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Technology exploration and forecasting of biofuels and biohydrogen energy from patent analysis

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ABSTRACT

The status and activity of technological development in the field of biofuel and biohydrogen energy from the year 2000–2011 were investigated utilizing patent bibliometric analysis. Based on the reports, the current status indicates that the key technologies for biofuel energy have reached technological maturity in the United States. However, the principal or predominant technologies for biohydrogen energy need a great deal of work to accelerate the development of biohydrogen technology. In addition, three important subjects were found from citation techniques, which are related to biodiesel fuel, biological fuel cell, and the biohydrogen. These patents described that the focus of key techniques of energy production should be established towards low energy demand technologies, and biohydrogen was found to be a potential candidate of the future. Finally, this proposed model can be applied to all high-technology cases, and particularly to green energy field.

1. Introduction

Patents contain extensive technological and commercial information. From the viewpoint of intellectual property rights, the patent is an important instrument to encourage inventors to invest in researches and creative works that will put those inventions to practical applications. Patents enhance the exploitation and commercialization of technologies through market transactions and contracting [1], consequently promoting the dissemination of knowledge and innovation. Therefore, patent documents are rich sources of technological and commercial information. They record the nature of the invention, the direction of the technological development, and the activities of the R&D team. For above reasons, the patent is not only an expression of technological progress, but it is also a powerful tool for exploring a technological potential from economic viewpoint.

Patent analysis helps to mine and arrange relevant data from the patent documents in terms of technological competitiveness, trajectory of technology development, and correlated patent claims thus converting them into valuable pieces of information [2–4]. Among various methods of patent analysis, patent bibliometric analysis is most commonly used technique to implement patent analysis [5]. Patent bibliometrics uses bibliometric data from patents to perform statistical analysis and citation analysis. Statistical analysis utilizes bibliometric data, such as number of patents, country, assignee, inventor, and so forth. Then, the citations of a patent or non-patent literature in subsequent patent citations in patents are also counted for further citation analysis [6].

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Citation analysis utilizes these citations in patent documents to find the important patents and other science linkages.

Biofuel is a type of fuel whose energy is derived from biological materials [7]. Generally, biofuels include fuels derived from biomass conversion, as well as solid biomass, liquids and biogases [8]. Biohydrogen is currently gaining importance as biofuel of the future and a potential replacement of fossil fuels. This biofuel consists of hydrogen produced via a number of biological processes. Biohydrogen is renewable and it does not produce toxic green house gases, hence it is currently being considered as one of the key sustainable power supplies in the world [7]. Many biomass-related studies focused on the hydrogen generation since the discovery of the generated heat value of hydrogen (244 kJ/mol), which is larger than other hydrocarbon fuels. In fact, hydrogen is clean and its high efficiency gives it the advantage of being the most potential substitute of fossil fuel. Presently, 96% of hydrogen energy generated is mainly by restructuring of industrial by-products which are non-renewable sources. Thus, the development of biohydrogen technology is a suitable alternative which addresses the issues of environment protection, economic efficiency and sustainable energy consumption. Hence, in the near future, biofuel and biohydrogen production will be considered as one of the crucial sustainable energy technology in the world [9].

Owing to the rising demands for green energy technology, it is an important issue to explore the technological development of biofuel and biohydrogen energy. Therefore, this study utilizes patent bibliometric analysis to investigate the status and trends of technological development in the field of biofuel and biohydrogen energy. Initially, statistical techniques were used to find out the information on various aspects of patenting activities including growth in inventions, country comparison, assignee performance, active assignees, co-inventorship pattern, and productivity of inventors in order to comprehend the developmental status of biofuel and biohydrogen energy. Next, citation techniques were employed to analyze highly cited patents to uncover the important technologies in the field of biofuel and biohydrogen energy. Finally, the results of technological development are suggested, in order to assist researchers in executing and managing technology for biofuel and biohydrogen energy.

Although previous studies have used patent bibliometric analysis to implement the patent exploration, this method can also help the scientific researchers to greatly acquire the cost-effectiveness in processing lots of patent documents and quickly grasp the technological insights in a short period of time. Therefore, this study aims to extract technological trends in the field of biofuel and biohydrogen energy by using patent bibliometric analysis and demonstrate patent analysis in the field of green energy.

2. Methodology

2.1. Data collection

The data of patent documents in the field of biofuel and biohydrogen energy were obtained from the U.S. Patent and Trademark Office (USPTO) database available at www.uspto.gov. This search was made by looking for the code "biofuel" or "biohydrogen" in the titles and abstracts of patent documents. Four experts, who work either in the field of biofuel or biohydrogen, helped to review the search results and eliminate the irrelevant ones. In this study, 227 patents from January 2000 to May 2011 were collected according to their issue date, and there are 12 patents issued before the year of 2000.

2.2. Patent bibliometric analysis

Bibliometric method is a quantitative analysis done to aid the evaluation of research performance [10]. Patent bibliometric analysis is a research method utilizing bibliometrics to perform patent analysis in order to evaluate technological activities [11]. The opinion of using bibliometrics for analyzing patent information could be dated back to 1940s when Arthur H. Seidel proposed producing a citation index from the patent documents and Harry C. Hart endorsed the idea in a later issue [12]. However, the first citation index to the patent documents was published in the year 1964. Although the opinion of building citation index for patent information was mentioned in 1940s, neither patent citation nor other bibliometrics were broadly applied for patent documents analysis until last decade [13].

In recent years, Narin [5,11] applied bibliometrics to establish the use of patent bibliometric analysis. These studies had been conducted by using the patent bibliometric analysis method. The bibliometric data in the patent documents include information as follows [14–16]:(1) Patent number; (2) Application number; (3) Date of issue; (4) Date of application; (5) Title; (6) Country; (7) Inventor; (8) Assignee; (9) Claims; (10) International patent classification; (11) References and (12) Priority.

Researchers can utilize various methods and techniques to analyze the data and find the developmental states of the patented technology. In general, statistical techniques and citation techniques are the main research methods for patent bibliometric analysis. Statistical techniques perform statistical calculations on the chosen set of bibliometric data to analyze the development and distribution of the patented technology. For statistical techniques, patent counting is the most common method used. By counting the number of patents granted each year, the growth of the patents could be analyzed [14]. Furthermore, this method was also applied to analyze the productivity on countries, assignees and inventors [5,6,14,17]. In addition, other patents and non-patent literatures cited in the patent documents are main analytical focal points of citation techniques. Determination of most highly cited patents reveals the important patents in this field and establishes the technological foundation of the patents being studied. The analysis of non-patent literature cited in the patent documents can uncover the linkages between the patented technology and basic science as well as ascertain the scientific foundation of the related patents [6,18].

3. Results and discussion

This study used bibliometric techniques to analyze the status of technological development in the field of biofuel and biohydrogen energy. The different aspects of patenting activities

were compared, and the goal of this preliminary analysis was to understand the developmental path and current status of biofuel and biohydrogen technology.

3.1. Growth in inventions

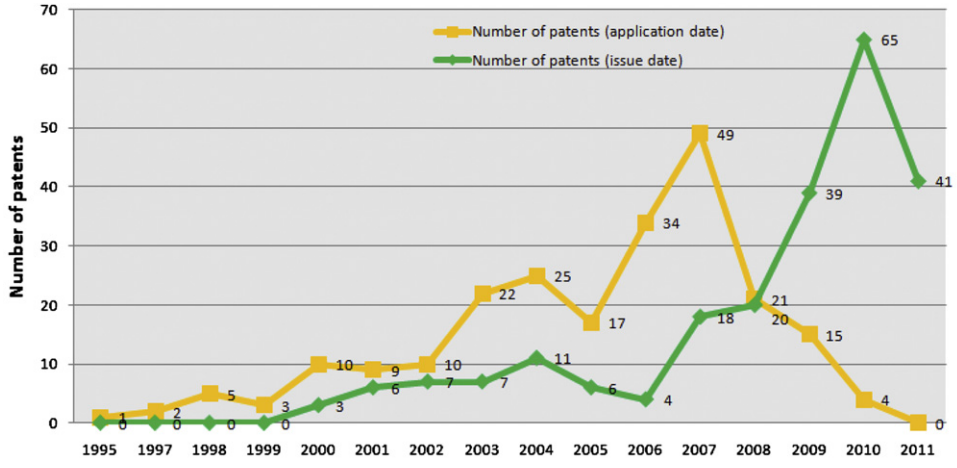
Fig. 1 shows the growth in the number of patents in the field of biofuel and biohydrogen energy. The first patent was filed in 1995, but its issue date was found to be in 2001. This indicates that the first patent was reviewed for a long period of time, and therefore the first issued paper in 2000 was field after 1995. From the trend of issue dates, patent publications were found to be most active from 2007 to 2010, and it is also evident from the literature that biofuels technology developed significantly from the year 2000 onwards. The patent activity in this field attained its peak in 2010, and a maximum number of 65 patents were issued in this year. Among these 65 patents, the majority was related to diesel fuel. In fact, the worldwide biofuel production reached 105 billion liters in 2010, which was a 17% hike from 2009, and biofuels provided 2.7% of the world's fuel for road transportation. Moreover, a large fraction of biofuel-related products were made up of ethanol and biodiesel. In addition, the majority of patents were filed between 2003 and 2007. This also indicated that biofuels-related patents took about 1–4 years to move from patent application to patent issue. Hence, the biohydrogen research being a considerably new area needs a longer period of time to develop new products. The related patents are expected to appear in the future years. However, after 2008 the number of patent applications has slowed down. The reason for this phenomenon may be due to the fact that the key technology in this field has been well established, and the technological bottlenecks for bioethanol and biodiesel production have been overcome.

3.2. Country comparison

Fig. 2 provides information on the distribution of patenting activity in different countries. Three countries namely USA, Canada and Brazil possessed a total of 180 patents in our collection. In particular, USA owns 171 patents, which is the most active country in the biofuels field. The subject of bioethanol plays an important role in these 171 patents. This could be due to the fact that USA needs more energy resources and holds the leading status in the development of novel green energy technology worldwide. Bioethanol as fuel for vehicles is used in Brazil and the USA. It is used as a gasoline additive to increase octane and improve vehicle emissions. Currently, the focus of bioenergy research is to convert the non-grain energy plants to fuel components like bioethanol by fermentation. The key technologies for bioethanol production are well established, whereas the biohydrogen production is still under technical development. Several countries in European Union and Asia occupy small portion of patents in the field of biofuels. This further confirms the fact that development of technology for biofuels production from renewable resources has attracted the attention of many countries in the world.

3.3. Assignee performance

Patent protection is an important process in the commercial exploitation of a new technology as it helps to insure the technology and maximizes its competitive advantage. In the field of biofuels and biohydrogen, most of the patent assignees are industrial enterprises [19]. This indicates that the production of biofuels and biohydrogen has commercial potential for industrial applications. Fig. 3 shows the patent activity of assignees ranging from corporations, academic institutes, individuals, R&D institutes, consortiums of corporations and R&D institutes, consortiums of corporations and academic institutes, as well as consortiums of corporations and individuals. The data shows that corporations owned 142 patents, which corresponds to 63% of the total patents, thus making them the major assignee in biofuels and biohydrogen field. In addition, the proportion of patents owned by academic institutes corresponds to 19% of the total patents, whereas only 10% of the total is owned by individuals.



	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Number of patents (application date)	1	2	5	3	10	9	10	22	25	17	34	49	21	15	4	0
Number of patents (issue date)	0	0	0	0	3	6	7	7	11	6	4	18	20	39	65	41

Fig. 1 – The growth in the number of patents in the field of biofuel and biohydrogen energy.

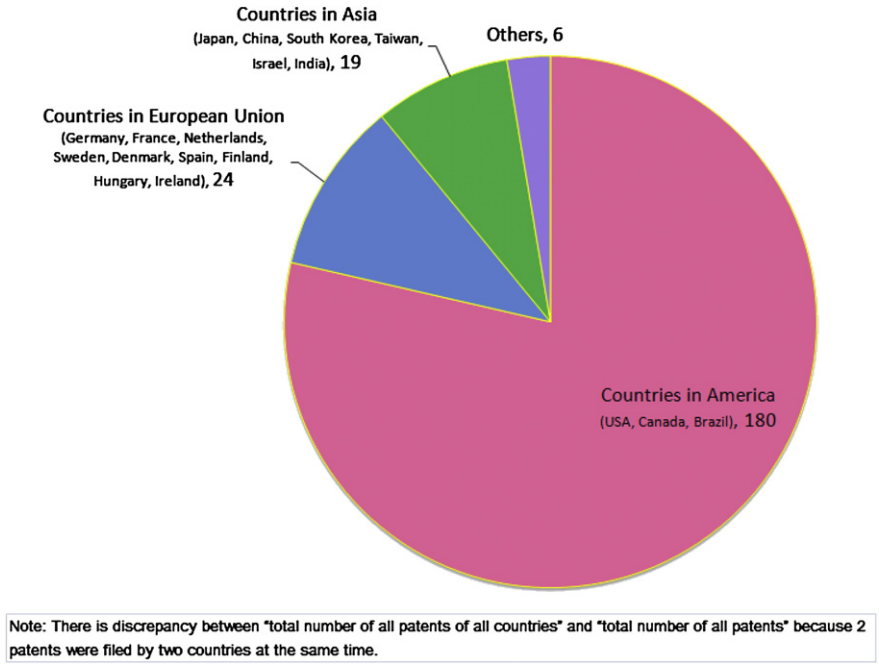


Fig. 2 – The analysis of patenting activity in different countries.

3.4. *Active assignees*

In order to figure out the most active assignees in the field of biofuel and biohydrogen, each assignee was analyzed further in this study. With respect to corporate assignees, Chevron Corporation from USA, which is one of the largest energy companies in the world, is the leading corporation with the highest number of patents in this field. In fact, Chevron endeavors to develop alternative energy technology in recent years. It invests 300 million USD per year into alternative fuel sources, and has created a biofuels business unit [20]. The second most active corporation is Exxon Mobil Corporation from USA, which is the largest publicly traded international oil and gas company in the world. This finding reveals the fact that USA corporations are the technological leaders in the field of biofuels development.

In the case of academic institutes, a total of 36 patents are owned by several universities from USA. The University of California and Michigan State University own the highest number of patents among these universities. This indicates that academic institutes in USA play key roles in the basic research of biofuels and biohydrogen. Regarding individuals, most of patents were applied in USA. Christopher Limcaco, Michael Pelly, and Rudolf Gunnerman from USA are the most

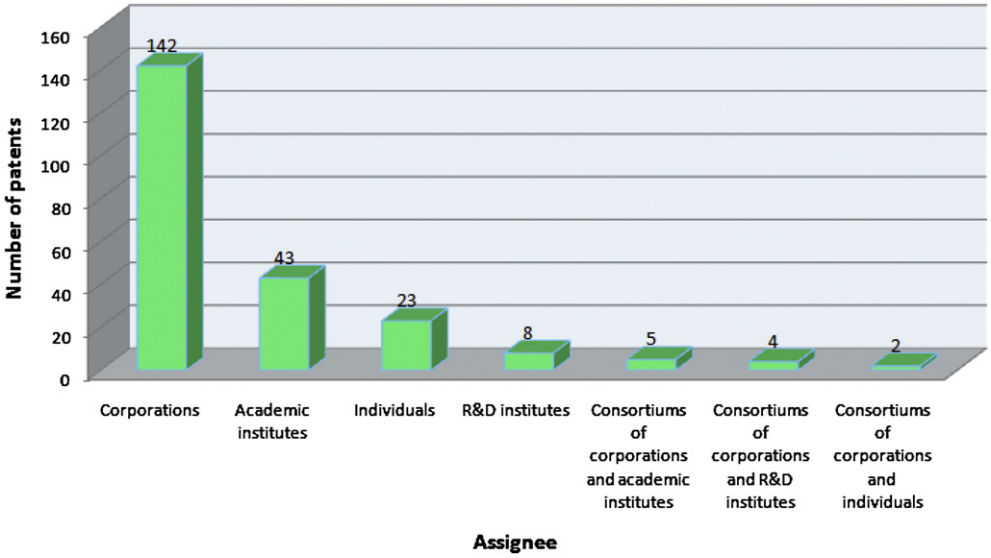


Fig. 3 – The analysis of patent activity of assignees.

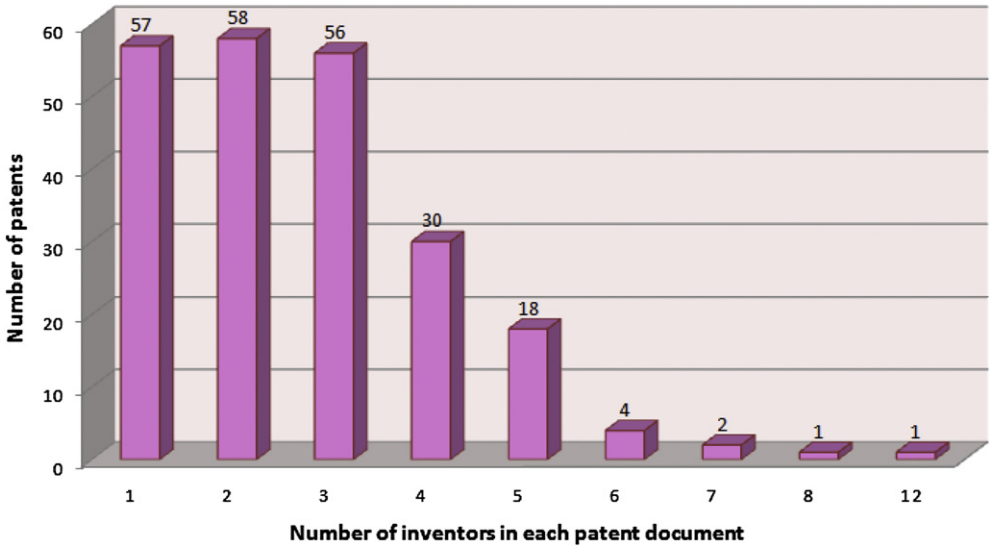


Fig. 4 – The distribution of inventorship in the field of biofuel and biohydrogen energy.

active assignees. Among all R&D institutes, Research Institute of Innovative Technology for the Earth (RITE) from Japan is the most active institute in this research field. RITE is a major research institute which contributes to the resolution of the global environmental problem in Japan, and the development of biofuels and biohydrogen technology is one of its research objectives. In terms of consortiums, Ion Power Company and Penn State University in USA owning two joint patents are the most active among consortiums of corporations and academic institutes. Sharp Corporation and RITE in Japan which have two patents are the most active among consortiums of corporations and R&D institutes. The above results reveal that there are still many opportunities for research worldwide which can be developed through partnership.

3.5. *Co-inventorship pattern*

The co-inventors in patents, means the names of all contributors and researchers who directly contributed to the patentable features of the invention [14]. Fig. 4 shows the distribution of inventorship in the field of biofuels and biohydrogen. Only one-quarter of the patents were owned by single inventors, whereas the remaining were joint patents with one or more co-inventors involved. Among all the joint patents, majority is owned by two or three inventors. Furthermore, the highest number of inventors for a patent was found to be twelve. Therefore, it is apparent that R&D collaboration is necessary and important in the field of biofuels and biohydrogen.

3.6. *Productivity of inventors*

This study also calculated the total number of patents from each inventor. This can help to evaluate the productivity of inventors in the field of biofuels and biohydrogen, and the results are shown in Fig. 5. Among these inventors, 408 inventors produced only one patent each. These 408 inventors consist of 82.93% of all inventors. Moreover, there are only 18 inventors who could produce more than two patents, and among those 18 only two inventors could produce a maximum of seven patents. These two inventors are P.J. Berlowitz and R.J. Wittenbrink from Exxon Mobil Corporation in USA. All

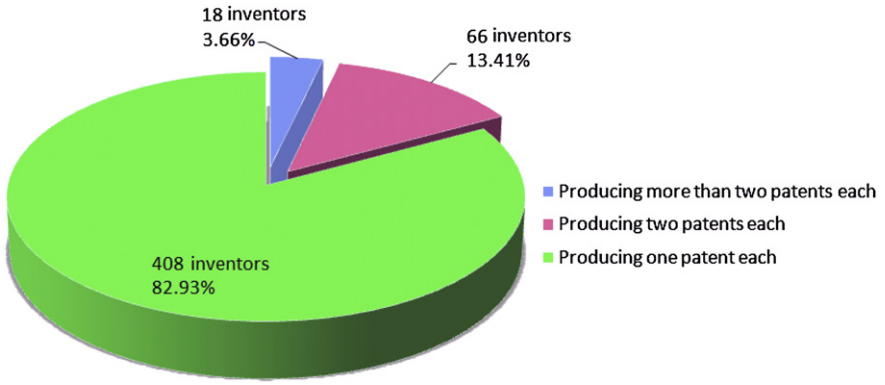


Fig. 5 – The productivity of individual inventors in the field of biofuel and biohydrogen energy.

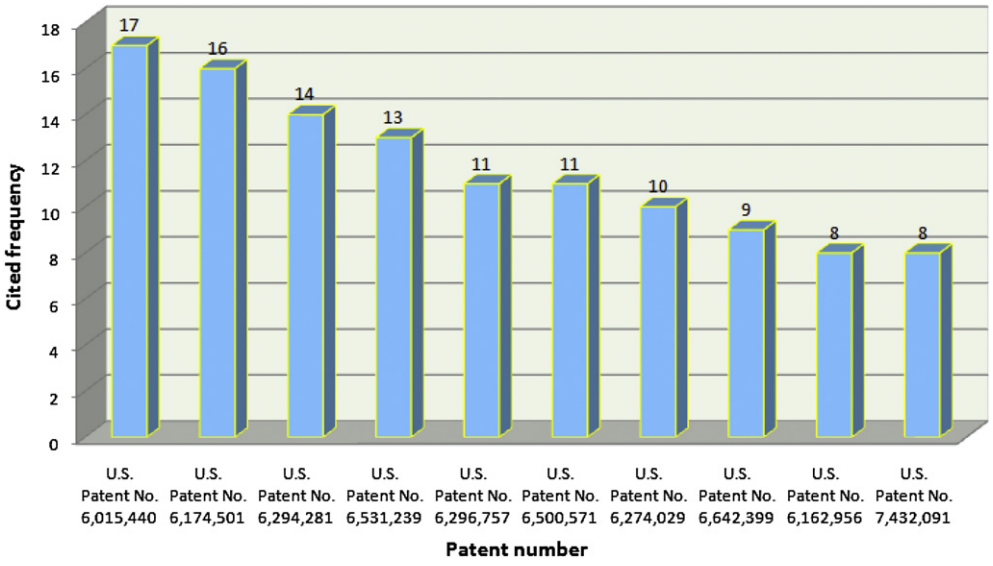


Fig. 6 – The first ten highly cited patents in the field of biofuel and biohydrogen energy.

their patents focus on biofuels production processes. Next, Adam Heller from Abbott Diabetes Care Company (USA) produced six patents in the field of biofuels cell. This trend indicates that high productivity inventors are those few inventors who are working in the field of biofuel-related research presently.

3.7. *Highly cited patents*

The highly cited patents are portions of patents which own more than average technological impact. These patents tend to become important inventions [6,18]. The more frequently a patent is cited in sequent patents, the more important is the cited patent. Furthermore, the highly cited US patents are often those that would be recognized by technological experts as major innovations [21]. Fig. 6 shows the information on first ten highly cited patents among all mutually cited patents in the field of biofuels and biohydrogen. All of them are invention patent with significant contributions in the field of biofuels and biohydrogen energy. These ten patents are relatively important ones among all patents, and represent the crucial technologies in the field of biofuels production and application.

The first nine patents (from left to right) were issued before 2003. The major topics of these patents focused on biofuels and biological fuel cells. More particularly, these inventions regarding biofuels are highly related to stable, inhibited distillates, useful as fuel or as fuel blending components, in which a Fischer–Tropsch derived distillate is blended with a gas field condensate. The distillate fuels derived from Fischer–Tropsch processes are always the biodiesel which eliminates unsaturated materials, e.g., olefins and oxygenates. In addition, the other inventions are related to fuel cells that operate using fuels from biological systems. The electrical energy produced by the fuel cell can be stored or used to power an attached device.

The last patent among the first ten highly cited patents was issued in the year 2008. This invention relates to a highly efficient biohydrogen production method using an anaerobic microorganism utilizing an organic substrate as a carbon source. Biohydrogen produced by the method of the present invention could be suitably used as a fuel similar to that of biofuel cells. This means biohydrogen is also an important topic in this field, and owns the potential for development and application in the next ten years.

4. Conclusion

Biofuels and biohydrogen are the best way of reducing the emission of the greenhouse gases compared to conventional transport fuels. They can also be viewed as a way of energy security which stands as an alternative of fossil fuels that are limited in availability. Due to the increasing demands for green energy technology, exploring the technological development of biofuels and biohydrogen has become an important research topic. This study utilized patent bibliometric analysis to explore the status and activities of technological development in the field of biofuels and biohydrogen.

The results firstly indicated that USA plays a leading role in the developmental trajectory of biofuel-related energies. Chevron Corporation is the most active assignee in this field. Furthermore, the researchers who work in Exxon Mobil Corporation produce the maximum of inventions related to the field of biofuel. Secondly, citation techniques were used to reveal the highly cited patents, in order to find out the key technologies in the field of biofuels and biohydrogen. The results of citation analysis revealed that the techniques of biofuels production should be based on low energy demand technologies. Furthermore, biohydrogen was also listed among these highly cited patents which prove that it has the possibility of further applications in the field of green energy. Finally, patent bibliometric analysis can assist the researchers

to easily understand the developmental states of biofuels and biohydrogen technology by looking at different aspects of patenting activities.

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