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# Promising Technology Analysis and Patent Roadmap Development in the Hydrogen Supply Chain

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**Abstract:** Hydrogen energy, one of the energy sources of the future, represents a substantial issue which affects the industries and national technologies that will develop in the future. In order to utilize hydrogen energy, a hydrogen supply chain is required so that hydrogen can be processed and transported to vehicles. It is helpful for technology and policy development to analyze technologies necessary to charge the hydrogen energy generated into vehicles through the supply chain to discover technologies with high potential for future development. The purpose of this paper is to identify promising technologies required in storing, transporting, and charging vehicles generated by the hydrogen fuel supply chain. Afterward, the promising technologies identified are expected to help researchers set a direction in researching technologies and developing related policies. Therefore, we provide technology information that can be used promisingly in the future so that researchers in the related field can utilize it effectively. In this paper, data analysis is performed using related patents and research papers for technical analysis. Promising technologies that will be the core of the hydrogen fuel supply chain in the future were identified using the published patents and research paper database (DB) in Korea, the United States, Europe, China, and Japan. A text mining technique was applied to preprocess data, and then a generic topographic map (GTM) analysis discovered promising technologies. Then, a technology roadmap was identified by analyzing the promising technology derived from patents and research papers in parallel. In this study, through the analysis of patents and research papers related to the hydrogen supply chain, the development status of hydrogen storage/transport/charging technology was analyzed, and promising technologies with high potential for future development were found. The technology roadmap derived from the analysis can help researchers in the field of hydrogen research establish policies and research technologies.

**Keywords:** hydrogen energy; hydrogen supply chain; patent analysis; research paper analysis; promising technology

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## 1. Introduction

In order to minimize damage caused by climate change, such as typhoons, heavy snow, and droughts, the use of fossil fuels should be reduced as much as possible. Since fossil fuels, such as crude oil and coal, emit a lot of greenhouse gases, it is necessary to expand renewable energy, such as solar power, wind power, and hydropower. One of the carbon reduction efforts is to use hydrogen as a propulsion source for land transport systems such as automobiles and railways.

Internal combustion engine vehicles emit carbon monoxide, nitrogen oxide, carbon dioxide, etc., while hydrogen vehicles create electrical energy through the chemical reaction between hydrogen and oxygen and emit only pure water. Therefore, it can be said that a transportation system using hydrogen as an energy source is remarkably eco-friendly. The importance of an eco-friendly transportation system is growing in that greenhouse gases emitted from land transportation systems such as automobiles and railways are increasing year by year [1,2].

Meanwhile, the supply chain of internal combustion engine transportation systems, such as automobiles, is very well established, but the infrastructure of land transportation for hydrogen vehicles is only the beginning. In the process of hydrogen energy being produced and reaching the vehicle, the flow of energy must be continued without interruption. Technologies that form the hydrogen energy supply chain should be managed using various digital infrastructures [3]. To build and operate a hydrogen supply chain, it is necessary to analyze the current development status of related technologies and analyze advanced future technologies based on the current technology. Due to this need, this paper analyzes promising technologies necessary for storing, transporting, and charging vehicles to build a more systematic hydrogen supply chain.

Hydrogen energy is expected to be one of the future energies utilized in fuel cell systems. It is one of the currently utilized energy infrastructures and is a clean and efficient eco-friendly energy. Hydrogen energy has the potential to become a future energy source in terms of being able to supply fuel with eco-friendly energy that can be generated from primary sources such as biomass, water, and solar power directly to internal combustion engines [4]. Fueling internal combustion engines requires an analysis of the supply chain [5]. It is necessary to study whether hydrogen energy can be produced, stored, transported, and finally supplied to an internal combustion engine at the lowest cost and most efficiently [6,7].

As shown in Figure 1, the hydrogen supply chain consists of production, storage, transportation, and charging infrastructure [8]. As a method of producing hydrogen, electrolysis of water, biomass, fuel, etc., are mainly used [9,10]. In the past, reformed hydrogen production techniques that produce hydrogen by applying byproduct hydrogen production techniques or reforming methods to fossil fuels were common. Recently, changes in production techniques have been required to produce eco-friendly hydrogen, and studies using solar and wind power are being conducted [11,12]. The hydrogen energy produced must be stored in a certain space before and after transportation. The method of storing hydrogen energy is as follows. There is a method of compressing and storing hydrogen, a method of storing hydrogen in a liquid state, and a method of storing hydrogen as an organic hydrogen carrier [5]. Currently, the method of storing hydrogen in the form of compressed hydrogen occupies the largest proportion [13]. Transportation technology is needed to take stored hydrogen to the charging station. Currently, the following methods are mainly used for hydrogen transport. Transport methods using tube trailers, transport methods through pipelines installed from origin to destination, and transport methods using tank cars or rails are being used [14]. The method of supplying hydrogen through pipelines or tube trailers incurs transportation costs but can reduce facility investment costs. The hydrogen charging stations that constitute the end of the hydrogen supply chain are distinguished by the way they receive hydrogen. A method of directly producing hydrogen at a hydrogen charging station has also been proposed. Currently, the most common hydrogen charging station is a tube trailer supply system. Although this method incurs transportation costs, it has the advantage of not incurring facility investment costs for building transportation infrastructure. As a method of directly producing hydrogen at a hydrogen charging station, a hydrogen charging station that produces hydrogen by supplying natural gas or has a water electrolysis hydrogen production facility has been proposed. Recently, studies have been proposed in which social factors are considered to optimize the sustainable hydrogen supply chain [15–17]. The hydrogen supply chain optimization model in the transportation field was also presented through the British model. Hydrogen purity is a very important factor in the application of hydrogen fuel cell vehicles. The study developed a hydrogen supply chain model, including purity-related technologies and purification technologies of the water supply. By analyzing the optimal cost configuration, the hydrogen cost per kg was derived as GBP 6.18. This case demonstrates the applicability of the model [15]. It was also applied to the "Green H2" project research in Hungary. In this study, we proposed the introduction of fuel cell vehicles (FCVs) through social cost-benefit optimization and stages optimized for several periods [16]. In Canada, research was conducted to expand the hydrogen supply infrastructure. It analyzed the market share of hydrogen production and transportation costs when converting existing vehicles into fuel cell electric vehicles (FCEVs). Environmental and health benefits were derived by analyzing the amount of $CO^2$ generated to prevent air pollution. We derive quantitatively that switching to FCEVs helps the climate change problem [17].

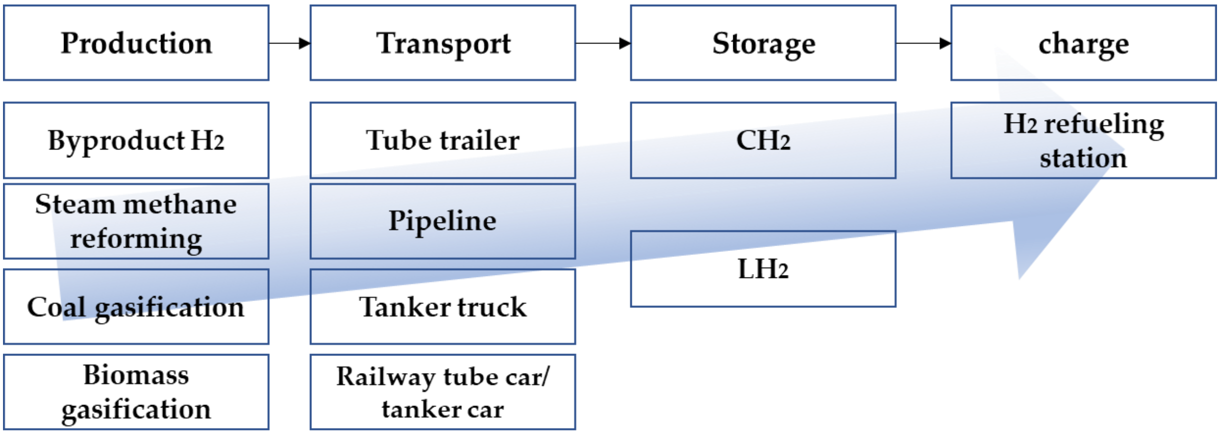



**Figure 1.** Structure of the hydrogen supply chain [8].

For the utilization of hydrogen, it is necessary to have the entire supply chain and technology from hydrogen production to charging [18]. The supply chain consists of processes from hydrogen energy production to charging, and each process affects the other, and the technology used in each stage is also often connected to other stages. In this paper, we intend to provide a technological strategy roadmap that can be utilized in the hydrogen supply chain field by analyzing technologies related to each process from storage to charging facilities and analyzing promising technologies with high potential for future development.

## 2. Literature Review

### *2.1. Hydrogen Supply Chain*

To utilize hydrogen, production technology, storage facilities, transport technology, and charging facilities are required [18]. The supply chain consists of the process of hydrogen energy from production to charging, and each process affects the other. Therefore, when designing a supply chain, it is necessary to cover the entire process together. Most of the early hydrogen supply chain research studies designed a simple supply chain or modeled each step [19–22]. It was about examining each process of the supply chain or about previously determined hydrogen pathways. Afterward, an optimal design of the hydrogen supply chain network was proposed using a mathematical modeling approach [4]. At the same time, research for hydrogen infrastructure design has been continuously conducted in a situation of uncertain demand. A probabilistic model was developed to suggest the optimal configuration of the hydrogen supply chain in an uncertain demand situation [7]. By applying bi-criterion mixed-integer linear programming (MILP), a hydrogen supply chain design was proposed considering economic and environmental issues [23]. While designing the optimal network for hydrogen production and distribution, the environmental impact was presented by measuring the contribution to climate change through the hydrogen network [23]. The design of a production–distribution network was proposed to optimize hydrogen demand in the context of uncertain operating costs, raw materials prices, etc. The modeling and solution strategies suggested in the study were applied to a real case study in Spain [24]. Extending the MILP model, a stochastic hydrogen supply chain network was also proposed, and this study attempted to account for the uncertainty caused by long-term fluctuations in hydrogen demand using a scenario approach. After that, research was conducted to realize the sustainability of the hydrogen supply chain [25]. To establish a sustainable hydrogen supply chain, a method to improve the sustainability of the hydrogen supply chain was developed by discovering key factors and finding causal relationships. At this time, the decision-making trial and evaluation laboratory (DEMATEL) method was introduced to analyze the causal relationship between major factors, and the proposed method was applied to a case study of hydrogen supply in China and analyzed in detail [26]. Several hydrogen supply chain studies are suggesting ways to support decision-making and optimize economic performance using probabilistic modeling tools for various uncertainty factors. Therefore, research on hydrogen supply chain technology is insufficient.

Liquid Organic Hydrogen Carriers (LOHC) were analyzed and their potential for hydrogen transport was presented. A well-to-wheel analysis was used to confirm the reduction in greenhouse gas (GHG) emissions, and the economic impacts such as cost, and energy consumption were also analyzed [5]. An optimization model for centralized hydrogen storages was developed. Using the MILP model, it was confirmed that the centralized hydrogen storage method is better in terms of cost than the decentralized model [8]. However, these studies also have limitations in exploring and discovering promising technologies in the field of the hydrogen supply chain.

There is no research to discover promising technologies in the hydrogen supply chain using big data such as patent information. Existing hydrogen big data research has been limited to specific sectors or technologies, not the entire supply chain. There was also a study suggesting a method for predicting technology using the S-curve by integrating hydrogen energy and fuel cell bibliometric and patent analysis [27]. A patent portfolio strategy was proposed to select key patents by analyzing patent citation information of fuel cell vehicles, and to discover companies and technologies by applying text mining techniques [28]. By comparing hydrogen energy and fuel cell electric vehicles in ASEAN countries with conventional powertrains, the future prediction results of hydrogen and FCEVs were presented through energy consumption, carbon emission, and cost analysis [29]. A hydrogen supply chain network using a stochastic mixed integer linear programming model was also designed [30,31]. An optimization model was also applied for the cost-optimal configuration of the hydrogen supply chain [16,32]. The text mining method using IRaMuTeQ tool was also applied [33]. We also used the Mixed Integer Planning (MIP) model to find ways to reduce costs [34,35]. Such research can suggest promising technologies for each detailed technology in terms of hydrogen supply and demand. However, research on how to explore promising technologies throughout the hydrogen supply chain and suggest future promising technologies is needed.

### *2.2. Patent Analysis*

A patent is a unique and exclusive right of any technology or invention to provide a product or a method to solve a problem in a new way that is different from the existing ones, or to provide a new technical solution that can be applied in practice. A patent is defined by the organization. The method they propose is documented, and information on the researched and developed technologies is written in the patent documents applied for, so it is easy to understand the technologies that have been released so far, and is possible to analyze the technologies using that information [36,37]. Through the analyzed data, new technology opportunities can be identified and forecasted.

Patent analysis is only effective when accurate results are communicated in an understandable form [38]. The patent analysis method frequently used to analyze accurate results consists of identification, search, clustering, segmentation, abstraction, visualization, and interpretation of results suitable for the subject to be analyzed [39]. Each process requires a certain level of expertise to accurately understand and analyze data. In addition, the whole analysis process takes a long time and is not very efficient unless the analysis expert has all the knowledge and skills in the field. As more and more patents are being applied for, more and more methods are being analyzed using text mining rather than relying on experts. The text mining method extracts keywords and analyzes patents. Through this method, patents are analyzed in various aspects such as trend analysis, technology prediction, strategic technology planning, infringement analysis, and novelty [40,41].

Many researchers are developing text mining methods to extract keywords to support patent analysis. It has been shown that it is best to extract keywords from the abstract of patents with the term frequency-inverse document frequency (TF-IDF) [36]. However, traditional keyword-based patent analysis cannot capture correlations between different patents. The strategy used to select keywords is substantial as the method of keyword extraction and selection influences the results of the analysis, and advances in text mining are diversifying the scope of patent analysis, enabling broader discovery of the technology.

The field of technology prediction identifies emerging technologies and gaps in technology by identifying markets that are likely to develop in the future or are likely to be newly developed through the relationship between several technologies. A lot of research is being applied in manufacturing, energy, raw materials, technology fields, etc., because it is more suitable for predicting technology fields that are likely to emerge in the future or that are undeveloped. Possible emerging technologies were predicted by identifying the relationship between technologies and countries and comparing the results of the Time Series Analysis of related new technologies [42]. Emerging technologies were predicted by constructing a product ecology network and then performing link predictive analysis [43]. The patent applicant was analyzed and the cooperative network was confirmed [44,45]. The technical analysis was performed by applying network analysis and key graphs [46,47].

However, the visualization had to be separately performed to easily distinguish the results obtained through patent analysis. When patent analysis and visualization of results are combined, the two processes can be combined into one, which can shorten the process. To this end, a method to visualize patents and predicted vacant technology through visualization was studied. Based on patent documents, matrix maps and K-medoids clustering were also used to make bin descriptive predictions. With the proposed method, the authors first extracted the top five keywords to define clusters and then identified empty descriptive regions in the constructed matrix map [48]. In another study, a patent map was constructed by extracting keyword vectors from patent documents using text mining and selecting keyword vectors by applying principal component analysis (PCA) [49,50]. Methods for creating patent maps include PCA, Self-Organizing Map (SOM), and Generative Topographic Mapping (GTM). PCA is a method of predicting results by making data in high-dimensional spaces into low-dimensional [51–55]. Data are converted into variables when converted to low dimensions, but it is difficult to interpret because there are too many data in each variable. SOM is a method of simultaneously reducing dimensions and clustering data when creating a patent map [54,56–58]. It is more useful in analyzing and grouping relationships between variables compared to traditional PCA methods. It is also possible to see the differences between groups by color-differentiating similar data [53,57]. However, SOM does not contain a cost function and does not have a patent on a blank node, which makes it difficult to analyze a node [59].

A method to create a patent map using data and visualize patent analysis results through visualization and applied a GTM method that makes it easy to identify vacant technologies through the derived patent map was proposed [60]. In another research paper that applied the technique, GTM was applied to patents visualized in two-dimensional space, with a focus on the detailed direction of technological development to identify empty spaces [61]. GTM is one of the probability density models that map data in low-dimensional space through latent variables by analyzing the characteristics of the data [62].

In this case, the data were grouped while locating the data in the low-dimensional space in the multi-dimensional space and find the space where the data do not exist [62]. Patent data are available, and patent analysis studies have been conducted and the state of the art has been analyzed [63]. Technology analysis through a comparison between SOM and GTM through the GTM-based patent map was conducted [64]. Using patent data and standard technical data, the standard GTM map and patent GTM map were visualized to analyze the difference between the two data [65]. It can also be applied to establish a patent roadmap, and the Bass model was applied to predict the emergence of new patents that do not currently exist [66]. GTM has been extended to patent database analysis, and intellectual property (IPR) patents, trademarks, and design patent analysis. Promising research and business development fields have also been identified [62]. However, there are limitations to using only the GTM technique. This is because the results of the analysis are keywords, so there is a difference of opinion in using the keyword. To solve this problem, in this paper, we use surrounding data to re-analyze keywords, define technology, and analyze the relationship between technology and technology to develop it into a roadmap. In the GTM method, if there is a patent, it is marked on the node, so it is possible to know the current technology and whether there is a vacant technology through the patent map. In this paper, we try to analyze the data of the hydrogen supply chain through text mining, not the entire technology, and to identify the relationship between the vacant technology and the vacant technology for each supply chain.

## 3. Research Methodology

The hydrogen supply chain, from the hydrogen fuel production until it reaches the charging station, is largely set up as storage-transport-charge. As shown in Figure 2, the analysis process of hydrogen supply chain data is as follows. First, we extract the data of patents and research papers related to each part. The retrieved data are selected through the valid data screening process. By deleting data not related to the subject from the extracted patent and research paper data, it is possible to increase the analysis accuracy by selecting only data related to the subject. Second, the current technology market position and development potential are analyzed by applying the technology market growth stage analysis method. Third, the keyword vector used for analysis is extracted using the validated data. Then, the extracted keyword vector is used to analyze the vacant technology. The process applies the GTM method. Finally, the ARM method is applied to examine the association between the extracted patent and the vacant technology of the research paper.

### *3.1. Patent Data Extraction and Preprocessing*

In this paper, the data extraction keywords corresponding to each part are first set through the research paper; then, patents and research papers are additionally searched using the relevant keywords, and the final data are retrieved by adding the opinions of experts in the related field. Patent and research paper data are extracted through the set keyword combination, and data are retrieved with the same keyword to analyze the technology of interest by comparing the patent and research paper data. Patent data are extracted from the WIPSON database and research paper data is extracted from the Web of Science.

The extracted data may include misspelled words or abbreviations. In particular, since patent documents are written for each technical field, there are many abbreviations that must be corrected or removed before analysis. The pre-processing process involves processing data into easy-to-use data through text cleaning and abbreviation conversion. Document pre-processing is the transformation of data into a format that can be applied more easily and effectively for analysis. The document pre-processing process is tokenizing, which first decomposes the original data in the form of sentences into individual words, undergoes case transformation, and then removes spaces, numbers, and other symbols. Second, words that are considered unnecessary through filtering are removed through the

Stopword method. Finally, the process of removing prefixes and suffixes that exist in all words, leaving only the words that make up the document.

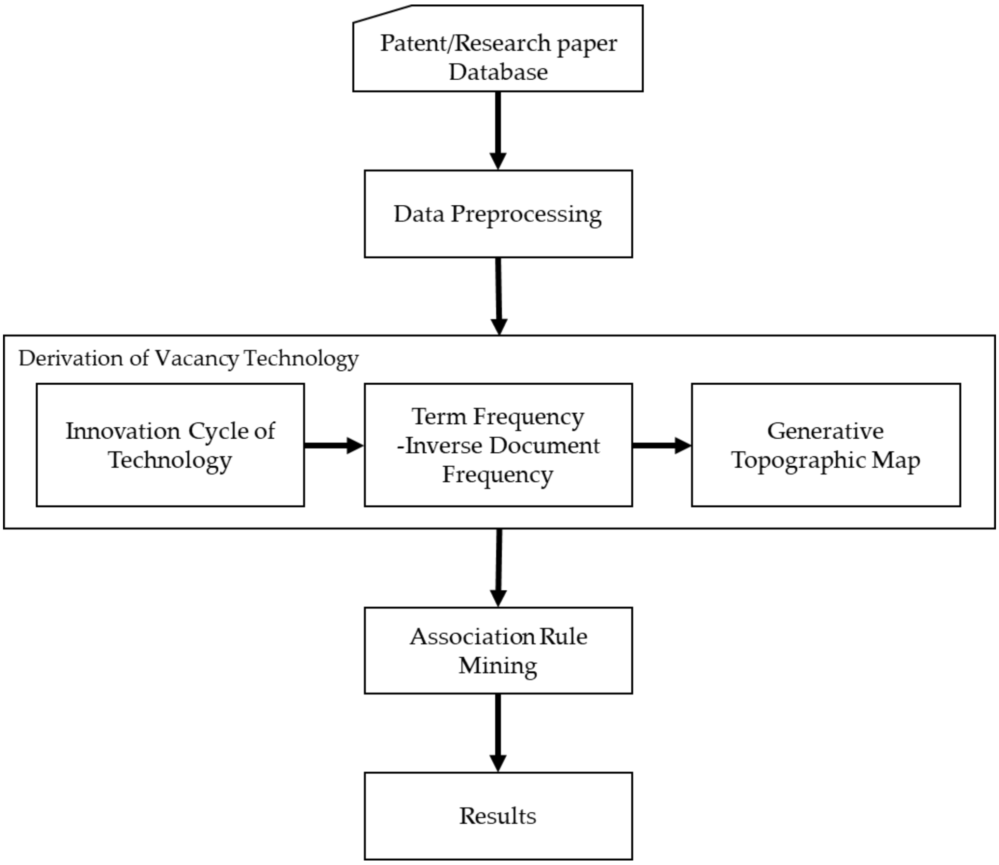



**Figure 2.** Research framework.

### *3.2. Identification of the Growth Stage of the Technology Market*

The technology market growth stage graph is a method used to evaluate and obtain information about technology, such as where the current technology is located and where it can be developed. As shown in Figure 3, the technology market growth stage graph is generally classified into five stages: birth, growth, maturity, decline, and recovery.

At the birth stage, new technology innovation is triggered, and patents begin to be applied for in small numbers. At the growth stage, the number of patent applications is rapidly increasing. Technologies that have entered the current stage are evaluated as emerging technologies. At the maturity stage, the number of patent applications increases, but not at the same rate of stage 2. At the decline phase, the number of patent applications begins to decline. At this stage, the market size of the technology also begins to decrease. Finally, at the recovery stage, new innovative technologies using the technologies developed so far appear, and the market size is gradually being restored.

Compared with other data, patents reflect well the unique characteristics of each stage in the technology market growth stage graph and can be usefully applied to evaluate the development stage such as emerging, vacant, or mature in the technology field. It is regarded as the preferred criterion for finding phases that are currently under development [66,67]. Determining the development stage of the technology is useful for identifying emerging and vacant in the technology field; therefore, in this paper, the technology market growth stage graph is used.

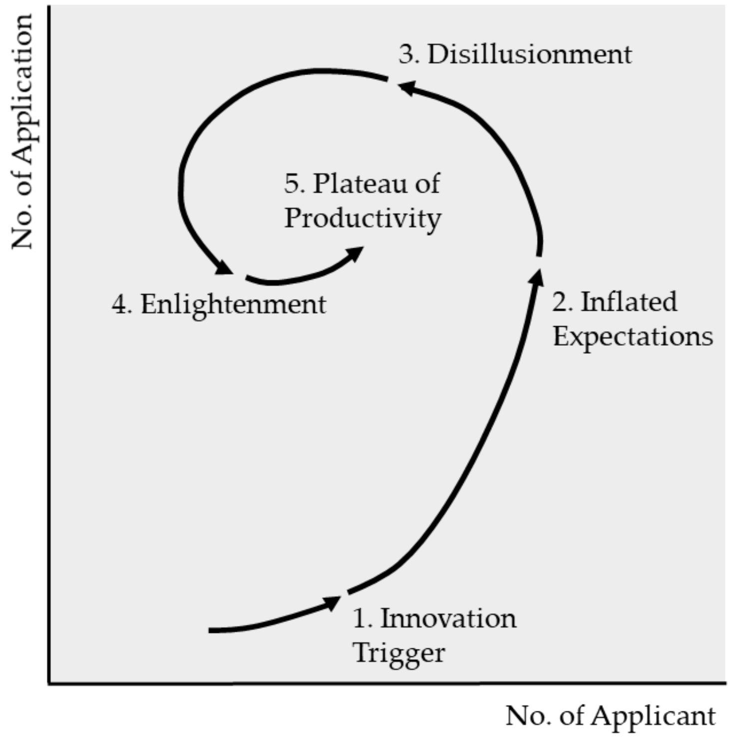



**Figure 3.** Technology market growth stage graph [67].

### 3.3. Keyword Vector Extraction

The selected data are analyzed in parts. We analyze promising or empty technologies of each part through the GTM method. This step is to analyze data and extract the undeveloped technologies and the technologies that are likely to develop among the technologies of each part of the supply chain consisting of storage-transport-charge. For the analysis of the corresponding stage, the top N keywords of the data for each part are analyzed. At this point, the N value identifies the TF-IDF weight and applies the highest value among the TF-IDF values that can be extracted from each part as a standard to enhance explanatory power and extract key technology keywords.

### 3.4. Generative Topographic Map (GTM) Analysis

When key technology keywords are extracted for each part of storage-transport-charge, GTM analysis is performed for each part using the corresponding keyword vector. Through analysis, keywords related to the vacant technology in each part can be checked, and through the keyword, the vacant technology of the part can be checked.

GTM is a non-linear mapping method that maps data from multidimensional space to a lower dimension using the characteristics of the data [68]. Due to the visualization characteristics of GTM, this method is widely used for data analysis and visualization. It can be viewed as a probabilistic extension of Self-Organizing Maps (SOM) and is widely used as a classification and regression model because it is easy to classify data through visualization [68,69].

As shown in Figure 4, this method maps data primarily into a two-dimensional latent space for ease of visualization and maps each point in the low-dimensional latent space to a silk sheet-like manifold embedded in the initial descriptor space [70]. The manifold has the shape of a square grid of nodes of size $N \times N$ and is represented as nodes on a grid in a low-dimensional latent space via Gaussian radial basis functions (RBFs) [70]. In the low-dimensional map created, x has the value of L-dimensional late variables, and y is the image coordinates of the data space where the data are converted through the RBF neural network [71–73]. The size of the low-dimensional latent space is typically set to $[-1,1]^2$ [62,74].

For each molecule M mapped onto the GTM, a probability matrix R (M, K) is computed to provide the probability of M present at node K, i.e., the responsibility of node K for the molecule M. Using this matrix, it is possible to figure out the characteristics of each node.

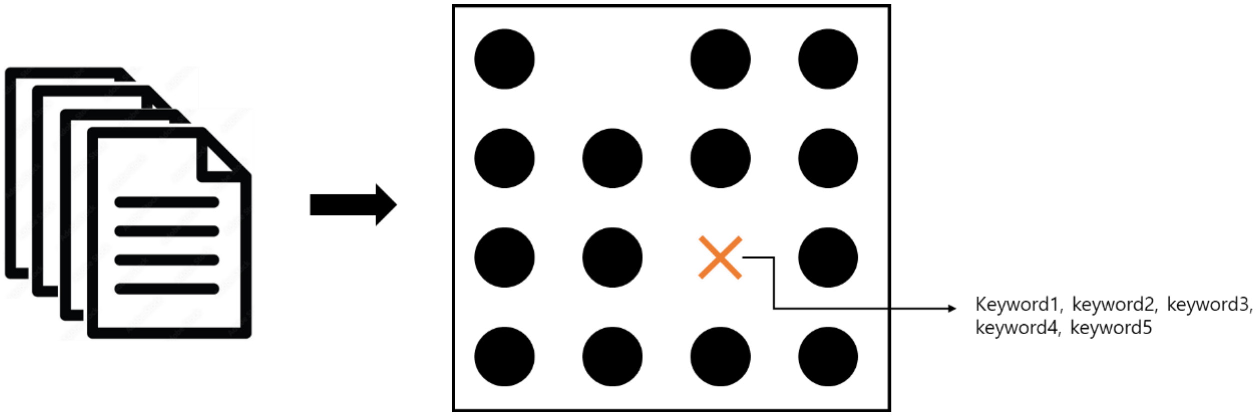



**Figure 4.** Basic idea of the GTM.

The patent map consists of nodes of size N X N, and there is no set rule for determining the size of N. Determining the size of N depends on the analyst, but since there may be too many or no blank nodes depending on the size of the map, an appropriate K value should be assigned [61,64]. In this paper, the analysis was carried out by gradually increasing the value of N from a small value (5) to a large value (15). To confirm that the analyzed patent map is appropriate, a sensitivity analysis was performed to evaluate the relevance of the selected parameters by changing the parameter values [61]. The created patent map is displayed as a black node if related patent data exists, and as a blank node for a promising node without related data. A blank node can extract the technology keyword of the node through the inverse function and define the promising technology by utilizing the extracted technology keywords and patents of neighboring nodes [75].

### *3.5. Association Rule Mining (ARM) Analysis*

Association Rule Mining (ARM) is used to check the association between the technologies of the derived vacant technologies. The ARM is a method that analyzes patterns between data by checking the items in the data and analyzing the number of simultaneous occurrences of the items. It is a method of checking whether an item extracted from a document appears or not, comparing it with other documents, finding frequently occurring items by checking the number of simultaneous occurrences, and checking the association rules. In the case of patent documents, keywords were often used as items. This study also analyzes association rules using keywords as items. Associations between items are represented by support, confidence, and lift values. The support value is the value of how often an item appears in the database during association analysis. The confidence value is the frequency at which the value is true when correlating items with conditional probability. The lift value represents a diagram of the relationship between individual items within a set of items. Through this method, the correlation between derived vacant technologies for each part through data analysis can be checked, and the result can be helpful in analyzing the technology roadmap.

## 4. Results

### *4.1. Data Extraction*

Patent data extracted through the WIPSON database was collected from Korea, the United States, Europe, China, and Japan, and the collection period was set between 1 January 2001~31 July 2021. The search keywords used to collect patent data are technology keywords that appear frequently by searching for patents and research papers related to the hydrogen supply chain. In order to collect keywords, more than 20 patents and research papers related to the hydrogen supply chain were searched and technical keywords were collected. The keywords were then reviewed and verified with experts in the field. After searching 20 more patents and research papers based on valid keywords, keywords were collected. The collected keywords have been validated and added. It completed the search formula by searching for patents and research paper data and collecting keywords more than 10 times. The number of collected patent data was 1517 for the storage part, 3571 for the transportation part, and 2443 for the charging technology part. The number of collected research paper data was 618 for the storage part, 752 for the transport part, and 2104 for the charging technology part. Afterward, the retrieved data are selected through the valid data screening process. From the extracted patent and research paper data, it is determined whether it is related to any part of the hydrogen supply chain or not, data unrelated to the subject are removed, and the accuracy is improved by adding expert opinions in the relevant field. As a result of the analysis of valid patents, the number of data used for actual analysis was 176 cases (patents)/172 cases (research paper) for the storage part, 242 cases (patents)/88 cases (research paper) for the transport part, and 443 cases (patents)/249 cases (research paper) for the charging technology part.

### *4.2. Identification of the Growth Stage of the Technology Market*

The innovation cycle of technology is applied to the validated data to check the potential for further development. The technology market growth stage graph is used to identify gaps in technology for a specific technology. In this paper, we identified the technology market growth stage by group using the data of clustered group. Among the total number of applications, the recent application trend is divided into four sections, indicating the number of patent applications and applicants for each section, so the position of the technology through the patent application trend can be examined. Each section is divided into section 1 (2000–2004), section 2 (2005–2009), section 3 (2010–2014), and section 4 (2015–2019). As shown in Table 1, the technology markets growth stages for each group using patent and research paper data are indicated. In this case, storage is shown as part 1, transport is shown as part 2, and charging technology is shown as part 3.

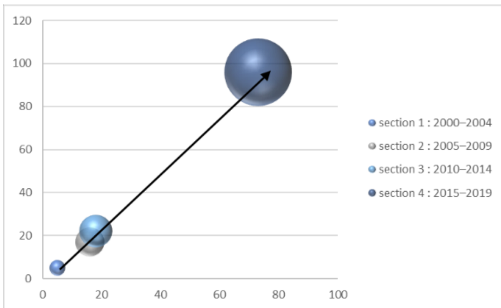
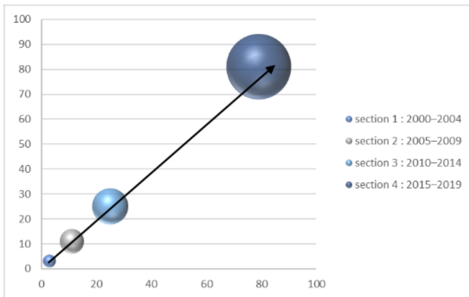
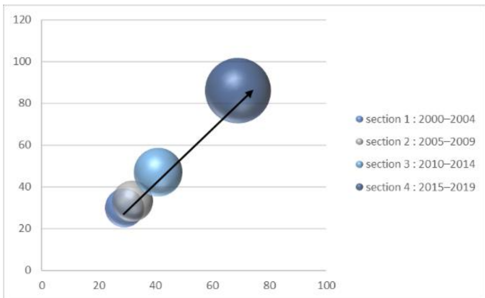
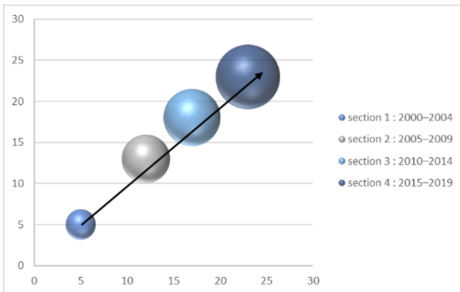
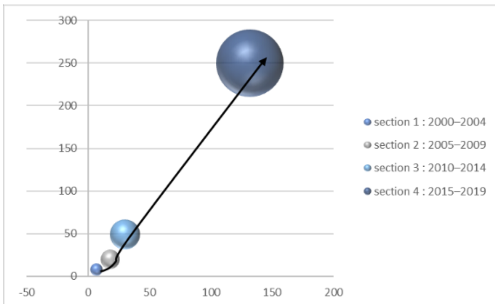
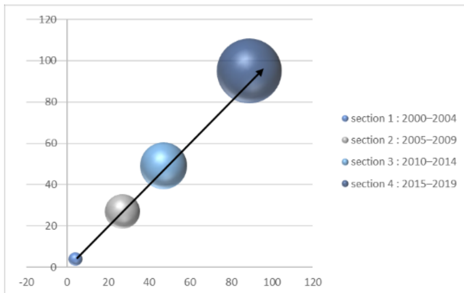
The analysis of the technology market growth stage using patent data is as follows. The number of patents and applications continues to increase. In part 1 and part 3, the number of patents is increasing very actively during section 3 and 4, suggesting that Cluster3 is in the development stage. part 2 also has a steady increase in the number of patents, and the number of patents has increased significantly over the past five years.

The analysis of the technology market growth stage using research paper data is as follows. The number of patents and applications continues to increase. In part 1 and part 3, the number of patents is increasing very actively during section 3 and 4, suggesting that Cluster3 is in the development stage. part 2 also has a steady increase in the number of patents, and the number of patents has increased significantly over the past five years.

### *4.3. GTM Analysis Using Patent/Research Paper Data*

By applying GTM analysis, patent data and research paper data of the hydrogen supply chain are analyzed to derive vacant technology keywords in the storage, transportation, and charging, respectively. Through the derived vacant technology keywords, vacant technologies with high potential for future development can be identified. As written above, storage is shown as part 1, transport is shown as part 2, and charging technology is shown as part 3. As shown in Table 2, the analysis results using patent data and research paper data in the corresponding analysis stage were as follows. As a result of the analysis using patent data, three blank nodes were derived in part 1 (storage), one blank node in part 2 (transport), and two blank nodes in part 3 (charging). As a result of the analysis using the research paper data, 5 blank nodes were derived in part 1, 12 blank nodes in part 2 (transport), and 5 blank nodes in part 3 (charging).

**Table 1.** Technology market growth stage by part of patents and research paper.

| Part | Patent | Research Paper |
|---|---|---|
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |

Related emerging techniques can be derived through keywords derived from blank nodes by extracting the technology keywords that each blank node has for technology analysis. As shown in Table 3, the result of deriving vacant technology keywords for each part of patent data by applying GTM analysis is as follows. As shown in Table 4, the results of deduplicating the derived keywords for each part are as follows.

As shown in Table 5, the result of deriving vacant technology keywords for each part of the research paper data by applying GTM analysis are as follows. As shown in Table 6, the results of deduplicating the derived keywords for each part are as follows.

The patents included in the vacant technology field identified through the GTM-based patent map were investigated, and the following possible representative technology names were identified. The vacant technology analyzed using the vacant technology keyword derived through GTM analysis is as follows.

The results of predicting the vacant technique using the patent data are as follows. The vacant technology in storage (part 1) is a technology that stores gaseous hydrogen in cylinders mounted on vehicles such as tanks through compression, cooling, and liquefaction processes. At this point, the technology related to the tank is the pressure tank technology with heating chamber. The vacant technology in transport (part 2) is a technology for transporting stored hydrogen fuel using a tank. A related technology is a network system that controls the state of hydrogen through temperature control in the tank. The vacant technology in charging (part 3) is a technology for charging transported liquid hydrogen to vehicles that require hydrogen energy charging in the station. It is a method of supplying the stored hydrogen energy to the vehicle by storing the transported hydrogen energy at a hydrogen charging station within the railway station.

**Table 2.** GTM analysis result of patent/research paper data.

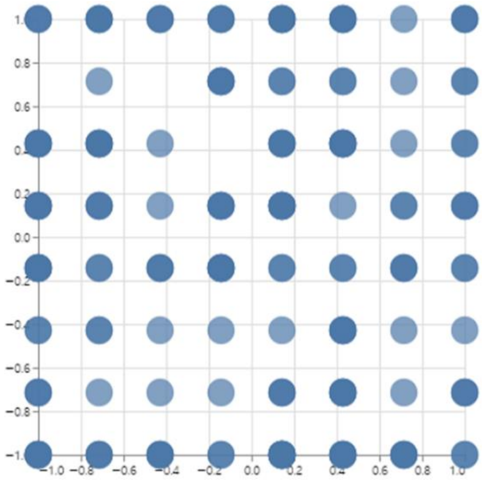
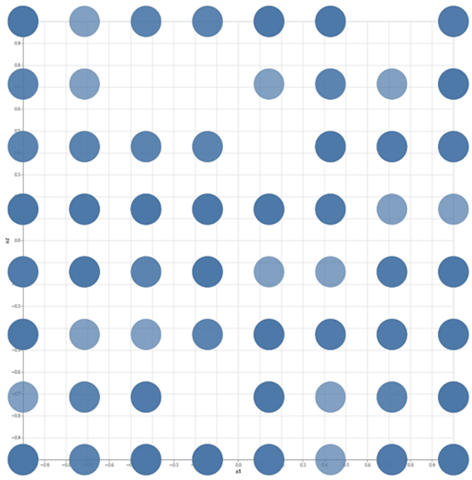
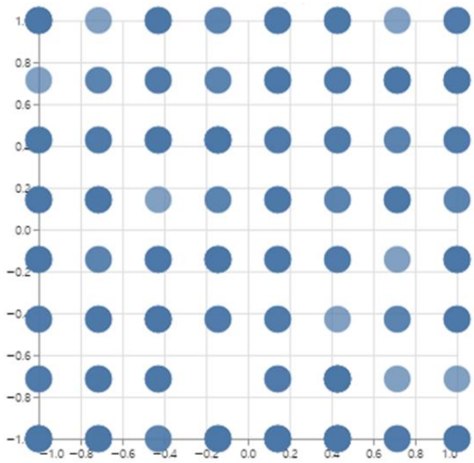
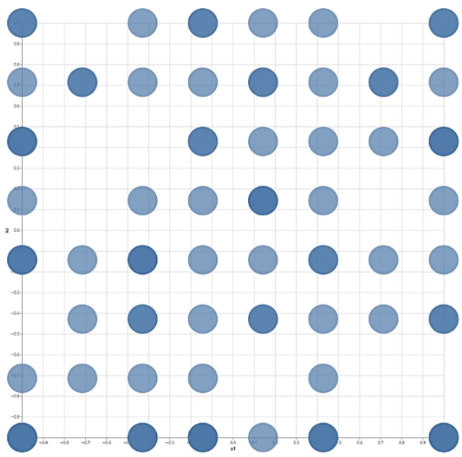
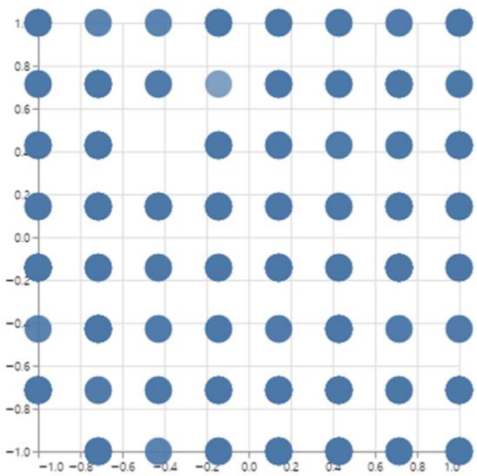
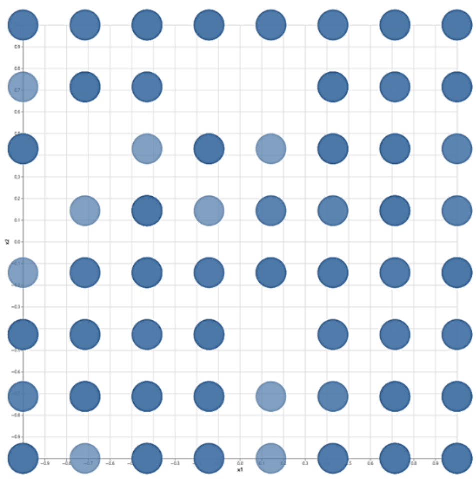
| Part | Patent | Research Paper |
|---|---|---|
| 1 |  |  |
| 2 |  |  |
| 3 |  |  |

**Table 3.** Results of deriving vacant technology keywords—Patent.

| Part | Blank Node | Keyword |
|---|---|---|
| 1 | 1 | gas, refueling, heat, station, compressor, cylinder, oil, cooling, hydrogen |
| | 2 | gas, tank, heat, station, cooling, temperature, hydrogen |
| | 3 | storage, energy, station, hydrogenation, vehicle, hydrogen |
| 2 | 1 | liquid, tank, storage, unit, system, refueling, heat, energy, station, hydrogenation, arranged, cooling, hydrogen |
| 3 | 1 | liquid, tank, storage, system, heat, valve, energy, hydrogenation, pipeline, material, temperature, flow, pump, organic, hydrogen, carrier, stations, consumption |
| | 2 | storage, water, container, arranged, hydrogen |

**Table 4.** Result of removing duplicate keywords—Patent.

| Part | Keyword |
|---|---|
| 1 | gas, refueling, heat, station, compressor, cylinder, oil, cooling, hydrogen, tank, temperature, storage, energy, hydrogenation, vehicle |
| 2 | liquid, tank, storage, unit, system, refueling, heat, energy, station, hydrogenation, arranged, cooling, hydrogen |
| 3 | liquid, tank, storage, system, heat, valve, energy, hydrogenation, pipeline, material, temperature, flow, pump, hydrogen, organic, carrier, stations, consumption, water, container, arranged |

**Table 5.** Results of deriving vacant technology keywords—research paper.

| Part | Blank Node | Keyword |
|---|---|---|
| 1 | 1 | LOHC, catalyst, temperature, energy, carrier, storage, organic, liquid, fuels |
| | 2 | LOHC, temperature, energy, carrier, storage, organic, liquid |
| | 3 | dehydrogenation, catalyst, temperature, energy, carrier, storage, compounds, metal, organic, liquid |
| | 4 | carrier, storage, organic, liquid |
| | 5 | energy, carrier, storage, power, liquid, cost |
| 2 | 1 | system, cost, consumption, power, hybrid, train, station, energy |
| | 2 | storage, transport, gas, container, hydride, metal |
| | 3 | system, storage, energy |
| | 4 | system, storage, transport, energy |
| | 5 | system, transport, production, vehicle, consumption, power, hybrid, train, cycle, energy, electric, railway, diesel, traction, heat, emission |
| | 6 | system, cost, storage, production, energy |
| | 7 | transport, vehicle, emissions, consumption, power, gas, energy, air, diesel, |
| | 8 | system, cost, storage, refuel, vehicle, truck, vessel, delivery, capacity, station, high pressure, compression, energy, potential, electric, tube, bar |
| | 9 | cost, storage, liquid, transport, production, vehicle, infrastructure, chain, truck, station, energy, pipeline, network, |
| | 10 | liquid, transport, production, vehicle, infrastructure, gas, truck, energy, fuels, |
| | 11 | liquid, transport, vehicle, infrastructure, emissions, gas, truck, efficiency, model, energy, potential, fuels, air, methane |
| | 12 | cost, liquid, transport, production, vehicle, infrastructure, gas, truck, delivery, station, energy, potential, fuels, pipeline |

**Table 5.** *Cont.*

| Part | Blank Node | Keyword |
|---|---|---|
| 3 | 1 | fueling, risk, station, model, safety, energy, approach |
| | 2 | risk, station, safety, vehicle, energy |
| | 3 | refueling, station, model, vehicle, infrastructure, energy |
| | 4 | fueling, refueling, cost, station, model, vehicle, infrastructure, energy, transport |
| | 5 | fueling, system, station, model, energy |

**Table 6.** Results of removing duplicate keywords—research paper.

| Part | Keyword |
|---|---|
| 1 | LOHC, catalyst, temperature, energy, carrier, storage, organic, liquid, fuels, dehydrogenation, compounds, metal, power, cost |
| 2 | system, cost, consumption, power, hybrid, train, station, energy, vehicle, emissions, gas, air, diesel, storage, transport, liquid, production, infrastructure, truck, potential, fuels, development, chain, pipeline, network, delivery, container, hydride, metal, refuel, vessel, capacity, high pressure, compression, electric, tube, bar, cycle, railway, traction, heat, emission, model, methane |
| 3 | fueling, risk, station, model, safety, energy, approach, refueling, vehicle, infrastructure, system, cost, transport |

The results of predicting the vacant technique using the research paper data are as follows. The vacant technology in storage (part 1) is a technology to store hydrogen fuel energy using LOHC. A related technology is a method of storing and transporting hydrogen energy through metal catalysts such as alloys. The vacant technology in transport (part 2) is a technology for transporting through trains or trucks using vessels and a technology related to transporting using a station as a base. The technology related to the vessel is a high-pressure composite metal hydride hydrogen storage vessel. The vacant technology in charging (part 3) is a technology to supply hydrogen energy fuel to vehicles within the station by remodeling the existing station. After installing a hydrogen charging station by remodeling a parking lot or vehicle maintenance station within an existing station, the hydrogen energy in the vehicle moving through the railway is stored in the hydrogen charging station.

### *4.4. Association Analysis Using ARM*

Using the vacant technology keywords derived from each part of storage–transport–charge technology, we analyze whether the vacant technology derived from each part has connectivity with other parts and create a roadmap between the vacant technologies through the results. At this point, to create a roadmap that leads to storage–transport–charge, we found a rule that leads to storage $\rightarrow$ transport/transport $\rightarrow$ charging/storage $\rightarrow$ charging. For this purpose, the results in the reverse order from the analyzed results (for example: transport $\rightarrow$ storage, etc.) were removed. For rule analysis, ARM analysis was performed using the R program. The weighted support value set for the analysis is 0.005 or higher, and the lift is listed among the corresponding results. The vacant technology of patent data was named storage (1)–transport (2)–charging (3) and the vacant technology of research paper data was named storage (4)–transport (5)–charging (6). This is a numbering that makes it easier to know the results of the data analysis. The corresponding numbers, technical names, and data types are shown in Table 7. Some of the analysis results are shown as shown in Table 8.

**Table 7.** Data Types by Part.

| Part No. | Part Name | Data Type |
| --- | --- | --- |
| {1} | storage | patent |
| {2} | transport | patent |
| {2} | charging | patent |
| {4} | storage | research paper |
| {5} | transport | research paper |
| {6} | charging | research paper |

**Table 8.** Top three results of the ARM analyses.

| No. | Start Part | | End Part | Support | Confidence | Lift |
| --- | --- | --- | --- | --- | --- | --- |
| (1) | {5} | => | {4} | 0.1200 | 0.7500 | 2.8125 |
| (2) | {1} | => | {2} | 0.1467 | 0.7333 | 1.0185 |
| (3) | {3} | => | {2} | 0.1067 | 0.7273 | 1.0101 |

After excluding the results connected in the reverse order, a roadmap is created by connecting the remaining results. As shown in Table 9, the final remaining ARM value is 5. A roadmap reflecting the five values resulting from this process is shown in Figure 5.

**Table 9.** Final ARM result.

| No. | Start Part | | End Part |
| --- | --- | --- | --- |
| (1) | {1} | => | {2} |
| (2) | {2} | => | {3} |
| (3) | {2} | => | {6} |
| (4) | {4} | => | {5} |
| (5) | {5} | => | {6} |

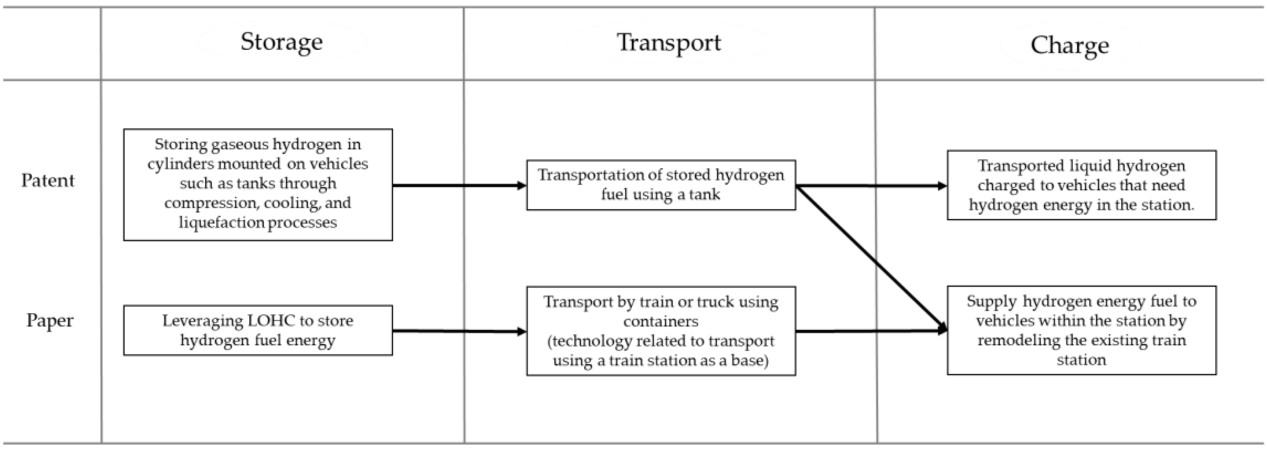



**Figure 5.** Results Roadmap.

As shown in Figure 5, the hydrogen supply chain is planned in storage–transport–charge stages. Promising technologies derived from the analysis results were derived one at a time for each stage, and when looking at promising technologies, there are technologies that affect promising technologies in other stages. For example, a promising technology derived from patent data in the transport stage is related to 'transporting stored hydrogen fuel using a tank', and promising technology in the storage stage, 'storing gaseous hydrogen in cylinders mounted on vehicles such as tanks through compression, cooling and liquefaction processes' techniques are affected. On the other hand, both promising technologies analyzed in the charge stage are affected.

Liquid hydrogen has a higher storage density than gaseous hydrogen and enables weight reduction. It can be 800 times smaller in volume than gaseous hydrogen. In addition, when charging hydrogen, the volume is small, and the charging speed is fast. This is because it takes less time to charge the same capacity. LOHC is a very promising technology due to its high safety against hydrogen explosion. However, technology development must be expanded for commercialization. By applying the results of this analysis, the development of liquid hydrogen and LOHC storage technology, tube trailer for liquid hydrogen transport, and liquid hydrogen charging infrastructure technology development should be established from the perspective of the hydrogen supply chain. This approach will be key to establishing a hydrogen supply chain technology development strategy and building a hydrogen economy.

The roadmap proposed in this study helps to identify future promising technologies that are considered to have a high potential for development in the future in the hydrogen supply chain, identify the links between the technologies, and confirm their influence on each other. Unlike other roadmaps, which are created using patents only, this roadmap derives emerging technology from the storage, transportation, and charging parts of patent and research paper data, respectively. By analyzing the part-by-part association of the derived emerging technology and the association between patents and research papers, we created a roadmap by checking whether there is an influence on each other. We analyzed the latest technologies and research trends together by checking the emerging technologies from patents and emerging technologies from research papers. It can help researchers in the field strategize in the hydrogen supply chain.

## 5. Conclusions

In this paper, we tried to predict the future promising technology of the hydrogen supply chain using hydrogen energy. The purpose of this study is to weave the process of storing hydrogen energy in a container, transporting it, and supplying it to a vehicle into the hydrogen supply chain, support the development of R&D policies, and present investment direction by deriving promising technologies that are necessary for the hydrogen supply chain. In this paper, promising technologies, which are the core of the future hydrogen supply chain, were derived by using the published patent DBs and research paper DBs in Korea, the United States, Europe, China, and Japan. Patents have an 18-month blind process, so we used patent databases and research papers to analyze the technology development process in more detail. In line with the purpose of the supply chain, the data were classified into storage technology, transport technology, and charging technology, then analysis of the technology market growth stage was conducted to understand the development status of each technology. Afterward, text mining and data preprocessing were applied, then vacant technology was discovered through GTM analysis. Keywords of the discovered emerging technology were derived and analyzed. Through this process, three promising technologies were derived from the patent DB analysis, and three were derived from the research paper DB analysis. In other papers that analyzed the technology using only existing patents, it was not possible to analyze the technology during the blind process period of the patent. Unlike other papers, this study was able to analyze the latest technologies by analyzing patents and research papers simultaneously. Unlike previous studies that check the results of patents and research papers separately, it is possible to derive a more useful technology roadmap by confirming the relationship between patents and research paper data and confirming the relationship between emerging technologies.

Promising technologies derived from patent analysis are 'Storing gaseous hydrogen in cylinders mounted on vehicles such as tanks through compression, cooling, and liquefaction processes', 'Transportation of stored hydrogen fuel using a tank', 'The transported liquid hydrogen charged to vehicles that need hydrogen energy in the station'. Promising technologies derived from research paper analysis are 'Leveraging LOHC to store hydrogen fuel energy', 'Transport by train or truck using containers (technology related to transport using a train station as a base)', and 'Supply hydrogen energy fuel to vehicles within the station by remodeling the existing train station'. In this study, we were able to analyze the technology roadmap that could be useful in the future by identifying promising technologies and analyzing the relationship between promising technologies.

In this paper, past technologies were analyzed through the patents and research papers DBs of the last 20 years and future technologies in the relevant field were identified. The blind period of 18 months, which is unknown in the patent, was thoroughly analyzed using the research paper data, and all the latest technologies were reflected. As a result of the study, it was found that the station could be usefully used to transport hydrogen fuel. The result of this study indicated that stations can be usefully used as hydrogen charging stations. A station is mainly a place where people or goods are transported by subway or railroad, and there are sites or parking facilities nearby. Stations built to date have the advantage of good accessibility because they were used as a means of transportation in the past or are still being used. In the case of stations, there are still many existing ones built to be used as a means of transportation, and since they are distributed from the capital to the provinces through the metropolitan area, construction costs can be reduced because there is no need for a separate construction if existing buildings are used. In addition, economically, the empty space can be used beneficially by remodeling an existing station. Installing a hydrogen charging station by remodeling or partially reconstructing an existing station has the advantages of the ease of accessibility and use for people. This study can assist in establishing technology and policy development related to the hydrogen supply chain using railways. This suggests that hydrogen supply chains utilizing railway stations could be a promising technology for the future.

In terms of the supply chain, we analyzed technologies with high potential for development in storage–transport–charge and we were able to derive a roadmap by analyzing the relationship between these technologies. The supply chain roadmap is an analysis of the relationship between promising technologies in the future, and the results of this study can be usefully applied to the hydrogen supply chain. The process of using hydrogen fuel to charge a hydrogen-fueled vehicle can be divided into a hydrogen supply chain, where potential technologies for future development can be identified. The existing technology roadmap is analyzed through interviews with experts in the relevant field and literature research. This paper produced similar results to the technology roadmap through the process of collecting and analyzing data from patents and research. Certainly not the same as the technology forecasting methods and technology roadmaps carried out by conventional experts. However, it invests less time and money, analyzes data in a scientific and accurate way, and leverages the analyzed results to provide more valuable results when setting up a technology roadmap. In addition, it can assist in deriving research or technology strategies by providing a roadmap for technology strategies that can be used in the hydrogen supply chain field by analyzing the correlation of promising technologies in the future.

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