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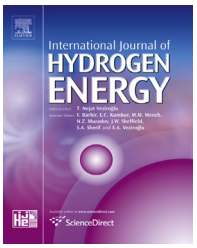

Using social network analysis to examine the technological evolution of fermentative hydrogen production from biomass

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ABSTRACT

In recent years, hydrogen energy has become important to sustainable energy supply as a source that can help mitigate the impact of climate change. This study examines the evolution of biomass fermentation, an important part of hydrogen production, by using patent searches and citations, and surveying the momentum of the technology. The social networking created by the relationships among patent citations for patent technologies are first analyzed, and the evolution of patent technology is discussed by describing its momentum. Following this, the core patents emerging from the evolution of patent technology are identified, and the cycle time for the patent technology is estimated from the cited patents. The study analyzed approximately 1970 patents by United States Patent and Trademark Office to describe the evolution of fermentative hydrogen production through biomass technology. The results revealed that the developmental stage of fermentative hydrogen production from biomass is growing, and its technological cycle of approximately 12.59 years indicated a gradually changing trend in fermentative hydrogen production from biomass. The study findings should provide governments with a reference point in the formulation of future energy policy.

Introduction

The development of hydrogen energy technology, its applications, and the hydrogen economy in general have emerged as important solutions for worldwide reduction of reliance on fossil fuels and the development of a sustainable energy supply. However, the applications of hydrogen technologies are either in their experimental stages or too new to introduce to the commercial market [1,2]. In order to promote the development and application of hydrogen energy technology in the service of a hydrogen economy, many countries have promoted the commercialization of associated technologies through technological and industrial policies. Emerging hydrogen energy technologies include hydrogen production, storage, and transportation as well as such applications of hydrogen energy as fuel cells, vehicles, and systems driven by fuel cell power. Several major hydrogen production technologies are prevalent at present, including coal gasification, natural gas recombination, water electrolysis, and biomass hydrogen production [3,4]. The production of hydrogen from

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biomass includes thermo-chemical and biological approaches [5].

Biological hydrogen production technologies include direct photosynthesis, light fermentation, and dark fermentation [5–9]. In hydrogen production using dark fermentation, biomass material is converted into syngas containing hydrogen and CO_2 through hydrogen-producing bacteria [3]. Dark fermentation has significant potential among the biological approaches to hydrogen production [7,10]. Biological hydrogen production has several advantages, such as the reduction of carbon emissions by using biomass substances, enhanced revenue for agriculture, the sustainability of biomass energy, and a reduction in the cost of urban waste disposal [11].

In order to promote hydrogen energy technology, including biomass fermentation, we need to consider all viable approaches to its large-scale commercial application and develop strategies for long-term, continual operations for stable hydrogen production [12,13]. Since these emerging technological applications are in their initial developmental stages, they face numerous obstacles and challenges, such as high cost, system lifetime, reliability, meeting market demand, and the lack of peripheral facilities, en route to commercialization [14,15]. The specific challenges facing the development of biological hydrogen production are as follows [16]: the hydrogen production yield must be continually improved, the optimal process of hydrogen production must be determined, low-cost methods need to be developed for planting, harvesting, transporting, and pre-treating biomass raw materials or biomass waste, and the hydrogen production process and the by-product process need to be integrated to enhance the economic benefit of biological hydrogen production.

By analyzing technical information associated with patents, we can determine trends in technological development and predict potential directions in the development of new technology [17]. Through detailed analysis, patents can be used as the basis for investment, and can provide insight into technical details, business trends, and industrial innovation plans that might be needed [18,19]. Patent analysis can be used to establish corporate technological strategy and evaluate the technical capability of a company as the basis for corporate mergers and acquisition strategies. It can also contribute to the understanding of competitors and trends in global competition [20]. Patent analysis is likewise an important tool for industrial development or technological forecasting [21]. At the national level, patent analysis can help governments plan for technological development [22] and simulate trends in the development of specific emerging technologies [23–25].

The main purpose of this study is to construct an analysis model of technological evolution with fermentative hydrogen production from biomass based on patent information. The analysis model uses a social network analysis method to develop an analytical step that can extract useful information and knowledge to analyze technological evolution using a patent database. Furthermore, this study identifies core patents in technological evolution as well as the pace of technology change. This study used the United States Patent and Trademark Office database in processing analysis models to determine the technological evolution of fermentative hydrogen production from biomass.

Literature review

Patent analysis of hydrogen energy technologies

Many scholars have used patent analysis to investigate the status of the research and development (R&D) as well as the trends in hydrogen energy and fuel cell technologies. The research conducted by Daim et al. used bibliometrics and the patent analysis method to predict trends in the development of three emerging technologies, including fuel cells [21]. Suominen and Tuominen used the patent analysis method to study the development of the direct methanol fuel cell (DMFC) [26].

In Kwon's research, trends in the R&D of fuel cell vehicles were analyzed through patent trends and patent owners [17,27]. Bakker used a patent combination to investigate the choice of hydrogen storage technology for the automobile industry [28]. Sheng and Xin used social network analysis to understand the correlation between the development of the proton exchange membrane fuel cell (PEMFC) patents by General Motors (GM) and Panasonic [29]. Social network analysis explores the relationship (ties) between actors (nodes), where the methodology is focused on relationships among humans. When taking patent information as basis, nodes can represent inventors, patent applicants, or documents like patents. Ties can symbolize cooperation between the nodes, or citation links [30]. Carvalho et al. used patent information to investigate the R&D status of PEMFC in Brazil from 1996 to 2005 [31].

Chen et al. combined bibliometrics and the patent analysis method to establish fuel cell technology, discover the S-curve, and confirm the optimal patent strategy for all kinds of fuel cell industries, including PEMFC [32]. Olivo et al. used the patent analysis method to compare the priority assigned to the development of advanced hydrogen production technology in China, Japan, South Korea, the E.U., and the U.S. They also observed the scope and competitiveness of these technologies as well as the developmental trends of biological hydrogen production technologies [33]. Leu et al. investigated the status and activity of technological development in the field of biofuel and biohydrogen energy from 2000 to 2011 through patent bibliometric analysis [34]. The results of this study suggest that the principal or predominant technologies in the field of biohydrogen energy need a significant amount of work to accelerate their development.

Analysis and application of patent citation

A citation-based patent study is called patent citation analysis. It seeks to link patents in the same way that science citation links references in the scientific literature [35]. From the citation relation among patents, we can further determine the importance of certain patents and the technical correlation among them. Therefore, patent citation analysis can be used as a tool for exploring key patents, confirming technical

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