Reducing Carbon Emission - Foresight of CCS Technology Developing, IP Management and Global Technology Transfer

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Abstract

Large-scale CO2 emissions are believed to be a major contributor to global warming. CO2 Capture and Storage (CCS) is the essential technology to significantly reduce greenhouse gas emissions and allow the use of fossil fuels for energy security without damaging climate. CCS technologies belong to interdisciplinary, cross-industry technologies with wide ranges. With the development of CCS applications and demonstration projects, many technical problems and key challenges are needed to be solved and might lead to IP and MOT issues, the studies about CCS technology system, intellectual property, technology management and technology transfer are of important practical significances.

This research provides an overview of the development of CCS technologies, including a key-technology list in three major stages of CO2 capture, transport, and storage, and refines the common technology chain of commercial CCS projects. The analysis of CCS patents in worldwide databases reveals information on the global CCS patents distribution, technical fields, development trends, countries, corporations, etc., to discover the technology maturity and weakness of the current CCS technologies. The objective is to uncover possibilities for technology cooperation and technology transfer and to highlight areas in which further research could be carried out.

MOT of CCS provides direction & guide to operate CCS technology transfer. Main subjects are included market assessment, information analysis, knowledge management and technology industrialization. Technology transfer can be conducted practically among all the developed and developing CCS countries and corporations, the study lists the essential issues and performances for cross-border CCS technology transfer, offers strategies for technology seekers and providers, including R&D and protection, technology application & utilization, IP licenses & enforcement, making up agreements and contracts. In the recommendation the paper gives CCS-MOT promoting suggestions at 5 imporant perspectives.

Keyword: Reduce CO2 emission, Carbon capture and storage, Technology developing, CCS patent, IP management, Technology transfer

1. Introduction

Carbon dioxide (CO2) emissions are believed to be a major contributor to global warming. Nearly all world states have committed themselves to the goal of avoiding climate change caused by human activity. As a consequence, large anthropogenic CO2 sources worldwide will eventually be required to implement CO2 capture and storage technologies to control CO2 emissions. The main objective of carbon capture and storage (CCS) is to prevent CO2 from entering the atmosphere by capturing CO2 from large industrial sources and securely storing it in various carbon sinks. CCS is considered a critical component of the portfolio of carbon mitigation solutions, because global economy heavily relies and will continue to rely on fossil fuels in the foreseeable future. Currently, there are close to 300 active and planned CCS-related projects around the world—an indication of a growing commitment to this technological option. Lately there has been significant progress in CCS technology, new CCS technical ways are developing, more problems also emerges, it is quite needed for technology management & tech-transfer to enhance CCS innovation and industrialization.

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This paper introduces scientific and engineering progress in three major stages of the CCS chain, CO2 capture, transport, and storage, and the current status of existing and planned commercial CCS projects. The research is designed to provide an overview of the development of CCS technologies, through both technology investigation and patent applications analysis around the world. Specifically, the study wants to: (i) examine development in the current CCS technologies and world CCS patent applications filed at Global main patent offices; (ii) identify the major countries and companies involved developing CCS technologies and analyzes their current CCS projects; (iii) research the future trend of CCS technology development, patent management and worldwide technology transfer.

2. Methodology

2.1 Technology Investigate

The author serves for two inter-governmental cooperation programs on CCS research & demonstration, the CERC (US- China Clean Energy Research Center) Program and the NZEC (EU-China Near Zero Emission of Carbon) Program, attended annual workshops which were arranged by the U.S. Department of Energy (DOE) and the China Ministry of Science and Technology (MOST) to specifically learn about CCS developing and discuss their IP concerns related. The discussions are documented by the author in workshop reports, these lead me good opportunities to collect a lot of CCS data and research experiences.

In order to research on the CCS technology development and the worldwide CCS projects, the author usually spoke directly with numerous CCS project participants from the United States, Canada, Europe, Japan, Australia and China. These represent all of the different groups involved in worldwide CCS areas. Interviews were conducted periodically between 2013 and 2015, the author attempted to speak with multiple representatives from various CCS organizations to try to encompass as many perspectives as possible.

To establish a main technology list of CCS and collect the current status of main CCS projects, the research methods include AHP, experts consultation, technology classification, literature investigation, scientometrics and CCS engineering cite study. The expert-consultation contains face-to-face interview, questionnaire survey, conference statement and workshop discussion, more information are collected from CCS relevant documents, official websites, etc. Besides all of above, a quite good way is the global CCS patents analysis.

2.2 CCS Patent Analyze

CCS patents analysis can reveal the CCS technological information, business information and also the competitive information, helps to make strategic technology management. It can unveil the technology development history, tendency and distribution of world patents, reflect the technical and market development status of competitors, unveil the opportunities and risks of technical innovation and market development and guide the technology transfer. In the global CCS patent analysis, the author reviewed the current status of CCS patents and technologies in the main world official databases.

The data used in this search was extracted from the patent databases of the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the European Patent Office (EPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), and the International Bureau of the World Intellectual Property Office (WIPO) as well as the WIPS patent database and the Derwent Innovation Index (DII) database provided by Thomson Reuters. International Patent Classification (IPC) symbols and simple keywords were used to identify relevant records in the databases. IPC symbols have the advantage of being language-independent and generally assigned to patent applications in a uniform manner across different countries.

3. Research on CCS Techs & IP

3.1 CCS Technology Development

The objective of CCS is to prevent CO2 from entering the atmosphere by capturing it from large industrial sources and permanently storing it in various carbon sinks. CCS is considered and will remain a critical component of the portfolio of carbon mitigation options. Present most of worldwide CCS projects are in North America (the USA, Canada), Europe (Norway, the UK, Netherlands, and others), Australia, and China. Technologically, CCS is a complex set of industrial processes and operations encompassing three major steps: CO2 capture, transport, and storage, and a manifold of technological options and variations associated with each of these steps.

Currently, the main technological approaches to CO2 capture from fossil fuel usage are: (i)Pre-combustion carbon capture; (ii)Post-combustion capture; (iii)Oxy-fuel combustion. There are multiple technological routes within each of these major categories that best suit specific fuel types, geographical locations, climate conditions, and economic development level. The main existing technological methods for CO2 capture are summarized in Table 3.1.

Table 3.1 CO2 capture technologies

Processes, methods	Compounds, materials, processes
Chemical solvents	Monoethanolamine (MEA)
	Diethanolamine (DEA)
	Methyldiethanolamine (MDEA)
	Potassium carbonate (Benfield process)
Physical solvents	Glycol: Selexol
	Methanol: Rectisol
	Propylene carbonates
	N-Methyl-2-pyrolidone (Purisol)
Chemical sorbents	CaO
	Amine-enriched sorbents
Physical sorbents	Zeolites
	Activated carbon
	Metal-organic frameworks (MOF)
Membranes	Polymer membranes
	Ceramic membranes
	Hollow fiber membrane supports
Cryogenic distillation	※
Hydrates	※

CO2 Transport is an intermediate operation (between CO2 capture and its storage) in the overall CCS technological chain. Although in some projects, CO2 capture and storage sites may be in a close proximity to each other; in most cases, CO2 has to be transported from point-to-point for tens to hundreds of kilometers. Naturally, the longer distances translate into the higher cost and, in some cases, the additional challenges of technological and nontechnical nature, e.g., need for recompression and monitoring, unfavorable terrain, and public acceptance. In principle, CO2 can be transported in three physical states: gaseous, liquid, and solid. In order to transport CO2 economically its volume should be substantially reduced: this can be done either by pressurization (compression), or liquefaction, or solidification, or hydration (to crystalline hydrates). After the process of CO2 compression and dehydration, the compressed dry CO2 will be transported in long sealed Pipelines or by Shipping, to their storage cites.

CO2 storage is a final step in the multistep CCS process. It is usually stored hermetically under the deep land layers or the ocean seabed. Fig. 3.1 shows the current different options for carbon storage:

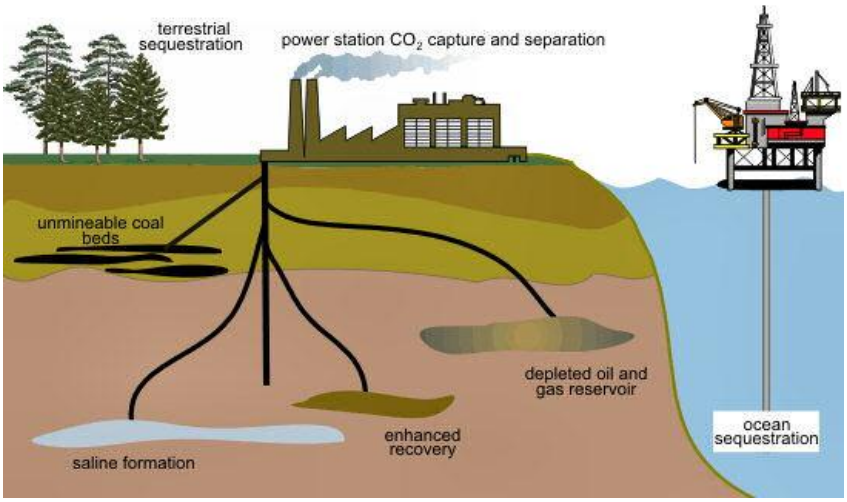

Fig. 3.1 Carbon storage in different options

Table 3.2 lists the current technical options for CO2 storage and several suitable types of geological formations to safely store CO2:

Table 3.2 Technical options for CO2 storage and suitable formations

Processes, methods	Suitable formations to safely store CO2
Geological storage	Deep saline formations (DSF)
	Depleted oil and gas reservoirs (DOGR)
	Unminable coal beds
	Salt caverns
	Abandoned mines
	Basalts
	Organic-rich shale and other geological media
Ocean storage	Ocean depth, Seafloor
Mineral sequestration	Silicates of Ca and Mg
Biological storage	Biochemical biomass conversion

Besides industrial use, compressed CO2 could also be used in Enhanced Oil Recovery (EOR), Enhanced Coal Bed Methane Recovery. CO2 can be sequestered in the terrestrial, aquatic, and ocean ecosystems as parts of the earth' s biosphere.

According to the research and expert advices, a list of CCS key technologies is analyzed, Table 3.3 provides a classification of CCS complete system including existing and emerging CO2 capture, transport, and storage technologies.

Table 3.3 Classification of CCS system including CO2 capture, transport, and storage

CCS component	main class –CCS technology	Sub class –technology method
CO2 Capture	Pre-combustion	Solvents, Adsorbent
	Post-combustion	Membranes, Mineralization
	Oxyfuel combustion	CO2 hydrates, Enzymes
CO2 Transport	Compression	Compression and Dehydration
	Transportation	Pipeline, Ship, Rail, Truck, Combination
CO2 Storage	Geological	Saline formations, Depleted oil/gas reservoirs, Basalt/shale formations, salt caverns
	Ocean	CO2 lakes, Ocean dissolution, Solid hydrates
	Biosphere	Forest lands, Agricultural lands, Wetlands & Peatlands

	Beneficial reuse	Enhanced oil/gas recovery, Enhanced coal bed methane recovery, Industrial utilization
	Mineral sequestration	In-situ sequestration , Ex-situ sequestration

Carbon dioxide produced by power production and other industrial processes can be captured and stored in order to prevent it from entering the atmosphere. The cost of capturing the gas currently corresponds to around 70 to 80 percent of the total cost of carbon capture and storage. But this adds to costs of energy production, reduces energy efficiency, capturing carbon dioxide present remains costly and difficult.

3.2 Global CCS Patent Analysis

Patents are the main carrier of innovative technologies. When a key CCS technologies list has been clarified and established, in order to master the CCS patent developing statue, distribution and diversity, the author searches the patents of the whole CCS process chain, analyzes the global CCS patents layout, technical fields, development trends, the patentee, the countries, corporations and so on, to discover the maturity and weakness of the current CCS technology. The objective is to uncover possibilities for technology cooperation and technology transfer and to highlight areas in which further research might be carried out.

Overall patenting activity in CCS technologies has risen from the 1970s to the present, as evidenced by applications filed at the USPTO, JPO, EPO, KIPO and SIPO and through the PCT system. Total patent filings have increased at a rate of 10 percent per year starting in the 1990s and at a rate of 25 percent from 2001.

3.2.1 The overall annual increasing trend of the global CCS patents with time

Fig.3.2 shows the trend statues that the global CCS patents have increasing quantities with time. CCS-relating patents got the application since the 1970s which is the earliest stage of CCS patent applications. From the mid-1980s to 2005, there are keeping the stable and low quantity growth of the CCS patents. But after 2005, there are a large number of CCS patent growth which reflects many countries pay more and more attentions to global warming, Climate changes, environment changes and other relating issues.

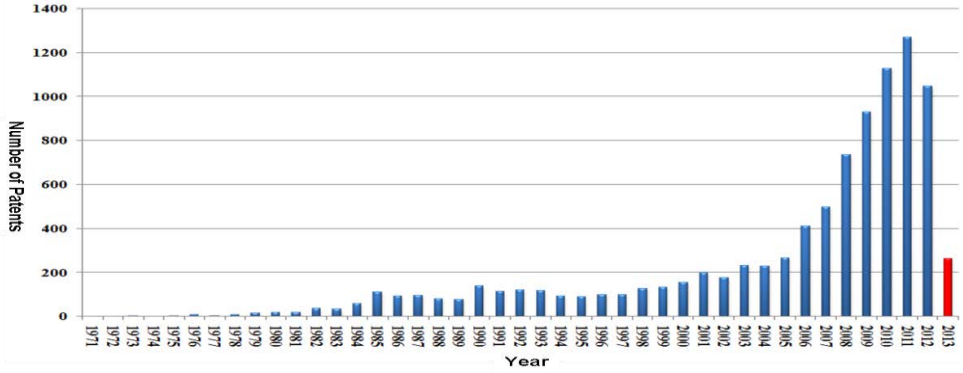

Fig.3.2 The annual increasing trend of CCS patent quantities

(Note: CCS date in 2013 might be lack in the databases due to the time.)

3.2.2 CCS patents developing trends of different countries

According to the sequence of the most CCS patent quantities, the top10 countries include Japan, USA, China, Korea, Germany, France, Russia, Britain, Netherlands and Norway in turn. Fig.3.3 shows that CCS patent developing trends of top 10 countries change with time. In the early stage (before 2005), the USA and Japan had more application for CCS patents and their quantities are much more than others'. After 2005, each countries have the rapid growth of CCS patents while USA had the largest increase and reached a peak of over 320 patents in 2011. China had also the rapid growth of CCS patens after 2005 and for the first time surpassed the Japan in 2010 and reached a historic peak of over 290 CCS patents in 2012, which related china's policies to put forward the CCS application and development.

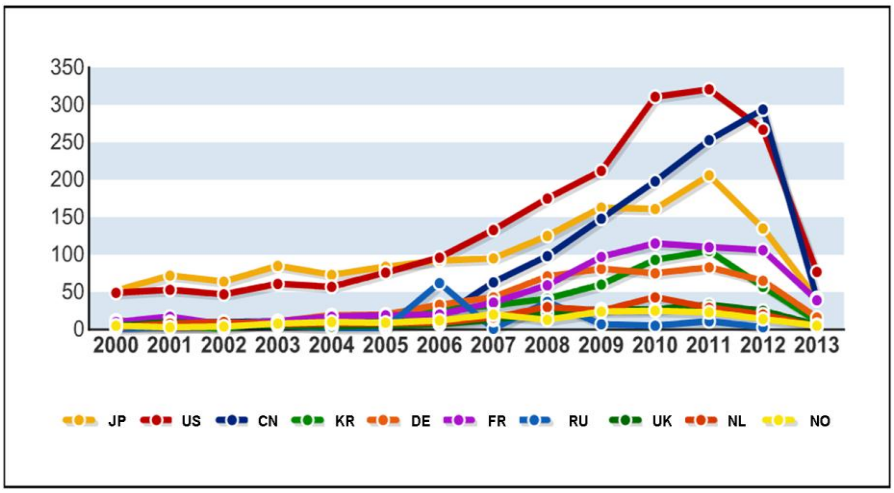

Fig.3.3 Changes of the top 10 countries' patent quantities with time

3.2.3 CCS patent distributions of different countries and their proportion analyses

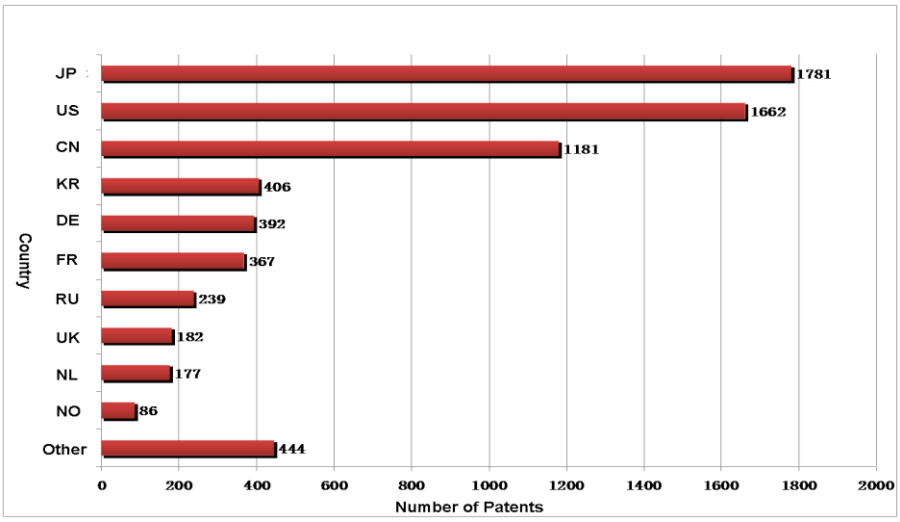

Fig. 3.4 The order of countries according to the quantities of CCS Patents

Fig.3.4 and fig.3.5 show the distributions and proportions of top 10 countries' CCS patents. From fig.3.4, the top 3 countries of the largest number of CCS patents are Japan, the United States and China which CCS patent quantities are beyond one thousand and others countries are far less than these three countries.

From fig.3.4, the United States and Japan have half of the global CCS patents, which of Japan are beyond quarter and which of the United States are near quarter. The proportion of Chinese patents is 17.07%, which reflects the CCS development in recent years and the attention to intellectual property rights.

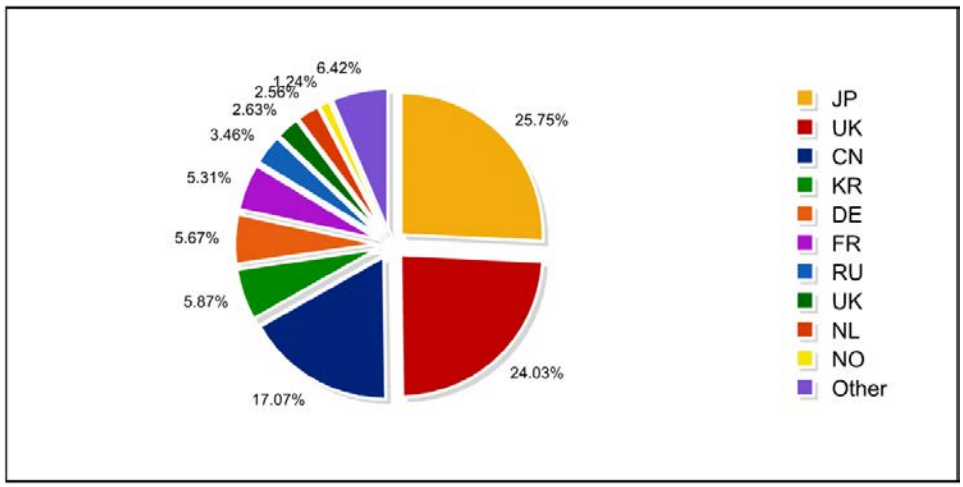

Fig.3.5 the proportions of Top 10 countries of the larger CCS patents

3.2.4 Distribution of the technological fields about the global CCS patents and their focuses

Generally CCS covers the electricity, steel, cement, oil and gas and other traditional industries. Tab.3.4 shows the distributions of CCS technology fields and their patent quantities, quantity of CCS patents in recent three years and so on, which quantities contains the CCS patents of cross-cutting technologies.

From the perspective of the CCS implementation Phase, the patent applications of CO_2 capture technologies and geological utilization began in 1970s and the stage of CO_2 capture has the more patents which is beyond 4025, which covers the different fields including flue gas, various physical and chemical methods, devices and equipment separating CO_2 in gas, such as solid adsorption, membrane separation, sorbent activation and so on. The patents in CO_2 geological sequestration stage are also greater and over 705. .

From the view of time, the application for CCS methods is prior to the CCS instruments and devices, and the patents of the CO_2 capture stage are prior to CO_2 geological utilization stage. In the stage of CO_2 capture, the patents of solid absorption methods and membrane separation methods are later. The solid absorption method patent applications began in the early 1980s and membrane separation method patent applications were from the middle and late 1980s, membrane materials of which were earlier than the patent applications of membrane shapes and membrane structures.

In recent 3 years, the CO2 capture technological field has more patents, which CO2 managing equipment and CO_2 separating techniques have the faster growth of patents and their rates respectively reach 48% and 41%.

Tab 3.4 Main CCS technological field (ranking the Top 13 technological fields of patent quantities) and their patent applications

IPC Classification Number	quantity	technological fields	years	percent proportion of recent years
B01D-053	4025	Separation of gases or vapours; Recovering vapours of volatile solvents from gases; Chemical or biological purification of waste gases, e.g. engine exhaust gases, smoke, fumes, flue gases or aerosols	1971 - 2013	32%
C01B-031	1770	Carbon; Compounds thereof	1973 - 2013	32%
B01J-020	763	Solid sorbent compositions or filter aid compositions; Sorbents for chromatography; Processes for preparing, regenerating or reactivating thereof	1980 - 2013	25%
E21B-043	705	Methods or apparatus for obtaining oil, gas, water, soluble or meltable materials or a slurry of minerals from wells	1973 - 2013	26%
F25J-003	378	Processes or apparatus for separating the constituents of gaseous mixtures involving the use of liquefaction or solidification	1973 - 2013	35%
B01J-019	254	Chemical, physical, or physico-chemical processes in general	1975 - 2013	33%
B01D-071	223	Semi-permeable membranes for separation processes or apparatus characterised by the material; Manufacturing processes specially adapted therefor	1984 - 2013	26%

F23J-015	197	Arrangements of devices for treating smoke or fumes	1985 - 2013	48%
B01D-000	177	SEPARATION	1973 - 2013	41%
F25J-001	144	Processes or apparatus for liquefying or solidifying gases or gaseous mixtures	1982 - 2013	33%
B01J-008	130	Chemical or physical processes in general, conducted in the presence of fluids and solid particles; Apparatus for such processes	1986 - 2013	33%
B01D-019	110	Degasification of liquids	1979 - 2013	38%
B01D-069	110	Semi-permeable membranes for separation processes or apparatus characterised by their form, structure or properties; Manufacturing processes specially adapted therefor	1989 - 2013	33%

3.2.5 Distributions of CCS patents' techniques of main countries and their technological emphases

Fig.3.6 shows that the CCS patents of top 10 countries cover the 10 fields of technologies including CO2 separation, CO2 removal methods, device, processes and so on, and these countries have the respective emphases, which technological numbers' meanings are found in tab.2. Most countries focus on CO2 capture fields and the more patents cover the technologies including CO2 separating from gas or flue gas, carbon and compounds, the preparation of CO2 solid absorbents and their regeneration and activation technologies.

Compared with other countries, American, Russia, Netherland and Norway have obvious advantages in increasing oil production or natural gas production or groundwater production through CO_2, while Britain and France have obvious advantages in the patent applications of CO_2 solidification and absorption technologies.

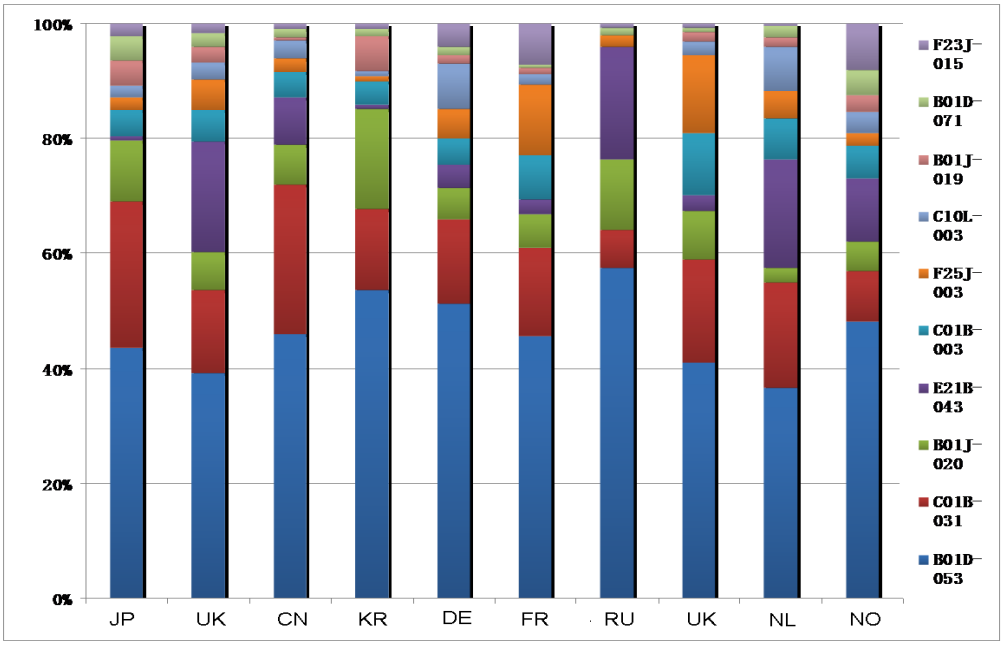

Fig.3.6 Technological fields covering CCS patents and the emphases of Top10 countries

3.2.6 Analysis of CCS patentee changes in recent three years

Tab.3.5 shows the quantities of CCS patents from the patentees, the patentees for the first time and ranking of top 20 patentees in recent three years. In recent three years, the patentee of the greatest patents is Alston Corporation who has 89 patents, while CAS and SINOPEC also have more patents and respectively are of rank

10 and 12. From the new patentees in recent three years, there are many patentees from China whose quantity comes to more than 10 but they have little patents applied. The patentee proportion from China is more than 50% and these patentees include China Huaneng Group, China coal res. Institution, Univ. Sichuan, Univ. China petroleum east and so on, which reflects the more and more institutions or persons focus on technology innovation of the CCS field.

Fig.3.7 shows the ranks of CCS patents according to the more quantities of patents.

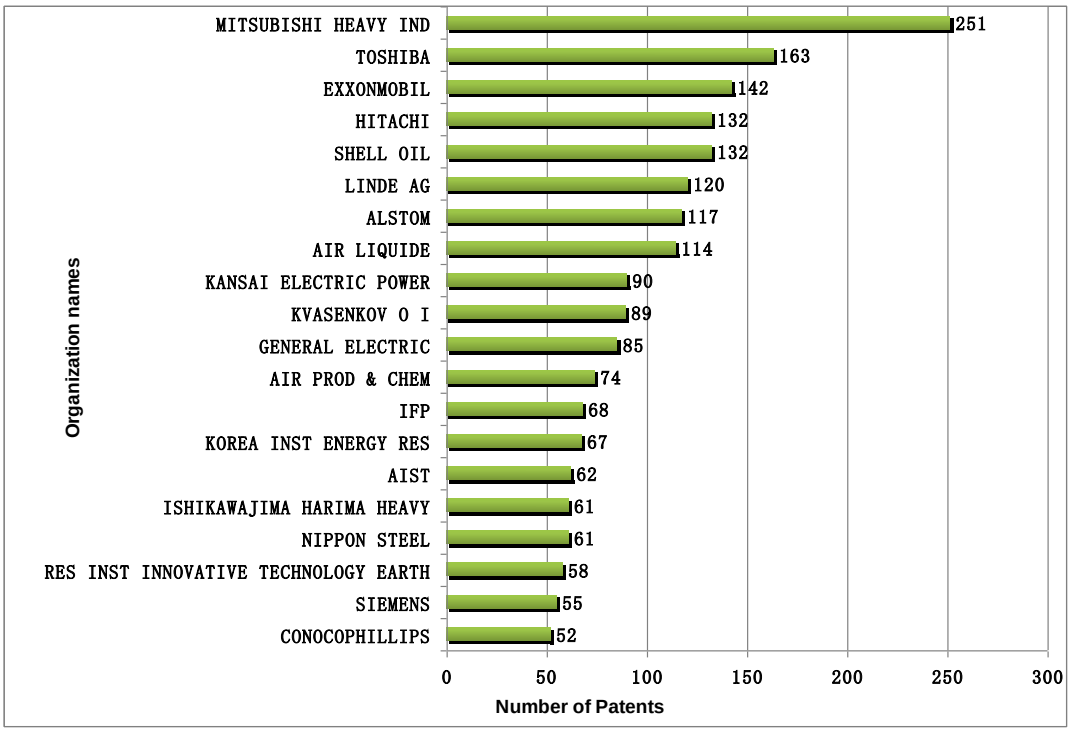

Fig.3.7 Ranks of CCS patentees according to the more quantities of patents

3.2.7 Summary of global CCS patent analysis

From the above analyses of the global CCS patent developing trends, distribution of technologies, comparison of countries and their focuses, patentees, etc., it is thought that the whole trends of CCS patents has been increasing and especially in recent ten years many countries have very quick growth of CCS patents to different extents, which reflects the international society's emphasis on the emerging field of CCS and then brings the more and more innovation of technologies. The conclusions are as follows:

(i) The CCS patents from Japan, American, China and Europe are far more than other countries. From the view of single country, Japan, American and China have more patents while German, England, French and other European countries have less patents than the former three countries but Europe holds half of top 10 countries，then the total CCS patents from Europe are not less.

(ii) From the view of the technological distributions, the CCS patents cover the more than 13 technologies including CO_2 capture, CO_2 transportation, CO_2 geological utilization and so on, but most patents belong to CO_2 capture techniques including separating CO_2 from gas or flue gas, carbon and its compounds, preparation, regeneration and activation of solid CO2 absorbents, etc..

(iii) From the view of comparing the different countries, American has the balance development and distribution towards the technologies relating CCS patents. American, Russia, Norway have the advantage on increasing oil production, natural gas production, underground water production through CO_2, while British and France have more patents in CO_2 solidification absorption techniques. The patents relating CO_2 capture technologies in Japan and Korea hold more than 80% of themselves' all the CCS patents while China and Russia have the less than 80% patent of themselves at the same field.

(iv) From the analysis of patentees, Alstom, General electric Corp. Shell and other cross-nationals Corp. have the more emphasis on innovation of technologies and applications of patents, which reflects that these

corporations have their strategy arrangement for the R&D of new emerging technologies in order to hold the dominant position in the emerging markets.

4. Technology Transfer

With the CCS key technologies investigation and the global CCS patent analysis, we could get the direction & guide to assess, evaluate and operate necessary technology transfer effectively. Management essentials for CCS technology transfer are on the subjects of collaborate innovation, patent mining & protection, IP enforcement, technology implementation and industrialization, etc. MOT of CCS would provide innovation and market assessment, information services, knowledge management and tech-transfer services to CCS enterprises and demonstration projects. IP management could also include with patent applications, laws and regulations consultancy, essential patents review, intellectual property enforcement, etc.

Technology transfer can emerge among all the major CCS countries and corporations combined with illustrated technology information, Developing countries look for mature technologies and equipments, CCS information analysis would guide them to meet what they need. Developed countries intend to plan and conduct their technology production, protection and utilization, from tech-innovation to IP management. By the analysis of demanded tech-objects, the technology seekers will search for tech-owners, to consult technology transfer, technology providers will identify what are the advantages and disadvantages, to make up their strategies to give licenses or equipment trades. Technology transfer agreements and contracts should be negotiated in details including IP licenses, rights granted, jointwork enforcement, etc.

Table 4.1 lists the essential issues and performances for CCS technology transfer.

Table 4.1 CCS technology transfer essentials and performances

No.	Process	Essentials
i	Research technological demands	● Mature technical parts and weaknesses ● Demand on technologies, instruments & operations
ii	Determine aims of technology objects	● Technology efficiency, equipment function ● Key technologies, instruments and compatibility
iii	Research technology resources	● Intention of technology sources and alternative options ● Investigation on the target technical objects
iv	Negotiations and agreements	● Preparation for negotiating and technical conditions ● Agreements on the whole chain of technology transfer
v	IP licenses and transfer contracts	● IP domain, fees, damages and standards ● area/ firm/time/numbers/particular use limited ● simple license / exclusive license
vi	Equipment trade and support	● equipment introduction and implementation ● technical support and personnel training
vii	Technology & equipment upgrading	● equipment system maintenance and upgrade ● Technology upgrading requirements
viii	Collaborate Innovation	● Patent protection, make up portfolio ● Enforcement & industrialization
Ad.	IP key points need attention	● IP situation of the technological objects ● Interest distribution of Collaborate Innovation ● IP licenses for the whole technology chain ● Management for know-how and necessary secrets

The tech-transfer operation should contain with necessary tasks: (i)content, scope and requirements of the objective technology; (ii)license, process, schedule and methods for tech-transfer; (iii)confidentiality of secret information; (iiii) technological achievements and profit distribution; (iiiii)risk and disputes resolution.

5. Recommendations

Based on the analysis of global CCS key technologies and patent situation, there are a lot of technology management tasks need to be carry up, containing with key technologies/equipment R&D，enhancing much-needed technologies/equipment development. It is recommended that:

(i) From the perspective of technological progress and technological innovation, we should increase support for the R&D of the advanced technologies and the key technologies/equipment which constraint CCS industrial development, especially increase input on large flow centrifugal pump and compressor and so on, and obtain the own intellectual property to operate new key technologies.

(ii) From the perspective of new technology utilization and industrial upgrading, we should intensify technology application and strengthen key practices data acquisition in CCS pre-feasibility demonstration projects, and accumulate the engineering practical experience to offer a variety of technical reserves path selection and experience for further large-scale application of CCS project.

(iii) From the perspective of solving much-needed technology problem in CCS projects, attention should be paid to handle materials, process design, manufacturing, processing technology related to high flow CO2 plume, and high efficient adsorbent, catalyst and reducing agent, high parameters centrifugal pump, compressor and so on. We should intensify R&D support to carry out the important science and technology research projects.

(iv) From the perspective of the key technology intellectual property, we should develop CCS technical intellectual property protection strategy, apply for patents on core and key innovative technologies, and form the patent net to protect the application of CCS technology innovation and the development of related industries.

(v) From the perspective of personnel training in CCS field, we should strengthen the cultivation of interdisciplinary talents involved energy engineering, applied chemistry, applied physics, fluid engineering, geological engineering and so on, organize regular discussion and exchange of academic and engineering information, and timely provide talent pool for CCS application development.

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