

# Revealing Technology Development of Carbon Capture and Storage Using Patent Portfolio Analysis

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**Abstract**—Carbon capture and storage is the most popular in recent years, the field of sustainability energy industrial management issues, was becoming increasingly relevant research. However, the research is still lack in the patent portfolio. The purpose of this research is to study the status of carbon capture and storage technology and patent portfolio, and investigates major countries to define a better understanding of the developmental trends of the carbon capture and storage. This can further provide the government and industry with additional strategic development proposals. We used data-mining methods [multidimensional scaling (MDS) analysis, and K-means clustering] to explore competing technological and strategic-group relationships within the carbon capture and storage countries. The results indicate that the technical positioning and patent portfolio between the countries are different. We assessed the relative technological advantages position of various countries and proposed technology development policy recommendations to the carbon capture and storage industry.

**Keywords**—carbon capture and storage, patent portfolio, multidimensional scaling analysis, k-means clustering

## I. Introduction

Carbon capture and storage (CCS) is designed for capturing carbon dioxide (CO<sub>2</sub>) from power plants, industrial sites, and even the air, and then, permanently storing these CO<sub>2</sub> underground for the mitigation of global warming. Traditional thermal power plants employ CCS technologies to reduce carbon emissions from power generation activities; therefore, fossil fuel producers consider CCS as a rising technology. Since the 1990s, the promotion of Large-Scale Integrated Projects (LSIP) has been one of the major strategies taken by various countries for the transformation of their low-carbon energy systems [1]. For several years, the analyses by the Committee on Climate Change (CCC) and the Energy Technologies Institute (ETI) have indicated that carbon capture, usage, and storage (CCUS) is indispensable to a cost effective low carbon transition for the UK [4]. As CO<sub>2</sub> recycling will be an emerging industry with great potential in the future, some countries are also committed to developing carbon recycling technologies [5]. Under such a background, governments rely on relevant patent portfolio analysis for keeping abreast of current technological development and supporting the development of key technologies; therefore, this paper presents further analysis.

This study conducted patent analysis, which primarily involves using statistics, analysis, and comparisons of relevant patent document information, in order to understand the development trends in CCS technology. These data were used to exhibit the relevant technical information regarding CCS and explore current technological developments.

Analysis of patents was used to understand patent rights, including the patent strategies of various countries and future developmental trends. A patent model involving multidimensional scaling (MDS) analysis was used by this study for the following purposes: (a) to analyze mainstream CCS technology and understand the current technological development status; (b) to analyze the primary assignee countries and identify different strategic groups; and (c) to conduct trend analyses on the technological development focus of the primary assignee countries and forecast future technology development trends. This study used patent portfolios and MDS analysis to understand the corresponding relationship between assignee countries and technology. The visual effects of this geometric space can effectively exhibit and reveal the technological distribution of competitors, highlight the gaps in current technology, and provide information to serve as a reference for governments when deciding on technology cooperation, exchanges, or the organizations to be licensed with patent rights.

## II. Literature Review

### A. Importance of CCS Technologies

Since the release of the “Special Report on Carbon Dioxide Capture and Storage” by the IPCC in 2005, CCS has been considered as an important CO<sub>2</sub> reduction technology, and nations have started developing CCS technologies. According to “The Global Status of CCS 2018”, as released by the Global CCS Institute (GCCSI), there are now 18 large-scale facilities in commercial operations around the world, which have already captured almost 40 Mtpa of CO<sub>2</sub>, and more than 230 Mt of CO<sub>2</sub> has been safely injected underground to date. In China alone there are more than 20 CCS facilities of different scales in progressive development, and myriad of others in planning. In Saudi Arabia and the UAE, CCS’s application to industry is being embraced by a number of industrial facilities; while in the Netherlands, Norway, and the UK, CCS “hub and cluster” developments are progressing [7].

Currently, various countries are implementing policies for promoting CCS technologies, such as: enactment of the 45Q (tax credit) legislation in the USA, the creation of the UK CCUS Council in the UK, and the CCUS Cost Challenge Taskforce, the promotion of low-carbon technologies (especially CCUS) in China, funding grants for CCS research, and the indexation of CCUS in the amended Environmental Impact Guidance, which is a commitment to establish a hydrogen society by 2030 in Japan and create a Hydrogen Energy Supply Chain (HESC) in Australia [7]. According to the Intergovernmental Panel on Climate Change (IPCC), in order to keep the global temperature rise

this century well below 2°C, and to pursue efforts to limit the temperature increase even further to 1.5°C, global energy systems require wide applications of low carbon technologies to achieve the transformation of a low-carbon energy mix [8]. According to the report of the International Energy Agency, to reduce global greenhouse emissions from the 6°C Scenario (6DS) to the 2°C Scenario (2DS) by 2050, critical carbon reduction technologies in the future include end-use fuel and electricity efficiency (38%), renewables (32%), and CCS (12%). Therefore, CCS technologies must be implemented as scheduled; otherwise, there will be a large gap in carbon reduction results. In view of the above, and driven by global technological development or the implementation of policies by countries, CCS technologies are still of great importance in the energy technology field.

## B. Current Development of CCS Technologies

CCS is considered one of the key carbon reduction technologies for the future. CCS can reduce carbon emissions through the three processes of capture, transport, and storage, and has become a major indicator of international energy savings, carbon reduction, and energy substitution while transitioning from fossil power to renewable power generation. The value chain of CCS, as shown in Figure 1, shows the capture of CO<sub>2</sub> from various emission sources (production of fossil fuel and biomass); the separation and collection of CO<sub>2</sub> by utilizing various capture technologies, such as Post Combustion Capture, Pre Combustion Capture, Oxyfuel-Combustion, and other existing separation technologies; recycling of captured CO<sub>2</sub> into fertilizer, (poly) carbonate, and cement substitutes, or the storage of CO<sub>2</sub>.

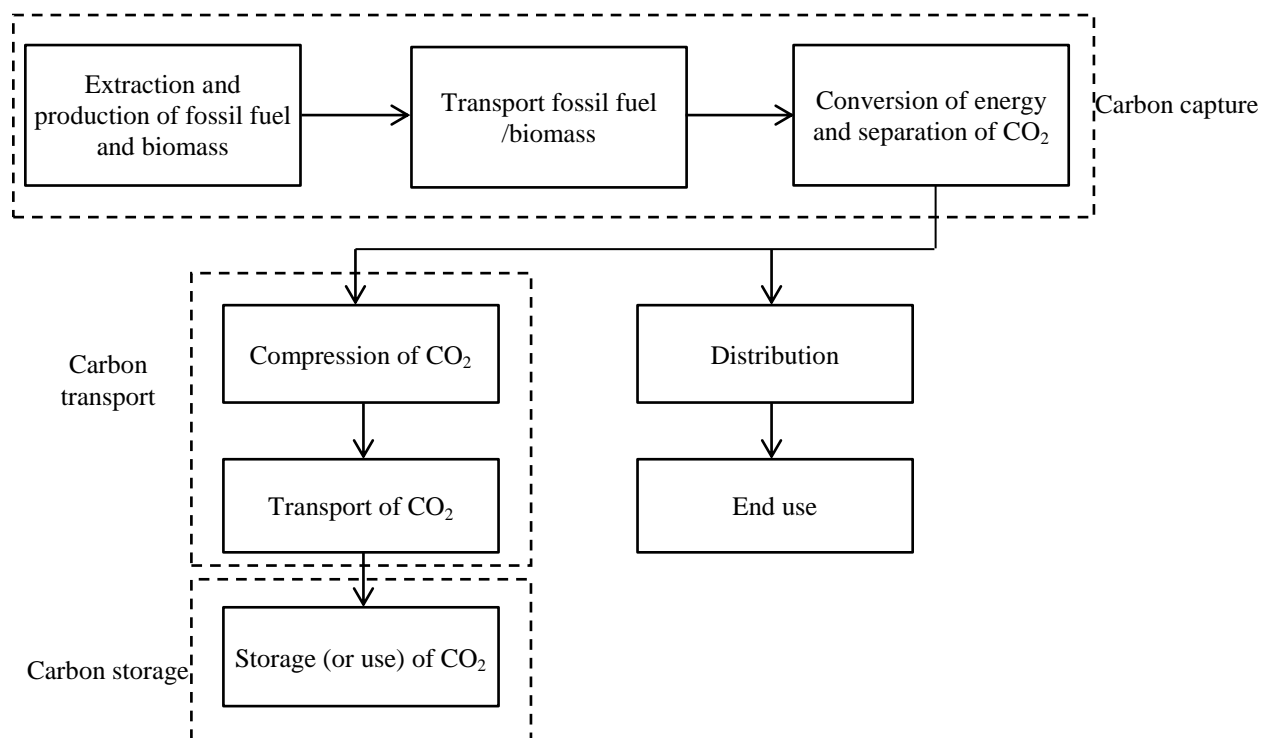


Figure 1 Value chain of CCS

Source: adapted from [9].

There are various types of carbon sequestration, such as geologic, ocean, mineral, and biological sequestration. Currently, CO<sub>2</sub> is recycled for producing urea (nitrogen fertilizer), salicylic acid (drug additive), Polycarbonate (plastics), fire extinguishers, carbonated beverages, and alga (biofuel). In addition, a current development of carbon recycling includes the use of CO<sub>2</sub> for producing high-performance batteries [10] and foam plastic [11]. Under such a background, CO<sub>2</sub> recycling will become an emerging industry with great potential in the future. Therefore, all developed countries worldwide are committed to developing CO<sub>2</sub> recycling technologies.

## III. Research Methods

### A. Data Sources and Search Strategies

This study selected the United States patent database for conducting patent analysis, and collected patents available to the public from the United States Patent and Trademark Office (USPTO) database. Patent data are limited to the patents publicly available in the United States from 2010 to March 12, 2019. The CCS patent search of this study adopted the definition of CCS technology using the International Patent Classification (IPC) system, as provided by the World Intellectual Property Organization [12]. The IPC distribution is displayed in Appendix 1. Initially, 2,516 patents were obtained.

## B. Multidimensional Scaling Analysis

Multidimensional scaling (MDS) analysis is a multivariate statistical analysis method employed to identify the relationships between objects. MDS aims to represent these objects in a single or multidimensional space according to the values of distances, as based on observed similarities or differences between the objects or units [13]. The MDS representation of  $n$  objects requires the definition of a measure  $\delta_{ij}$  for distance between items  $i$  and  $j$ ,  $i, j = 1, \dots, n$ , followed by the calculation of a  $n \times n$  symmetrical matrix  $\Delta$  measuring the distance between all pairs of objects:

$$\Delta = \begin{bmatrix} \delta_{11} & \dots & \delta_{1n} \\ \vdots & \ddots & \vdots \\ \delta_{n1} & \dots & \delta_{nn} \end{bmatrix} \quad (1)$$

Given distance  $\delta_{ij}$ , MDS tries to obtain the position vectors  $x_i$  and  $x_j$ , in order that the vector norm  $d_{ij} = |x_i - x_j|$  is close to  $\delta_{ij}$ . In other words, MDS represents an optimization problem, where vectors  $\{x_1, \dots, x_n\}$  are found by minimizing some kind of cost function, often called "stress"  $S$ , such as [14]:

$$\min_{x_1, \dots, x_n} \sum_{i < j} (d_{ij} - \delta_{ij})^2 \quad (2)$$

In addition, this study classifies patent documents through two-stage clustering analysis. Based on the patent document coordinates acquired by MDS analysis and clustering analysis, this study conducts clustering, and judges the clusters of countries' patent portfolios according to the figures of the positions.

The perceptual map exhibits the following data: (a) the relationship between countries, in which close points indicate high correlation, and thus, can be classified into the same category; (b) the relationship between countries and IPC means that when countries are closer to the IPC points, the countries have better IPC technical performance in the category.

## IV. Result Analysis

### A. Patent Search Result

Before MDS analysis was conducted, patent search result analysis was performed to obtain an overview of technological development. Figure 1 displays the number of accumulated CCS patents/approval dates.

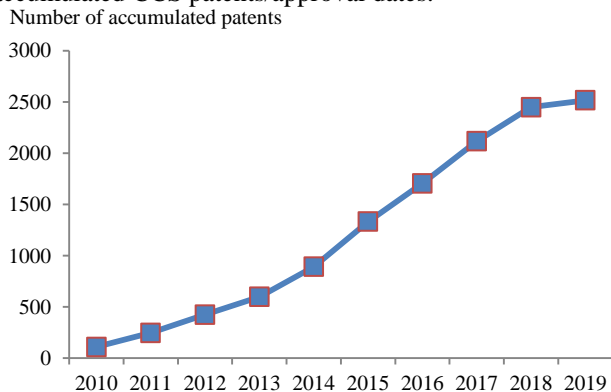


Figure 1. Number of accumulated CCS patents/approval dates

Table I presents the 5 assignee countries with the most CCS patents contained in the United States patent database. Regarding the assignee countries, the five leading countries are the United States, Japan, Germany, the United Kingdom, and France, at 1040, 706, 259, 89, and 82 patents, respectively. Table 2 shows the distribution of the 10 most numerous IPC categories (namely, the first IPC in each patent). The results shown in Table II indicate that CCS technology is mostly concentrated in F01N3, B01D53, F01N13, F02D41, and F01N9. According to the definitions of the IPC, the F01N3 category represents exhaust or silencing apparatus with t abilities to purify, render innocuous, or otherwise treat exhaust. B01D53 denotes the separation of gases or vapors, the recovery of the vapors of volatile solvents from gases, and chemical or biological purification of waste gases: e.g. engine exhaust gases, smoke, fumes, flue gases, or aerosols. F01N13 denotes exhaust or silencing apparatus characterized by constructional features. F02D41 represents the electrical control of the supply of a combustible mixture or its constituents. F01N9 denotes the electrical control of exhaust gas treating apparatus.

TABLE I. Quantity of patents held by the 5 leading assignee countries

| Rank | Assignee country | Quantity | Percentage |
|------|------------------|----------|------------|
| 1    | US               | 1040     | 41.34%     |
| 2    | JP               | 706      | 28.06%     |
| 3    | DE               | 259      | 10.29%     |
| 4    | GB               | 89       | 3.54%      |
| 5    | FR               | 82       | 3.26%      |

TABLE II. Distribution of the leading 10 IPC categories

| Rank | IPC categories | Quantity | Percentage |
|------|----------------|----------|------------|
| 1    | F01N3          | 1996     | 21.84%     |
| 2    | B01D53         | 695      | 7.60%      |
| 3    | F01N13         | 614      | 6.72%      |
| 4    | F02D41         | 370      | 4.05%      |
| 5    | F01N9          | 282      | 3.09%      |
| 6    | C01B31         | 273      | 2.99%      |
| 7    | F01N11         | 270      | 2.95%      |
| 8    | B01J23         | 239      | 2.62%      |
| 9    | F25J3          | 193      | 2.11%      |
| 10   | B01J35         | 168      | 1.84%      |

### B. Patent Portfolio Positioning Analysis

This study conducted MDS on the top 50 IPC four-stratum classification codes, and the top 10 countries, and the results show that the technical fields involved in CCS patents are broad, and that MDS is suitable for analyzing assignee countries and IPC categories. In addition, two-step cluster analysis was conducted on the patent data. First, hierarchical clustering analysis was used to determine the optimal group number (i.e., four). According to the coefficient change of clustering agglomeration, the best number of a group is 3. K-means clustering was then used to divide the IPC categories into three groups. Figure 2 shows the patent portfolios of the assignee countries and IPC. Table III shows the main members of the groups.

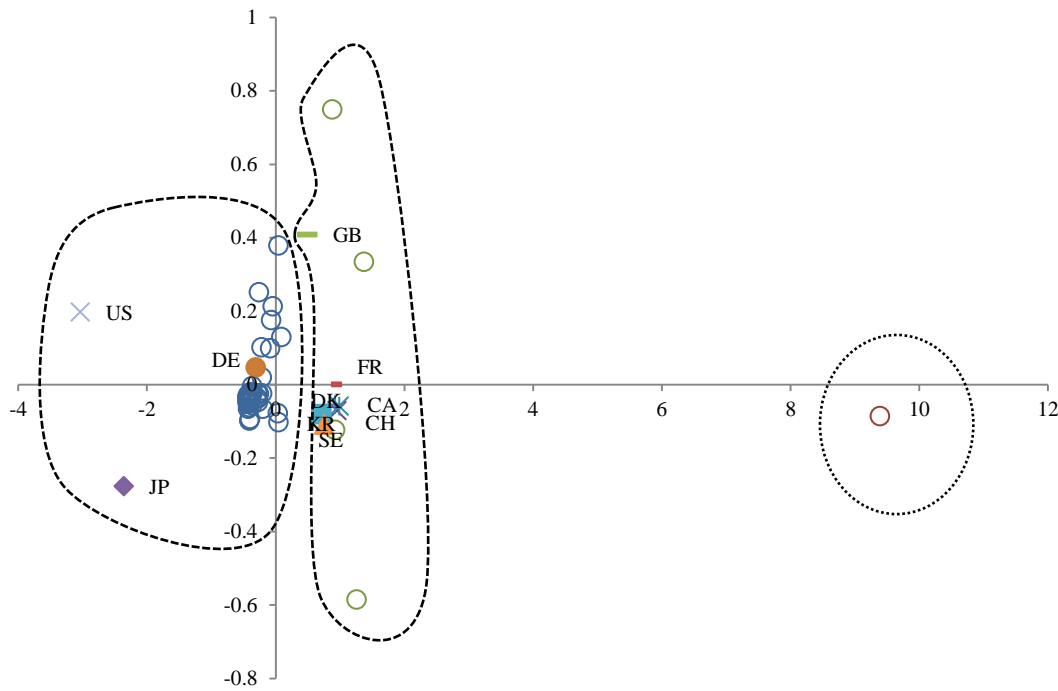


Figure 2 Patent portfolio of assignee countries and IPC

TABLE III Main members of groups

| Group | Main members of groups                                                                              |
|-------|-----------------------------------------------------------------------------------------------------|
| 1     | F01N3                                                                                               |
| 2     | B01D53, F01N13, F02D41, B01J23, Canada, Switzerland, Denmark, France, United Kingdom, Korea, Sweden |
| 3     | F01N9, C01B31, F01N11, F25J3, B01J35, B01J37, C07C7, B01J21, B01J29, Germany, Japan, United States  |

Figure 2 and Table III show that the majority of IPC and assignee countries are close to Group 2. The technologies in Group 2 are B01D53, F01N13, F02D41, and B01J23, and the countries in this group comprise Canada, Switzerland, Denmark, France, the United Kingdom, Korea, and Sweden, which indicates that, in CCS technology, the technological developments in these advanced countries are extremely similar. This method can be used to explore the direction of current mainstream technological developments. These categories emphasize recovering the vapors of volatile solvents from gases, as well as the electrical control of the supply of combustible mixtures or their constituents. In addition, the positions of the offshore wind-power patent portfolios for Germany, Japan, and the United States were similar, and these countries were the countries containing the most approved CCS patents. The portfolios mainly involved F01N9, C01B31, F01N11, and F25J3; that is, the development of CCS countries, which emphasizes the development of exhaust gas treating apparatus and the processes or apparatus for separating the constituents of gaseous mixtures involving the use of liquefaction or solidification.

## v. Conclusion and Recommendations

This study conducted relevant patent analysis, MDS, and cluster analysis to identify current mainstream and technological trends, as well as the strategy and positioning of patent portfolios. The results can provide a reference for governments when devising patent-portfolio strategies,

which enables firms to choose effective strategies and reduce their technology investment risks when developing strategies. The results showed that CCS patents are concentrated in the United States, Japan, Germany, United Kingdom, and France. Currently, CCS technology is concentrated in F01N3 (i.e., exhaust or silencing apparatus for purifying, rendering innocuous, or otherwise treating exhaust), B01D53 (i.e., separation of gases or vapors), and F01N13 (i.e., exhaust or silencing apparatus characterized by constructional), which indicates that the technological direction in current CCS technology is partially moving toward gas-flow silencers or exhaust apparatus for machines or engines in general.

The patent portfolio positioning analysis shows that the portfolios of Canada, Switzerland, Denmark, France, the United Kingdom, Korea, and Sweden are primarily focused on VOC treatment technologies and operations. The recent energy crisis and increased environmental awareness has driven the development of CCS technologies. Canada is a global leader in CCS and is committed to exploring this technology; the Weyburn project in Canada – one of the first large-scale efforts in the world – was launched in 2000. These projects involve capturing CO<sub>2</sub> emissions in North Dakota, transporting the CO<sub>2</sub> across the Canada-United States border and delivering it for enhanced oil recovery (EOR) operations [15]. Denmark tops a new global energy revolutionary league table ranking to implement measures to mitigate climate change, which includes carbon capture. In the report Energy Revolution: A Global Outlook, Denmark is leading the way in transforming its energy system, followed closely by the UK and Canada, respectively [16].

Germany, Japan, and the United States are primarily focused on CO<sub>2</sub> recycling, including the processes of separating and purifying gas mixtures. Germany's Federal Ministry of Economics and Technology (BMWi) is supporting the development of "power plant technology and CCS technology" through its research and development initiative COORETEC (CO<sub>2</sub> Reduction Technologies for



Fossil-fired Power Plants), which aims to reduce the CO<sub>2</sub> emissions of its power facilities to near zero [17]. In December 2015, Japan accepted the 'Paris Agreement' with its proposed targets. The Japanese government has the intention of establishing a domestic legal framework for CCS, which will potentially enable them to reduce a large amount of CO<sub>2</sub> emissions domestically [18].

To keep the global temperature rise this century well below 2°C and to pursue efforts to limit the temperature increase even further to 1.5°C under the Paris Agreement, global energy systems require wide applications of low carbon technologies, in order to achieve the transformation of low-carbon energy mix. Since 1990s, promotion of Large-Scale Integrated Projects (LSIP) has been one of the major strategies taken by countries in the world for the transformation of their low-carbon energy system. CCS has been considered by major countries in the world as an important carbon reduction option, as evidenced by a number of commercial cases applied in nations worldwide, such as the Sleipner and Snohvit projects offshore Norway and the In Salah gas field in Algeria. These gas fields represent the sequestration of 1 million tons of CO<sub>2</sub> per year, respectively. In particular, CO<sub>2</sub> filling at Sleipner can be dated back to 1996. CO<sub>2</sub> is filled into a petroleum reservoir for recovering remaining petroleum; such technology can improve oil production, and has been implemented in the USA, Canada, and China for years. Under such a background, CO<sub>2</sub> recycling will become an emerging industry with great potential in the future, and all developed countries worldwide are committed to developing CO<sub>2</sub> recycling technologies. Therefore, in response to both the global carbon reduction trend and the commercial use of CO<sub>2</sub> recycling technologies, governments are advised to continuously support the development of CCS technologies in terms of policy.

Regarding suggestions for future researchers, this study can be further improved in certain areas. First, this research was conducted with limited funding and manpower, which meant that only the USPTO database was employed as a data source for patents. Future research with sufficient time and funding should gather patent information from the databases of additional key player countries (e.g., the Japan Patent Office and the European Patent Office), in order to widen the scope of their research. Second, future research can adopt different patent variables, such as assignees or inventors, to obtain more useful patent information. Finally, follow-up research can apply different patent conditions (e.g., Triadic Patent Families) to disclose more complete patent information.

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Appendix 1 IPC codes of CCS patents

| CCS technologies | IPC                                                                                              |
|------------------|--------------------------------------------------------------------------------------------------|
|                  | B63B35, C01B3, C01B31/20, C01B31/22, C02F1, C07C7/10, F01N3/10, F25J3/02, B01J20, B01D53, B01D11 |

Source: [12]