THE FUTURE PROSPECTS OF CCU TECHNOLOGY REVEALED BY PATENT ANALYSIS

– NOTEWORTHY TECHNOLOGIES AND COMPANIES CONTRIBUTING TO DECARBONIZATION –

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SUMMARY

- CCU (carbon dioxide capture and utilization) is attracting attention in the quest to achieve carbon neutrality by 2050. Research and development into CCU started in earnest in various countries from around 2007 to 2010, and the number of related patents has been increasing since 2015, particularly in China.
- The increase in patents has been pronounced in certain CCU technology fields, including artificial photosynthesis, use for concrete and cement, and promotion of photosynthesis for plants. Among these, technologies for nanostructures and plant factories are attracting particular attention.
- As many players are conducting research and development into technologies related to CCU, it is possible that collaboration among related companies aiming towards the social implementation of these technologies will increase.

1. THE IMPORTANCE OF PATENT INFORMATION

With the advance of economic globalization, it is becoming increasingly important for many companies to possess manufacturing and R&D functions in countries other than their own. Moreover, as industrial structures and technologies become ever more complex, it has become difficult for companies to develop and create products and services using the latest technology on their own. Patent information, which gives an insight into the R&D trends and intellectual property strategies of individual companies and research institutes, is seen as a useful tool for revealing the focal technology fields and future aims of companies, and serve as important information that can be used in various technology fields.

As many countries and regions around the world have declared their intention to become carbon neutral by 2050, and the efforts of companies in this respect are attracting attention, this report casts a light on the trends in research and development into CCU, which is one of a number of important technologies contributing to the reduction of CO_2, on the basis of information including the status of patent applications by companies and research institutes, looking into technologies that are attracting particular attention, as well as the future prospects.

2. CCU-RELATED TECHNOLOGY PATENT TRENDS

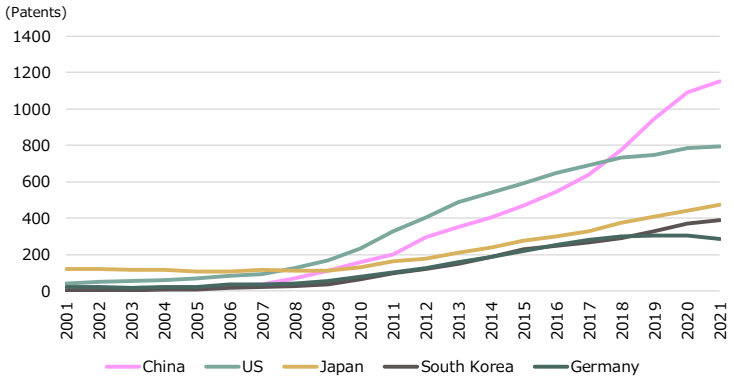
2-1. Overview of CCU-related technology

Generally speaking, CCU is broadly divided into (1) physical utilization for enhanced oil recovery (EOR), in which carbon dioxide and other gasses are injected into oil reservoirs to increase the oil recovery rate, industrial applications (welding, beverages, etc.), and agricultural applications (e.g., protected horticulture), and (2) chemical utilization, where CO_2 is combined with other substances to produce chemical products. This report extracted patents related to worldwide CCU technology (as of July 2021) from the *2017 Patent Application Technology Trends Survey Report: CO_2 Fixation and CCU Technology* (Japan Patent Office) to analyze the trends.

2-2. Trends in CCU-related technology patents (by country/region and technology)

Figure 1 shows the change in the number of patents for CCU-related technologies by country. While the number of patents began increasing in each country from around 2007 to 2010, China recorded a particularly rapid increase from 2015, overtaking the US to take top position in 2018.

Figure 1: Number of patents for CCU-related technologies by country



Source: Compiled by MGSSI based on data from PatentSight

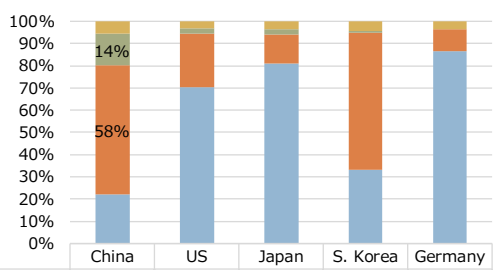
Figure 2 shows the number of patents in each country/region by the nationality of the applicant. The majority of the Chinese applicants in China, where the number of patents has increased remarkably in recent years, are government agencies and research institutes (Figure 3), and applications by Chinese applicants in other countries are currently limited.

Figure 2: Number of patents in each country/region by nationality of applicant

Country/Region \ Applicant's nationality	China	US	Japan	S. Korea	Germany
China	841	130	30	15	60
US	29	418	79	46	53
Japan	8	94	299	9	19
S. Korea	12	64	13	266	11
Germany	4	71	23	13	97
Canada	9	130	6	2	14
UK	6	66	13	12	45
Europe	6	83	18	3	42
France	4	44	7	5	28
Australia	6	74	10	3	32

Source: Compiled by MGSSI based on data from PatentSight

Figure 3: Percentage share of applicant organizations by nationality of applicant

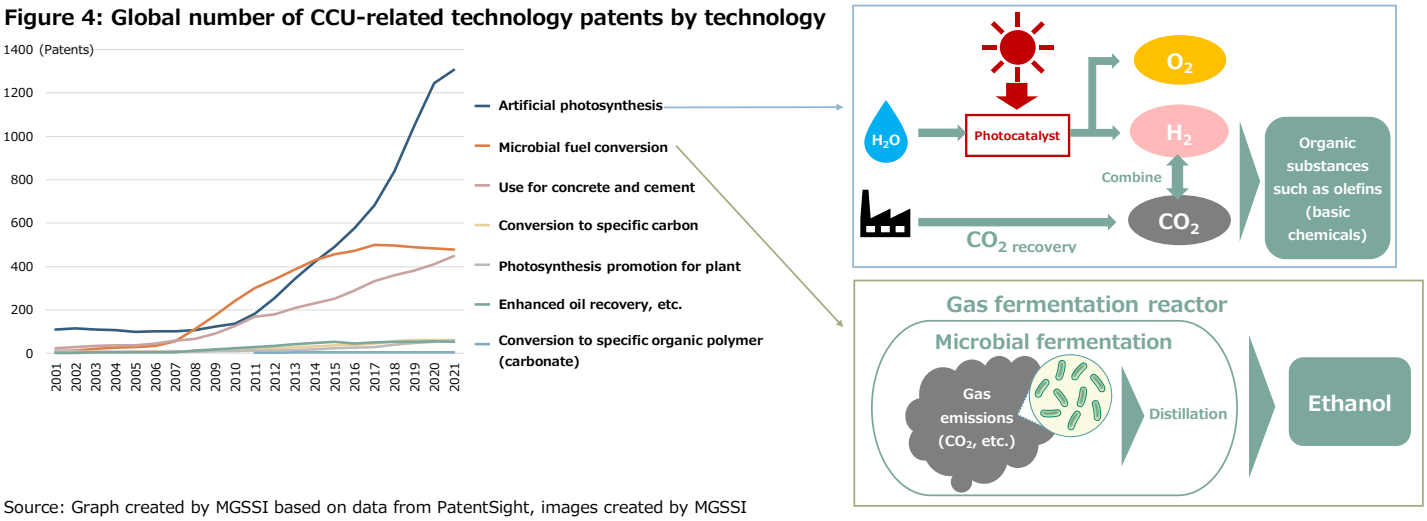


	China	US	Japan	S. Korea	Germany
Other	6%	3%	4%	4%	4%
Government agency	14%	2%	2%	1%	0%
Research institute	58%	24%	13%	62%	10%
Company	22%	70%	81%	33%	87%

Source: Compiled by MGSSI based on data from PatentSight

Figure 4 shows the change in the number of patents for all technologies related to CCU by technology, and Figure 5 shows the number of patents by technology (upper half) and the percentage increase in the number of patents (lower half) in each country/region. Viewed by technology, there is a notable preponderance of patents for chemical applications such as artificial photosynthesis (see the image in Figure 4), whereby water is decomposed using solar energy and is synthesized with CO_2 to produce chemicals, fuel conversion using microorganisms (see the image in Figure 4), and use for concrete and cement using calcium carbonate produced by adding CO_2. Competition in developing these technologies is expected to intensify in the future. While the number of patents related to physical applications that have been put to practical use to date is limited compared to those with chemical applications, among these the number of patents related to photosynthesis promotion for horticultural facilities and plant factories is increasing at a high rate in countries and regions around the world (Figure 5), and development activity in this area is seen to be growing.

Figure 4: Global number of CCU-related technology patents by technology



Source: Graph created by MGSSI based on data from PatentSight, images created by MGSSI

Figure 5: Number (as of July 2021) and increase (compared to 2016) in CCU-related patents by country/region and technology

		Country/Region									
		China	US	Japan	S. Korea	Germany	Canada	UK	Europe	Australia	France
Number of patents (as of July 2021)	Artificial photosynthesis	671	404	313	154	173	100	109	116	86	84
	Microbial fuel conversion	194	228	66	110	68	74	65	53	47	54
	Use for concrete and cement	208	116	78	106	37	57	36	40	34	29
	Photosynthesis promotion for plant factories	30	15	11	10	5	8	2	2	5	3
	Storage or use underground (EOR, etc.)	26	22	2	2	5	17	6	5	5	4
	Conversion to specific carbon	28	20	9	9	7	2	9	5	4	5
	Conversion to specific organic polymer (carbonate)	5	2	0	2	0	0	0	0	0	0
Percentage increase (compared to 2016)	Artificial photosynthesis	196%	62%	98%	100%	47%	9%	25%	-2%	43%	-10%
	Microbial fuel conversion	18%	-10%	14%	26%	-18%	-20%	-17%	-46%	-30%	-24%
	Use for concrete and cement	96%	12%	22%	47%	-16%	0%	-20%	25%	-8%	-33%
	Photosynthesis promotion for plant factories	275%	200%	-8%	150%	150%	167%	0%	100%	150%	50%
	Storage or use underground (EOR, etc.)	44%	-15%	-33%	0%	0%	-15%	20%	-29%	-29%	0%
	Conversion to specific carbon	22%	11%	0%	13%	17%	-60%	0%	-58%	-43%	-17%
	Conversion to specific organic polymer (carbonate)	0%	0%	---	0%	---	---	---	---	---	---

Source: Compiled by MGSSI based on data from PatentSight

3. IDENTIFYING NOTEWORTHY CCU TECHNOLOGIES AND COMPANIES THROUGH PATENT ANALYSIS

3-1. Understanding the status of technological development from technology classification codes

All patents are given an international patent classification known as IPC. The IPC makes it possible to see the status of patents, such as the number of patents and the rate of increase in the number of patents, from the codes assigned to technology categories arranged under a hierarchical system of divisions from main to subcategories. It is an effective tool for acquiring a detailed grasp of the efforts undertaken by companies and research institutes to address technological issues and the status of technological development.

3-2. Identifying noteworthy companies and patents using patent quality scores

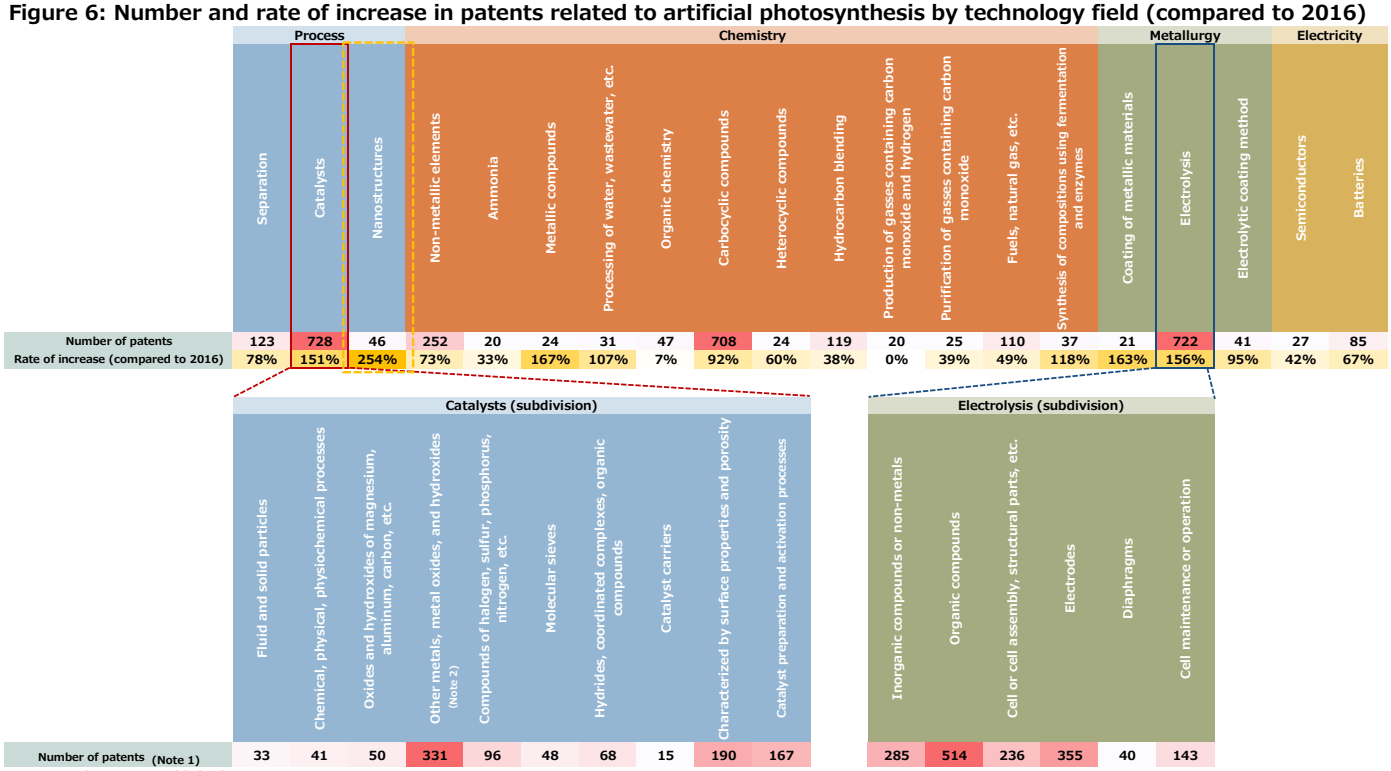
With the recent improvements in the functionality of patent analysis tools, it has become possible to compare the quality of patents using patent quality scores in addition to the number of patents. The number of citations (the number of times that a patent is referred to in the novelty examination of a patent filed at a later date), which is a reflection of the degree of interest of other companies, is often used to calculate the patent score, and this is an effective method of comparing the quality of (i.e., the degree of interest in) a patent.

From the following section, this report looks at some of the CCU-related technologies mentioned in section 2 above, specifically artificial photosynthesis and use for concrete and cement, two areas that have seen a remarkable increase in the number of patents in recent years, as well as photosynthesis promotion for plant factories, where although the number of patents is increasing rapidly, although it is low compared to the foregoing. The report examines the state of technological development in these areas using the IPC and uses patent quality scores to identify companies and patents that warrant attention.

3-3. Artificial photosynthesis technology trends, notable applicants and patents

Figure 6 shows the number and the rate of increase (compared to 2016) in patents related to artificial photosynthesis by technology category. It can be seen from the figure that companies are actively engaged in the fields of catalysts and electrolysis, and the number of patents has increased steadily since 2016. Further classification of these two fields into their subdivisions, reveals first that in the subdivision of catalysts (framed in red in Figure 6), there are many applications for technologies using substances such as porous metal oxides in patents published after 2016. In the subdivision of electrolysis (framed in blue in Figure 6), it can be seen that there are many applications related to technology for the electrolytic production of organic compounds, followed by applications related to electrodes. In addition, patents for nanostructures (framed by an orange dashed line in Figure 6), which have increased significantly in number compared to 2016, are related to technology to improve conversion efficiency by increasing the contact area of the conversion material mainly using nanostructured catalyst material, indicating that this is one technology to keep an eye on in the future.

Figure 6: Number and rate of increase in patents related to artificial photosynthesis by technology field (compared to 2016)



Note 1: Only patents published since 2016
Note 2: Metals not classified as oxides and hydroxides of magnesium, aluminum, carbon, etc.
Source: Compiled by MGSSI based on data from PatentSight

With regard to catalysts and electrolysis related to artificial photosynthesis, which are areas that many companies have been working on in recent years, the companies and research institutes with high patent value scores shown in Figure 7 are to a great extent the same as the patent holders with high patent quality scores in both areas shown in Figure 8. Accordingly, the presence of these companies and research institutes is expected to increase in the future. Of these, the US venture company Twelve, established in 2015 and a leading player in both these areas, holds six patents that score high in terms of quality despite being small in number. The company has raised US$68 million since 2019 and is one to watch for the future. Meanwhile, patent No. EP3191621, filed by the US company 3M in 2015, is a patent for an ionic polymer membrane for CO_2 electrolyzer, which is an important underlying technology for synthesizing chemicals from CO_2. The fact that this patent is cited in subsequent patents filed by the likes of Dioxide Materials, Siemens, Twelve, the University of Toronto, and Toshiba, all leading companies in both fields, indicates that it is a particularly important one.

With respect to nanostructures, while the Chinese Academy of Sciences tops the list with eleven patents, Japan's Honda Motor also holds three related patents with high quality scores, including a technique for using nanostructures as the electrode catalyst material when using electrochemical cells in the conversion of CO_2 to synthetic fuels. Honda has the potential to become a major player in the future.

Figure 7: Leading applicants by technology field related to artificial photosynthesis (in order of total patent value)

Catalysts

Holder	Number of patents	Patent quality	Total patent
(China) Chinese Academy of Sciences	56	1.13	63.23
(US) Dioxide Materials	7	6.28	43.96
(China) Dalian Institute of Chemical Physics	21	1.72	36.16
(US) Twelve (formerly Opus 12)	2	12.42	24.85
(US) 3M	1	23.85	23.85
(Switzerland) Gaznat SA	1	19.12	19.12
(US) Dow Chemical	2	9.55	19.10
(Japan) Toshiba	10	1.63	16.30
(US) ExxonMobil	5	2.87	14.37
(Japan) Hitachi Zosen	9	1.58	14.18

Electrolysis

Holder	Number of patents	Patent quality	Total patent
(Germany) Siemens Energy	17	4.61	78.35
(Japan) Toshiba	45	1.71	76.92
(Germany) Siemens	23	2.39	54.88
(US) Dioxide Materials	10	4.70	47.04
(China) Chinese Academy of Sciences	52	0.77	39.89
(US) Twelve (formerly Opus 12)	3	9.10	27.31
(Canada) University of Toronto	7	3.69	25.86
(US) 3M	1	23.85	23.85
(Germany) Sunfire	2	11.55	23.10
(Switzerland) Gaznat SA	1	19.12	19.12

Source: Compiled by MGSSI based on data from PatentSight

Figure 8: Noteworthy patents for catalysts and electrolysis related to artificial photosynthesis (note)

Patent No. (Representative patent)	Year of application	Patent quality score	Catalysts	Electrolysis	Title	Holder	Status	Protected countries/ regions
EP3191621.A1	2015	23.9	Y	Y	Ionic polymer membrane for a carbon dioxide electrolyzer	(US) 3M	Granted	7 incl. US, China, Japan
EP3280512.A1	2015	20.3		Y	Production process and production system for producing methane / gaseous and/or liquid hydrocarbons	(Germany) Sunfire	Granted	5 incl. US, China, Europe
EP3752460.A1	2018	19.1	Y	Y	Fe-n-c catalyst, method of preparation and uses thereof	(Switzerland) Gaznat SA	Pending	US, China, Europe
EP3166912.A1	2015	16.5	Y		Conversion of carbon monoxide, carbon dioxide, or a combination thereof over hybrid catalyst	(US) Dow Chemical	Granted	11 incl. US, China
EP3607111.A1	2017	15.7		Y	Two-membrane construction for electrochemically reducing co2	(Germany) Siemens Energy	Pending	5 incl. US, China, Europe
EP3209816.A1	2015	14.4	Y	Y	Electrolyzer and membranes	(US) Dioxide Materials	Granted	9 incl. US, Japan
US2017037522.A1	2016	14.3	Y	Y	Method And System For Electrochemical Production Of Formic Acid From Carbon Dioxide	(US) Dioxide Materials	Granted	US
EP3743371.A1	2019	13.4	Y	Y	System and method for carbon dioxide reactor control	(US) Twelve (formerly Opus	Pending	7 incl. US, China, Japan
US2019071374.A1	2016	12.7	Y		Method for preparing aromatic hydrocarbon with carbon dioxide hydrogenation	(China) Chinese Academy of Sciences	Granted	US, China, Canada
EP3460104.A1	2017	12.0		Y	Carbon dioxide electrolytic device and method of electrolyzing carbon dioxide	(Japan) Toshiba	Granted	US, Japan, Europe
EP3622100.A1	2017	11.6		Y	Membrane-coupled cathode for the reduction of carbon dioxide in acid-based electrolytes without mobile cations	(Germany) Siemens	Pending	US, China, Europe, Australia
US2016107154.A1	2015	11.5	Y	Y	Ion-Conducting Membranes	(US) Dioxide Materials	Granted	US
EP3453064.A1	2017	11.5	Y	Y	Reactor with advanced architecture for the electrochemical reaction of co2, co, and other chemical compounds	(US) Twelve (formerly Opus 12)	Granted	13 incl. US, China, Japan

Note: Only patents published since 2016
Source: Compiled by MGSSI based on data from PatentSight

3-4. Use for concrete and cement and promotion of photosynthesis for plant factories

Viewing use for concrete and cement by technology category reveals a large number of patents related to lime, slag, and cement compositions, and the number is still increasing. The leading holder of such patents, the US startup Solidia Technologies, which holds many patents with a high quality score, is a major presence (Figure 9).

Figure 9: Leading applicants by technology field related to use for concrete and cement (in order of total patent value)

Compositions such as lime, slag, cement

Holder	Number of patents	Patent quality	Total patent
(US) Solidia Technologies	16	5.50	**88.05**
(Germany) HeidelbergCement	8	4.01	**32.09**
(Canada) CarbonCure Technologies	3	4.06	**12.19**
(France) Imerys	1	11.14	**11.14**
(HK) Nano and Advanced Materials Inst.	1	9.56	**9.56**
(US) LanzaTech	1	8.60	**8.60**
(China) Southeast University	7	1.20	**8.38**
(China) Tianjin Cement Industry Design & Research Institute	9	0.92	**8.24**
(US) Geopolymer Solutions	1	5.89	**5.89**
(Canada) CarbiCrete	2	2.79	**5.58**

Source: Compiled by MGSSI based on data from PatentSight

Viewing patents related to photosynthesis promotion for plant factories, although the number is smaller than those related to artificial photosynthesis, there has been a remarkable increase in such patents compared to 2016 (Figure 5). Japan's Futaba Industrial, an automobile parts manufacturer that is also active in the agricultural business, mainly in CO_2 storage and supply equipment for greenhouse cultivation, is the leading holder in this area with three patents. In addition, patent No. EP3349563 (Figure 10), filed by Italy's Carbonsink in 2016, is a method for providing CO_2 captured from the atmosphere and polluted water from agricultural effluent and rivers to aquatic plants in cultivation facilities to purify the water and reduce CO_2. This patent has a high quality score and warrants attention. It also covers other possible needs and technologies such as the use of renewable energy and the production of biofuels, fertilizers, and feeds from aquatic plants grown in cultivation facilities. For CCU, which tends to be oriented towards conversion of material in large-scale plants, this is likely to attract attention as a new form of business that can be realized on a compact scale in developing regions, not just in urban cities.

Figure 10: Noteworthy patents related to CO_2 fixing in biomass (note)

Patent No. (representative	of applic	Patent quality	Title	Holder	Status	Protected country
EP3280253.A1	2016	9.9	Hydroponics	(US) Eden Green Technology	Granted	11 incl. US, China, Japan
EP3349563.A1	2016	7.4	Devices, systems and methods for enhanced biomass growth in greenhouses	(Italy) Carbonsink	Granted	9 incl. US, China, Japan

Note: Only patents published since 2016
Source: Compiled by MGSSI based on data from PatentSight

4. FUTURE PROSPECTS REVEALED BY PATENT ANALYSIS

CCU is expected to contribute to the realization of carbon neutrality by 2050, and it is clear from this patent analysis that many companies, from electrical equipment and automobile manufacturers to chemical manufacturers, are conducting research on artificial photosynthesis as one CCU technology. It is believed that collaboration between related companies towards the social implementation of this technology will increase. It has also been shown that the development of photosynthesis promotion technology for plant factories is accelerating and research and development encompassing multiple needs and technologies within the technologies concerned is making progress, revealing signs of new CCU business. As industrial structures and

technologies become increasingly complex, utilizing patent information should make it possible to anticipate the technology fields and future directions on which companies will focus attention, and to collaborate effectively with those companies also in areas other than CCU.