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Technological forecasting of hydrogen storage materials using patent indicators

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ABSTRACT

Hydrogen is a promising future energy carrier due to its high energetic content and sustainable appeal when produced via clean manufacturing processes. One of the technological challenges concerns its storage in a safe, compact, low mass and high gravimetric capacity manner. In this sense, many Hydrogen Storage Materials (HSM) have been investigated to house this source of energy, such as Simple Hydrides, Borohydrides, Metal-Organic Frameworks (MOFs), Alanates, AB5 Alloys, Ammonia Borane, Carbon Nanotubes and Graphene. Scientific advances aside, less attention has been paid in establishing a panorama of the technological developments in HSM. To assess the technological advances in HSM, patent analysis can be carried out using bibliometrics and text mining approaches in order to forecast the future trend of development and the main players involved in this process. In this work, we evaluated the technological life cycle stage, HSM class prominence and the role of different countries in HSM patenting. The results show that overall HSM patenting decreased after 2007, except in the case of China. On the other hand, the USA, Japan, China and the European Union (EU) were the main patenting territories. Simple Hydrides and Borohydrides were the main classes of HSM that received more attention from the USA and the EU, while Japan had a high share in Solid Solution Alloys. The life cycle stage of HSM seems to be between the first prototype market experiences and full market deployment, even though future assessment is needed to fine-tune the analysis. The developed indicators may also support the funding of new projects and decision making.

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Introduction

Hydrogen is considered a promising energy carrier for the future, due to its abundance, high energy content (142 MJ/kg) and its ability to be employed both in fuel cells and combustion engines, in stationary or mobile applications, potentially producing only H_2O as an environmentally benign by-product. Hydrogen can also be generated from water using renewable energy in a sustainable closed-cycle [1]. Nevertheless, the wider use of hydrogen energy still depends on the overcoming of technological challenges, in particular, the development of safe and effective hydrogen storage technologies, since the more traditional high pressure or liquefied H_2 storage methods require high capital costs and raise safety concerns, as well as having low gravimetric and volumetric storage capacities [2].

Solid-state hydrogen storage in Hydrogen Storage Materials (HSM[1]) has been extensively investigated in recent years [3]. Different attributes must be evaluated during the development and selection of HSM, such as the gravimetric and volumetric hydrogen capacities, its ease of activation (first hydrogenation), reversibility and cyclability, recyclability, toxicity, the cost of the raw materials and processing, and the temperature and pressure operation ranges. Several materials classes are being considered for hydrogen storage solutions both for mobile and stationary applications [4]. Table 1 presents the storage materials classes considered in this study, with example materials and typical operating conditions. The classes are: Simple Hydrides, AB5 Alloys, BCC Solid Solution Alloys, AB Alloys, AB2 Alloys [5], Borohydrides, Alanates, Amides [6], Nitrogen-Boron Compounds (N-B[2] Compounds) [7], Carbon Nanotubes, Activated Carbon, Carbon Nanofibers, Fullerene, Graphene [8], Metal-Organic Frameworks (MOFs) [9] and Zeolites [10].

Although several types of HSM have been investigated, none of them possess an ideal set of properties for all applications. Therefore, niche applications are being developed taking advantage of the strong points of the individual classes. For example, vehicular applications require the storage materials to be lightweight, since they implicate in extra curb weight, and the use of off-site regeneration of cartridges in chemical plants is feasible. For stationary grid storage applications, the weight of the system is less important. However, they require excellent reversibility, since the off-site regeneration is not feasible, and the cost per kWh of storage capacity must be low, since the amount of energy to be stored is very high [3].

Technological advances in HSM can be tracked using Science and Technology (S&T) Indicators. According to Moed, Glänzel and Schmoch [16], these quantitative indicators aim at supporting S&T policies by monitoring the output of research and development (R&D). Mogee [17] argues that these indicators may update the technological advances for companies and increase the security of business investments. S&T indicators are elaborated employing concepts, tools and procedures researched in Bibliometrics, which is a discipline that quantifies registered communications, such as scientific articles, technical reports and patent documents. Recent advances in Bibliometrics include the use of information from non-structured text, such as the title, abstract, and manuscript *corpus*. This process is called ‘Text Mining’ and it extracts specific and relevant terms that can be used to develop content-oriented indicators [18]. For instance, a mined term ‘MgH_2’ in the title or abstract of a document may be used to relate it to a specific material class, e.g., Simple Metal Hydrides.

Patent documents constitute an important source of technological information, since they contain detailed descriptions of inventions and are used by patent assignees to request the exclusive rights to commercial exploitation [17]. Patent documents constitute a rich source of technical and business information, and their use can provide high-value information, for example, detailing which companies and institutes are investing in which technologies and to what extent, and thus supporting the assessment of technological life cycles and policies of countries and companies in specific technological developments [17,19,20].

The use of patent document information is, however, not uncontroversial, and some characteristics must be taken into consideration [17,21]:

- The legal framework, filing procedures and patenting culture varies among different countries
- Patents are not only filed for registering inventions. Given their legal value, they become strategic assets for potential market reservation and commercial blocking, among other uses. And especially in research, they may merely be a way of turning research results into a tangible output.
- Patents do not cover all inventions. Technologies may be maintained as industrial secrets, for example.
- After their deposit, patent documents remain confidential for 18 months. Furthermore, with third party databases, there is an indexing delay, and not all patent documents may be indexed.
- The propensity to patent varies among different areas, although it may be assumed homogeneous within a single area.
- In patent counting, the same weight is given to each document, regardless of, for example, economic value, unless a specific methodology is applied.

Nevertheless, patent-based indicators are extensively used by enterprises and entities such as the Organization for Economic Co-operation and Development (OECD[3]) [22] and the United States National Science Foundation (NSF) [23], indicating their high value.

The life cycle of technologies is considered to typically follow an S-curve type of development, and is divided into four stages, as shown in Fig. 1 [21]. The emergence stage is characterized by the first market trials and prototypes. Technological progress tends to be slow, as the complete understanding of the fundamentals is still in progress. The

[1] HSM: Hydrogen Storage Materials.

[2] N-B Compounds: Nitrogen-Boron Compounds (e.g. Ammonia Borane).

[3] OECD: Organization for Economic Co-operation and Development.