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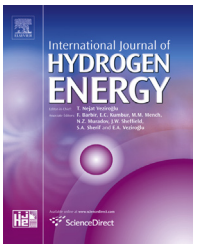

Examining the trends of technological development in hydrogen energy using patent co-word map analysis

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ABSTRACT

Hydrogen fuel is a zero CO_2 emission fuel which uses in electrochemical cells, or internal combustion engines, to power vehicles and electric devices. It is also can potentially be mass-produced for various applications and be used in propulsion of spacecraft with safely high pressure storage. Therefore, it is an interesting subject to identify the technological trends of hydrogen energy. This study suggests a patent co-word map analysis (PCMA) to examine the trends of technological development in the area of hydrogen energy. The PCMA provides a systematic procedure to demonstrate the overall relationship among patents and produces the important technological insights regarding hydrogen energy. The results of analysis firstly indicate that the technological trends of worldwide hydrogen energy focus on the converting and application of hydrogen. Furthermore, critical technologies obtained from three patent sub-maps can be identified as the production, storage and conversion for hydrogen energy. Finally, hydrogen application is taken for the key factor in sustainable energy research works to improve the use for hydrogen.

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Introduction

Hydrogen, the simplest and the most abundant element in the earth, is easily found in water and many organic compounds such as methane or natural gas. It can be separated from hydrocarbons by reforming, application of heat, or by electrolysis, separation of water into oxygen and hydrogen. Hydrogen, although high in energy, produces almost no pollution when burned, but its low density requires special compression and storage facilities. Scientists use liquid hydrogen to propel space shuttles, hydrogen fuel cells to power the shuttle's electrical systems, producing water as a byproduct, which the crew drinks.

Hydrogen can be produced from natural gas, coal, hydrocarbons, biomass and even municipal waste by using a variety of techniques, as well as by splitting water from electricity supporting [1]. Such diversity significantly contributes to the security of fuel supply. Fuel cells convert hydrogen fuel and an oxidant directly into electricity by using a low-temperature

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electrochemical process. While operating with hydrogen or hydrogen-rich fuels, fuel cells potentially play an important role in catalyzing the transition to a future sustainable energy system with low CO_2 emissions. Hydrogen is produced in large quantities by steam reformation of hydrocarbons, generally methane. This method yields CO_2 as a byproduct, yet does not burn the same amount of methane. Hydrogen can also be produced by splitting water through various processes, including electrolysis, photo-electrolysis, high-temperature decomposition and photo-biological water splitting [2–5]. Therefore, hydrogen energy plays an important role in the promising technological area of new clean energy [6]. It compares favorably with other fuel technologies in many aspects such as high-quality, non-polluting and safety [7]. Although hydrogen energy has many advantages and potential, currently relevant technologies are in growth stage and some technological bottlenecks need to be solved such as energy efficiency and heat loss during production and converting processes [8]. Before the next stage of technological development, examining the critical technology and future trends of the promising green energy is necessary.

Among various analytic tools for technology monitoring, patent analysis has long been recognized as a valuable analytic technique used to identify the critical technology and technological trends in the area of novel technology [9]. Patents are major outputs of research and development, and have been regarded as very rich and potentially fruitful sources of data for the study of innovation and technological change [10]. Patent analysis is able to convert patent data into useful information on technology [11]. The analysis is widely used for investigation of technological trends, identification of critical technologies, exploration of emerging technologies, and forecast of technological development [9,12–14]. Especially, patent analysis has been employed to explore related subjects of clean energy in recent years [12,15,16]. Concerning the methods for patent analysis, patent citation analysis has become the most frequently adopted technique [17,18]. The concept of patent citation analysis is that the patents cited by many later patents represent relative importance of inventions. Although patent citation analysis is easy to use, it has no capability of grasping the internal relationships among patents because citation analysis only takes into consideration the citing-cited information [19]. Furthermore, patent citation analysis is inclined to underestimate the importance of new patents due to the time lag of the patenting process. Thus, it is difficult to use this traditional method to monitor up-to-date trends of technological changes, particularly for quickly developing and complicated area of technology.

To overcome the limitations mentioned above, the patent co-word map analysis (PCMA) is suggested in this study to effectively examine the trends of technological development. The proposed PCMA is based on the idea of co-word analysis. Co-word analysis is a content analysis technique that reveals patterns and trends in a specific area of science and technology by measuring the association strengths of terms representative of relevant publications produced in this area [20]. Many studies have used co-word analysis to explore research trends in different areas such as polymer chemistry [21], medicine [22], biology [23], robot technology [24], and so on. Therefore, the purpose of this study is to apply the concept of co-word analysis to developing the PCMA for analyzing complicated relations among patents and identifying trends of technological development in the area of hydrogen energy. By computing the co-occurrences of key words in the patents on the subject of hydrogen energy, PCMA attempts to establish the linkages between semantically similar patents in order to generate a visualized patent co-word map for the area of hydrogen energy. The visualization of patent co-word map is able to assist users in comprehending complex relationship among patents intuitively and grasping the diverse features of important patents effectively. In particular, the proposed method uses technology key words which describe the contents of patents as input base to generate a visual map, so it is adept at discerning the inner structure of patent co-word map and thereby yields relevant results. Moreover, the proposed method suggests quantitative indexes for further analysis of the visualized map including the critical patented technologies, technological progress of patents, and characteristics of patent sub-maps in the area of hydrogen energy. The ample and valuable technological implications regarding hydrogen energy can be deduced from the analysis of proposed indexes.

The rest of this study is structured as follows. After the theoretical background on the proposed PCMA in Section Theoretical foundation, the detailed process of methodology for PCMA is explained in Section Methodology. The results of analysis from the whole patent co-word map and sub-maps using the PCMA in the area of hydrogen energy are then described in Section Results and discussion. Finally, the conclusions are discussed in Section Conclusion.

Theoretical foundation

The theoretical foundation of the proposed PCMA is composed of co-word analysis and graph theory. Co-word analysis, which is a content analysis technique, is used to identify future trends of development in a specific research area by measuring the relationship between publications which contain the same key words [20,21]. Based on the nature of key words which represent important contents of scientific concepts, ideas and knowledge, co-word analysis establishes a subject similarity between two publications [25]. If two publications include the same key words, they can be said to be related to each other. The higher the co-occurrence frequency of key words in publications means the closer the relation between publications. A matrix is further constructed by the relationship of co-occurrence to generate a map in order to identify the trends in a specific area of science and technology. Furthermore, co-word analysis is widely used to examine the trends of scientific research and technological development [21–24].

In addition to co-word analysis, graph theory serves as an important theoretical base of PCMA. Graph theory is the study of maps (graphs), which are mathematical structures used to model pair-wise relations between objects [26]. A map consists of nodes which are the given entities in a map, and lines called edges that connect nodes. The structure of edges between nodes can be visually illustrated by graph theory [27]. The relationship among nodes and the location of individual nodes in a map provide rich information and enable the users

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