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Use of patents as a tool to map the technological development involving the hydrogen economy

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ABSTRACT

The use of fossil fuels favors the emission of greenhouse gases (GHG). With that in mind, there is a growing need to find sustainable energy options for the transport sector. Hydrogen appears as a potential substitute for fossil fuels. In this way, the objective of this study is to map the hydrogen economy through the patent consultation in the period 1998–2018. The documents found were tabulated in order to characterize the technological advance over the 1998–2018, showing countries that publish and priority patents and the major assignees. This time range was chosen due to the fact that prior to 1998 the number of patents for these technologies was not significant. The searches were conducted on the Questel Orbit platform. Data were filtered using some keywords and the International Patent Classification (IPC). The results show that Japan and United States are the countries with the highest number of patent families by priority. This fact indicates that there are expressive efforts for the technological advance, thus contributing, to be the countries that stand out in these technologies. This research shows that the assignees with the highest number of patents families by priority are Toyota Motor and Honda Motor.

1. Introduction

The high energy density of fossil fuels, the ease of transport and the storage of these fuels has been used extensively for more than a century. Currently, the transport sector is highly dependent on fossil fuels [1,2], but knowing that this type of energy resource affects the greenhouse effect [3,4], there is a need to find sustainable and abundant energy solutions. In this way, the tendency is that new fuels will gain space in the global energy matrix. Among the possible fuels to replace fossil fuels are ethanol, biodiesel, electricity and hydrogen. Hydrogen is one of the most abundant elements on the planet [5], but it is not a primary energy source, having to be extracted from water, biomass, coal, fossil fuels, among other sources [6].

Acar [7] point out that the main advantages of using hydrogen are: reduction of oil importation, sustainability, use of renewable energy sources, better urban air quality, zero carbon emissions, hydrocarbons, GHG and nitrogen oxides (NO_x) in terms of economic viability by increasing future global energy markets. Another important characteristic of hydrogen is the high specific energy, with approximately 120 MJ/kg compared to 44 MJ/kg for gasoline [8].

To enjoy the advantages of this fuel and to start using this fuel in the transport sector, an entire infrastructure for production, storage, transport, and filling stations must be established. Currently hydrogen is used in the chemical industry and for the processing of fossil fuels. The current demand for hydrogen is 48% for natural gas; 30% for the oil industry; 18% for coal gasification; 3,9% for electrolysis and 0,1% for other processes [9]. However, to be used on a larger scale and to meet the need to reduce GHG emissions, the production will need to be sustainable, and it is indispensable to produce at a competitive cost.

Once the hydrogen has been produced, it needs to be stored and transported to the filling stations. Transportation can be done through trucks and ships with cryogenic tanks, in pipelines or tube trailers for gaseous hydrogen, or being produced at the point of use [10]. When at last available for use, hydrogen can be used in internal combustion engines or even in fuel cells. All these steps constitute what is called the “hydrogen economy”. The concept that led to a hydrogen economy first emerged in the work of a Nazi engineer, Lawaceck in 1968 and in the year 1972, Appleby published the first article on the economics of hydrogen [11].

In this way, the purpose of this article is to map through the patent

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consultation the countries that are in a more advanced technological stage in the hydrogen economy, the main companies, and the evolution over the years of the number of publications. Patents were consulted through the Questel Orbit platform between 1998 and 2018, with some keywords and also IPC. The IPC codes used were chosen based on technologies in which they fit within the hydrogen economy. That is, technologies considered important for the development and competitiveness of the hydrogen production, storage, distribution and use stages in vehicles.

2. Literature review

2.1. Hydrogen economy

Some aspects of each step of the hydrogen economy are detailed below for a better understanding of the context.

2.1.1. Hydrogen production

The production of hydrogen (H_2) can be done through various production methods. Among them, the reforming of fossil fuels, gasification of biomass, electrolysis of water, among other methods, which can use renewable or non-renewable energy sources.

The key factor for the use of H_2 energy in real life is the production of hydrogen using cheap and renewable sources [12]. The production cost of hydrogen depends on the level of technology used for the production, availability of infrastructure and price of the raw material [7].

Another important factor that must be observed in the production of hydrogen is the environmental impacts. It can be observed that all forms of emissions cause damage to the ecosystem or even to the human. The selection of hydrogen production process requires various criteria, for example, environmental impact, energy and exergy efficiency, cost effectiveness, energy resources, commercial availability, to be considered [13].

2.1.2. Hydrogen storage

Once hydrogen has been produced, it needs to be stored using one of the storage methods, which can be physical storage (compressed or liquefied hydrogen), chemical storage by using metal hydrides or storage in carbon nanostructures [14].

The storage density is one of the main difficulties of the hydrogen economy. As compared to fossil fuels, hydrogen has a low volumetric density, as can be seen in Fig. 1. The volumetric density of the gaseous hydrogen is approximately 0,0108 MJ/L, about 3000 times lower than

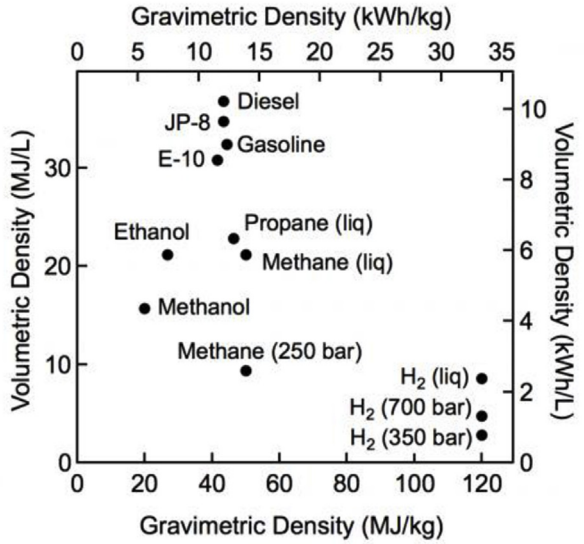

Fig. 1. Comparison of specific energy. Adapted from DOE [16].

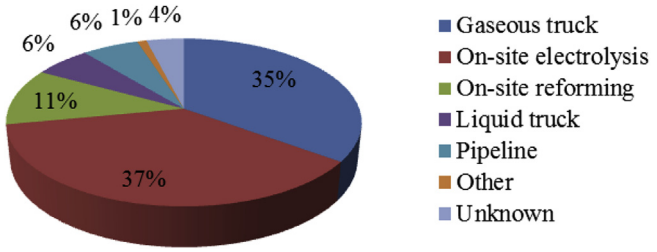

Fig. 2. Forms of hydrogen transportation for publicly accessible stations around the world. Adapted from International Energy Agency [18].

the volumetric density of gasoline [15]. Comparing compressed hydrogen and liquefied hydrogen, the second has a slightly better volumetric density, but is still low compared to fossil fuels. When dealing with gravimetric density, hydrogen is much higher compared to other fuels.

2.1.3. Hydrogen delivery

After production, hydrogen needs to be transported in the following ways to the refueling stations [17]:

- In pipelines or truck tube trailers, for gaseous hydrogen;
- Trucks, barges and ships with cryogenic tanks for liquefied hydrogen;
- Transport of biomass, ethanol, methanol or other derivatives, and reformed at the place of usage.

Currently, the hydrogen produced that is publicly accessible at filling stations, when considering the whole world, 37% is produced at the site of use via electrolysis and 35% transported in truck tube trailers with hydrogen gas, Fig. 2 [18]. As can be seen, a considerable part of the produced hydrogen is transported in tube trucks with gaseous hydrogen, which is feasible only for small distances. For long distances, the best way is transporting it through pipelines.

2.1.4. Hydrogen fueling station

Hydrogen fueling stations are an important part of the hydrogen economy infrastructure. Maniatopoulos et al. [19] point out the hydrogen economy would require a nationwide supply network including:

- Refueling stations for the public;
- Private refueling stations, such as for transport companies;
- Private filling stations for large companies, medium-sized companies and large residential complexes.

Hydrogen can be produced at hydrogen filling stations or at other locations and delivered to the filling station to be distributed. Currently, the largest concentration of hydrogen supply stations is in North America, Europe and Asia. In the United States, there are 37 public filling stations in operation, 26 private stations, 25 planned stations, with the highest quantity of stations being located in California [20]. In Europe, there are 76 stations in operation, 33 of which are out of operation [21]. In Germany, there are 18 stations in operation, 4 in Spain, 12 in the United Kingdom, 9 in France, 5 in Norway and 10 in Denmark [21].

2.1.5. Fuel cell vehicle

One of the main applications of hydrogen is in fuel cell vehicles. Fuel cells generate electrochemical reactions that produce energy in the form of continuous chain [22]. Furthermore, fuel cells have a low emission and high efficiency if compared to an internal combustion engine.

Nowadays, some automakers have fuel cell vehicles available for purchase, but only in some places in which has some infrastructure.