety in automotive put in evidence the needs for sophisticated sensors, but a comparison with the safety of gasoline and fire risks, evidences that some common incertitudes on hydrogen usage should be overcome. Some other safety issues are introduced in the section of hydrogen transportation. An overview of costs related hydrogen production, storage and transportation is finally given. This aspect is of a capital importance for the future dissemination of the hydrogen energy carrier.



## Introduction

The growth of the world population and the natural aspiration of new out-coming countries to achieve high economic levels and quality of life are some of the main causes of the restless growth in energy demand and in the concurrent increase in pollution (especially for $CO_2$). Meeting this energy demand is most important technology challenge of the 21-st century

* *Corresponding author.*
E-mail addresses: fabio.genduso@unipa.it, genduso@dieet.unipa.it (F. Genduso).

http://dx.doi.org/10.1016/j.ijhydene.2014.03.174
0360-3199/

[1–5], keeping however low levels of pollution and, thereby, reducing the medium term risk of climate change. Such a scenario should ideally be based on an energy carrier with negligible environmental impact (either locally and globally) [6,7]. Energy should be produced more by primary interchangeable and available energy sources and with preferably distributed locations across a network.

Hydrogen is an energy carrier able to fully satisfy such requisites because:

- its air combustion produces energy and pure water only as the unique reaction product;
- it can be produced from fossil fuels and, hopefully, from renewable sources;
- its energy can be distributed quite easily, in accordance with the end user requests and with the development of new technologies for transportation and storage;
- it may be used in different applications such as centralized or distributed energy production, specific heat production with an extremely reduced, impact.

In view of its special and environmental quality, hydrogen as an energy carrier requires the development of optimum technologies for production, transport, storage and usage [8–15]. Once the technological issues are satisfied, the gradual market introduction of hydrogen-powered vehicles will raise along with the problem of organization and support of infrastructure, guaranteeing the production and distribution within the countries of this interesting fuel.

Technology, logistics and economic issues are, in this case, strongly connected each other. The introduction of hydrogen-powered vehicles is actually hampered by inadequate distribution networks, whose growth can not be achieved without a critical mass market to justify the necessary investment. The problem of planning logistics and networks is further complicated by the large number of existing technological alternatives. These strongly influence costs, and the interdependence between the logistics infrastructure and the technological choices made by vehicles manufacturers [16–19].

The paper is clearly a summary of many possible issues, some of which would have deserved a deeper analysis. It want to introduce the reader into the consideration of very promising technological field. Clearly, for the sake of clarity and synthesis, every aspect can not be deeply analyzed and discussed, but a large bibliography extent is finally given.

## Hydrogen production

Since it is impossible to find hydrogen as available molecules in nature, it has to be produced from other materials that contain it. In particular, hydrogen can be produced from fossil fuels and hydrocarbons, or even from renewable sources. In the following, the most common processes for hydrogen production are recalled [20–25].

### *Production from fossil fuels and hydrocarbons*

Among the methods of hydrogen production from fossil fuels and hydrocarbons, the most suitable are [26–34]:

- catalytic steam reforming (steam reforming of natural gas or oil);
- steam reforming of methanol;
- coal gasification;
- partial oxidation of hydrocarbons;
- alternative technologies (process or Kvaerner Termocracking).

In the catalytic steam reforming, used only for light hydrocarbons (methane and naphtha), it is possible to identify three stages of hydrocarbon treatment: generation of synthesis gas, shift reaction reforming, gas purific ation [22].

As can be seen from the simplified block diagram of this process (Fig. 1), after an initial desulfurization phase, the gas passes through a reformer, constituted by a system of steel pipes containing a nickel based catalyst, where the steam enter obtaining a gas with a variable content of CO and $CO_2$ between 10% and 15%. The shift reaction reforming allows to decrease the CO and $CO_2$ content up to 0.2–0.4% of volume. The final stage allows the purification of the gas from the residual CO and $CO_2$.

In the methanol steam reforming a molecule of methanol ($CH_3OH$) is separated into hydrogen and carbon monoxide: the process consists in an initial decomposition of methanol, followed by a shift reaction and subsequent removal of $CO_2$ [8].

Gasification is an high temperature endothermic reaction of pulverized coal, pure oxygen and water steam, to produce a gas mainly consisting of hydrogen and carbon monoxide. In this process, finely chopped mixed coal and water forms a mash pumped into the reactor, where oxidation reaction with

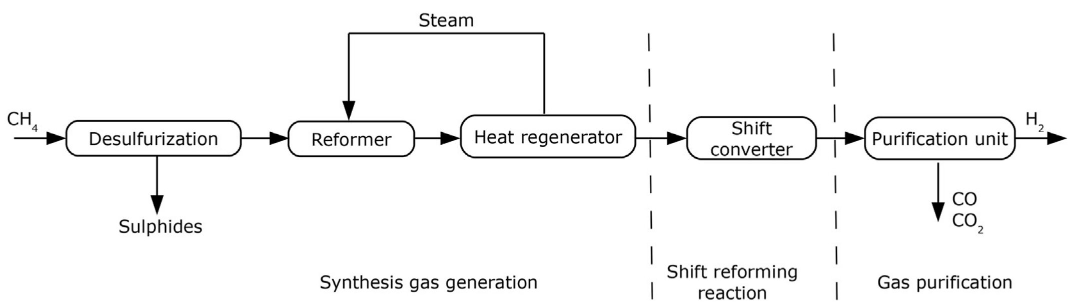


**Fig. 1 – Simplified scheme of catalytic reforming.**