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4P Model for Strategic Research Planning: Focusing on the Cases of Korea Research Institute of Chemical Technology

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Abstract The demand for efficient utilization of input resources and productive outcomes is increasing as the government's R&D investments in Government-funded research institutes (GRIs) expand. These changes call for improving research-planning activities, which are defined as a set of activities wherein objectives are established, strategies for acquisition and expenditures of research resources are devised, and utilizations of research outcomes are addressed. This study introduces the integrated 4P analysis model that identifies the relationships among patents, papers, products, and projects. It looks into 4P analysis structure and its efficiency as a research planning means through case studies of the Korea Research Institute of Chemical Technology. This study introduces 4P analysis applied to KRICT, which can be utilized for outcome-oriented research planning of GRIs. At the same time, it investigates into the benefits and implications of 4P analysis. It proffers policy suggestions on such aspects as how research planning of GRIs should go through changes in a strategic and systematic way.

Keywords 4P analysis (patent, paper, product, project), strategic research planning, government-funded research institute

I. Introduction

Changes in macro environment centering around science and technology, together with demands for the contribution of national R&D programs to society, push research planning activities beyond conventional limit; they are geared toward optimal utilization of resources, improvement of research productivity, and increase of successful commercialization. Research planning

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denotes a series of behaviors that establish research objectives, devise ways to estimate and secure resources and set up a plan to utilize research outcomes, prior to the onset of research (Cho et al., 2011). Research planning activities are the strongest element in influencing success in research and have significant effect on the benefits customers reap from final research outcomes (Dvir et al., 1999).

Recent years witnessed the changes in research planning activities; they actively seek information analysis method with a view towards coping with ever changing external environment and pursuing new opportunities (Cho et al., 2011). Major information analysis methods for research planning include technology tree, technology roadmap, and 3P (patent, paper, product) analysis (Cho et al., 2011). Technology tree and technology roadmap are about forecasting market needs or target technologies and providing technology development milestones for their achievement. The 3P analysis method, on the other hand, thoroughly reviews papers, patents and market information while reflecting market and industrial changes based upon them, and thus establishes lines of direction for research. This method has some advantages in that it provides R&D strategy through systematic analysis of objective information.

However, there has not been sufficient discussion on the process, utilization, and implications of 3P analysis for day-to-day dynamics of research. This study aim at throwing a light on the benefits and implications of 4P analysis through a case of KRICT in which 4P analysis, adding project analysis to 3P analysis, was employed for research planning for the first time among GRIs. This study intends to give insights into the desirable direction of 4P analysis.

II. Literature Review

Recent trends of Korea's national R&D programs look towards the fourth generation R&D that seeks to create new markets and industries. But in reality, it is not difficult to find research projects pursuing a catching-up R&D strategy. Getting out of catching-up strategy involves developing novel technology or large-scale, convergence technology with high uncertainty. It connotes the increase of failure in R&D. In this light, as the risk of failure in R&D projects increases, it is necessary to establish research planning and management system in order to lower and manage the risk and thus better cope with it proactively (Song et al., 2006).

Recently, analysis and utilization of information at the initial stage of research is deemed critical raising awareness on the importance of research planning and strategic investment in R&D projects (Kim et al., 2012). Yun et al. (2006) pointed out that such conventional research planning methods as technology forecast, technology roadmap, and technology assessment are intuition-oriented yet non-systematic, and hence can be a one-off activity; they also can be an imitative-stage planning centering on technology rather than market or social needs. Moon et al. (2006) recognized that systematic information analysis activities, including research trend analysis and prior information review, exploring promising technology, industrial information analysis and market forecast play a critical role in research planning. The arguments of Yun et al. (2006) and Moon et al. (2006) ascertain the necessity of information analysis based on objective data in research planning. There have been researches on the information analysis methodologies that can be utilized from the research planning stage for strengthening the productivity of R&D programs. Hyun et al. (2006) emphasized that the analysis of patents, papers and market is very important for basic, applied and development research as complementary tools tor conventional research planning methods.

According to Lee and Shin (2009), information analysis method utilizes the media where knowledge and information on science and technology are stored. It searches for new technology, discovers intrinsic domain of knowledge, and explores the linkage between science and technology, transfer of knowledge among academic disciplines, and cooperation among researchers by analyzing the patterns and trends of acquired information. Yun et al. (2006) suggested a novel research planning method that remedied shortcomings of conventional ones by adding 3P (patents, papers, and products/markets) analysis.

In sum, the development of information analysis methodologies centering on such data as patents, papers, and products are yet to be completed. Their distinct characteristics necessitate the identification of their linkages.

Patents, equipped with technology-oriented information, are in reciprocal relationship with scientific papers. Whether final research outcomes are of any values from the market perspective will be accurately assessed through product information analysis.

1. Patent Information Analysis

In the era of information society, patents are the most objective and standardized technological information and knowledge. Patents differ from academic papers in that they pursue industrial development through exclusive rights in return for disclosing technologies. Patents are of substantial use for identifying potential competitive and core technology and finding out areas of application (Heo and Ko, 2015). In this reason, patents are very helpful for analyzing novel technological knowledge and setting up direction for technological innovation (Archibugi, 1992). Lee et al. (2003) speculated technology flows and technology innovation trends through the identification of the relationship among indices in patent citation analysis. Lee et al. (2012) delved into the relationship between technology and industry by using patent citation information. They highlighted the importance of analyzing the relationship between technology and industry at the initial stage of research. Ernst (2003) and Fabry et al. (2006) maintained that it is important to analyze a patent portfolio of competing organizations in setting up R&D investment strategy, which facilitates creating an integrated portfolio from the perspective of markets and patents.

2. Paper Information Analysis

Scientific papers, in tradition, are important elements that have been expediting academic development, through which recent research trends can be easily learned. Its objective lies in distributing technology and knowledge through sharing research outcomes. A patent is an intangible asset mostly owned by a company who pursues commercialization by procuring exclusive rights of technology. While companies are main actors with regard to patents, universities and research organizations that examine pure academic subject matters play a leading role in producing papers.

Kwon (2015) came up with a research planning method through which areas of promising technology were identified. These areas will be of practical use for research planning. This method was devised through the analysis of co-citation pattern between highly cited papers[1] and hot papers[2] and identification of leading and promising research key words as a result (Figure 1). An analytic method of Lee (2005) targets co-authorship; it identifies joint research network through reviewing co-authorship in scientific publications and figures out core areas for joint research in the future. Scientific papers are in the center of basic research where their findings can bring forth breakthrough discovery. Yun et al. (2006) maintained that paper analysis should be given highest priority in the planning stage of research if its purpose is to acquire new scientific knowledge.

[1] Papers with top 1% citations per areas among those published in SCI(E) journals within the past ten years.
[2] Papers with top 0.1% citations per areas among those published in SCI(E) journals within the past two years.

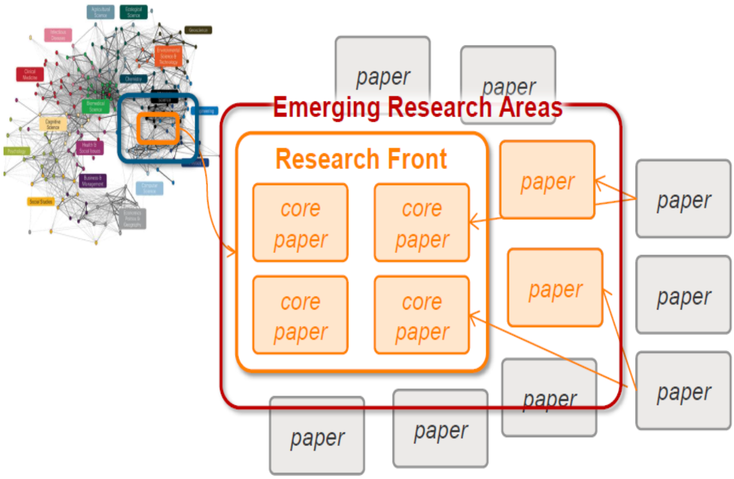


Figure 1 Identification of emerging research areas through paper information

3. Product Information Analysis[3]

As the concept of the fourth-generation R&BD (research & business development) emerged in the late 1990s, a market-leading information analysis method was geared towards putting the concept into implementation (Shin and Hyun, 2008). However, it is not an easy task for researchers to conduct market analysis because it is an area of great uncertainty due to ever-changing, volatile technology markets. In order to maximize the future market value of technology, it is required to make elaborate market analysis from the initial stage of research planning. In-depth market analysis, however, is difficult to conduct because of the limitations in analyzing organization and analysis tools, unlike paper analysis or patent analysis (Kang, 2014). Shin and Hyun (2008) claimed that the government should render active support for supplying market analysis program to researchers with a view towards reducing the risk of R&D failure.

As was stated, information analysis methods centering on such data as patents, papers, and markets are being systemized, but their distinct characteristics necessitate the identification of their linkages. Yun et al. (2006) pointed out that conventional research planning methods embraced analyses on patents, papers, and markets to some degrees, but they were not systematical and only intermittently used. Thus, they worked on a systematic and integrated analysis method contingent on the characteristics of research areas, such as

[3] It is the concept that includes market analysis.

basic research, application research, and development research. Cho et al. (2011) introduced a plan to improve the productivity of national R&D by adopting 3P analysis and stressed the necessity and efficiency of conducting analysis on patents, papers, and markets from the beginning phase.

Patents, equipped with technology-oriented information, are in reciprocal relationship with papers, results of academic research. Whether final research outcomes are of any values from the market perspective will be more accurately assessed through market information. In this sense, it will be instrumental to conduct an integrated and close analysis among information media.

III. 4P Analysis Model

1. Background

KRICT (Korea Research Institute of Chemical Technology), a GRI that has been spearheading the nation's chemical research, is expected to play a leading role in planning national R&D programs and to serve as a driving force in the area of chemistry. To fulfill this responsibility, it is of the utmost importance that KRICT is geared to differentiated research planning capability.

Another area for attention is the efficient use of limited R&D budget. It is thus important to prevent redundant investment on similar technologies and technologies with low competitiveness by thoroughly reviewing existing national R&D projects. No less important is the ability to establish strategy that enables sustaining competitive advantage in high a technology environment. Accordingly, KRICT added the analysis on the projects completed or being conducted by the seventeen ministries/agencies, and came up with the novel scientific information analysis method, the integrated 4P (patent, paper, product, project) analysis. KRICT's 4P analysis relates results of independent analysis on patents, papers, products and projects to types and characteristics of research planning and the realms of technology (Figure 2). It thus offers perspectives on developing ideas and opportunities. Recent researches with the 4P analysis method include the study of Heo and Ko (2015) that used the method for identifying research trends and deriving the areas of application for given technologies.

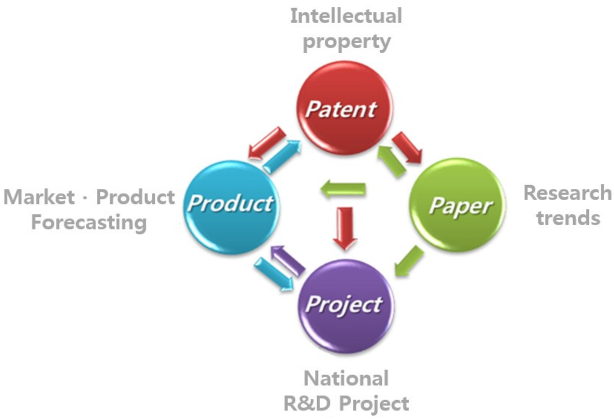


Figure 2 KRICT's 4P analysis model

2. The Process of 4P Analysis

Figure 3 illustrates the process of 4P analysis conducting by KRICT. For systematic and strategic research planning, it is very important to create reliable information sources per patents, papers, and products, and to clearly define search criteria for deriving credible analysis results (Table 1).

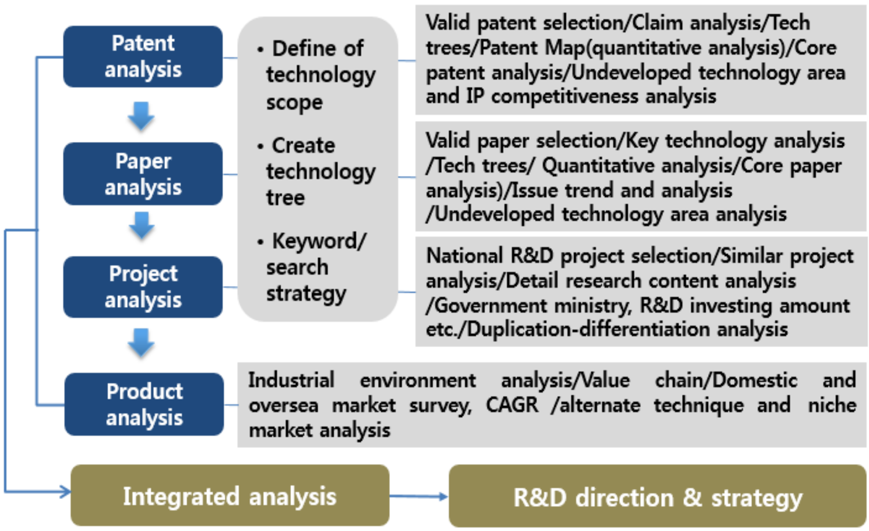


Figure 3 KRICT's 4P analysis process

Table 1 4P sources and criteria

4P analysis	Search sources (DB)	Characteristics	Search criteria (examples)
Patent analysis	· Thomson Innovation · WipsOn · Patent Strategies · WisDomain · STN	· Novelty/use/text mining analysis · Patent application & prosecution history · Patent litigation information & applicant competitiveness · Patent market value & grade assessment · Markush claims search	· IP5 offices (US, EU, Japan, China, Korea) · Invention names, abstract, patent claims
Paper analysis	· Thomson Innovation · SciFinder	· Paper citation information · Chemical structure search	· SCI(E) journal papers · Article, Letter, Review search
Project analysis	· NTIS-Cloud	· Search & analyze national R&D projects	· 17 ministries/agencies for the past 10 years
Product analysis	· Frost & Sullivan · Datamonitor · Profound · Chemlocus · Cischem	· Strong in technology-industry-market environment evaluation · Strong in pharmaceutical & biotechnology markets · Integrated search for diverse organizations' publication · Market outlook for domestic chemical industry & market · Domestic petrochemistry & fine chemistry trends	·Clarify positioning on value chain (raw materials-intermediate goods-components-final products) · Alternative technology & expansion of application areas

IV. Case Studies

KRICT conducted a 4P analysis for research planning and evaluation purposes seventy-seven times between 2012 and 2016: forty-nine for planning and selecting grant-based projects; twenty-one for acquiring consigned research projects; and seven for rendering support for information analysis that aims at contributing to solving social problems.

This study intends to speculate the efficiency of 4P analysis as a research planning method by reviewing the two cases; they contributed to determining research direction of main projects and acquiring consigned projects.

1. Determining R&D Direction: Grant-Based Projects

KRICT monitors the progress of grant-based research projects on a regular basis through a research affair reviewing body. It is responsible for deliberating long-term R&D plans linked to technology commercialization and selecting the projects that require the establishment of a roadmap for exit strategy including technology transfer. To take a project, for example, the 'Development of specialty chemicals for automobile industry' project went through this process and necessitated the establishment of detailed planning and research direction by mean of 4P analysis. This study examines the 4P analysis conducted for the sub-project of the aforementioned project, which brought force the need to determine research direction for 'Polydicyclopentadiene (PDCPD) materials for automobile exterior material'.

1.1 Overview

A detailed technology tree in accordance with components of PDCPD materials was first created (Figure 4), followed by the identification of their technology trends and main players through patents[4] and papers[5] review. Based on the findings, technological competitiveness analysis was conducted.

In particular, in-depth analysis was conducted in order to integrate strategies for identifying novel catalyst for PDCPD, designated as core technology of 4P analysis, and acquiring intellectual property (IP). The analysis screened[6] the chemical structures appeared in papers and patent claims and registered catalyst structures.

This study analyzes the elements of industrial environment that influence market entry in terms of value chain for the manufacturing process of PDCPD materials. It aims to present the possibility of expanding areas of application via integrated analysis on patent uses and the result of market research. Moreover, this study analyzes the existing investment strategy for promoting national R&D programs and its major technology contents with a view towards offering hands-on suggestions.

[4] Invention names, abstracts, patent claim of the patents registered in IP5 offices for the past 20 years were searched via Thomson Innovation DB.
[5] Papers published in SCI(E) journals for the past 20 years via Thomson Innovation DB.
[6] It means a process of selecting specific chemical substances or biological entities from a multitude of them.

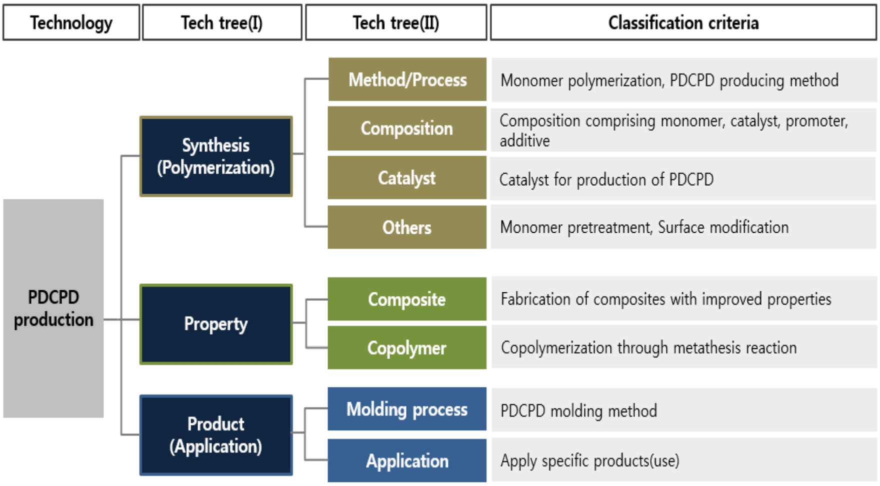


Figure 4 Technology tree for PDCPD manufacturing areas

1.2 Research Direction and In-Depth Planning

a) Research-technology landscape analysis

Japan led the development of PDCPD materials before 2000 where patents are concerned. However, recent years saw the increase in patent applications of other countries; universities in China, Materia and Cymetech (US) filed patent applications in polymerization technology at an increasing rate, and Blue Wave (Luxemburg) and GM (US) zeroed in on the areas of application for PDCPD materials. Among the polymerization technology area, the portion of catalyst-related patents was significantly high, implying that catalyst serves as a technological core in PDCPD manufacturing. Developing and acquiring novel catalysts deserve keener attention. Looking at the domestic market, companies centering on Samsung, Kolon, and Lotte Chemical entered into the areas of application for PDCPD materials since mid-2000s, but their IP competitiveness was pronounced low.

In terms of papers, like patents, research on catalyst and polymerization technology is most active throughout the world. On the other hand, the area of application for PDCPD materials is almost ignored by researchers. But given the increase of scientific publications in the areas of property improvement and composite materials since 2012, we can reason out increasing demands for innovating material technology through high-functional property improvement (Figure 5).

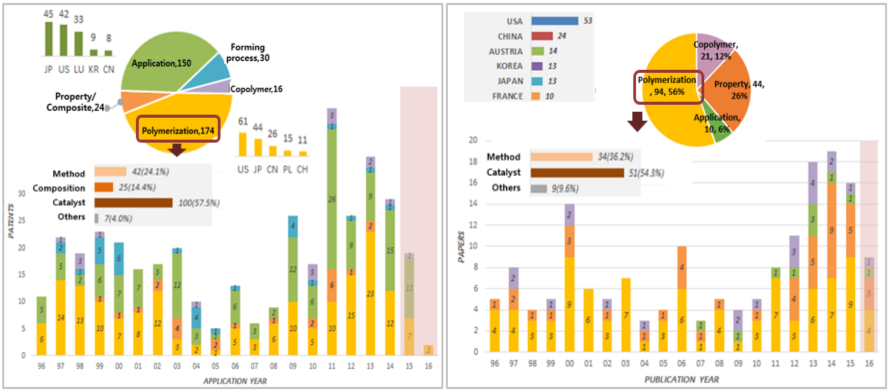


Figure 5 Trend analysis: patents (left) and papers (right) on PDCPD technology trees

In case of catalyst-manufacturing technology, ascertained as core element in PDCPD polymerization technology in patents and papers, patent applications galore in Ru-based and Os-based catalysts; main applicants include: Cymetech (US), Ciba Specialty Chem (Switzerland), Aperiron Synthesis (Poland), Zeon (Japan). Zeon (Japan), Tu Graz (Australia), and ECUST (China) also publish papers on W-based and Ru-based catalysts. In Korea, Kolon is the only company that files patent applications in these areas. (Figure 6). Since major manufacturers of catalyst for PDCPD possess dominant IP market positions for Ru-based catalyst, it will be wise to look toward other metal-based catalysts, such as W-based and Mo-based, which are now popular themes of papers.

Applicant	Nationality	Method/ Process	Catalyst	Composition	Patents (sum)
MATERIA	US	9	2	7	18
ZEON	JP	7	9	1	17
CYMETECH	US		14	1	15
APEIRON SYNTHESIS	PL	US	11	2	11
CIBA SP CHEM	CH	JP	11		11
SEKISUI CHEMICAL	JP	US	8	7	9
TOSOH	JP	PL	5	1	6
ITRI	TW	CH	6	1	6
METTON AMERICA	US	JP	1	5	5
HUST	CN	1	2	1	4

Organization	Nationality	Method/ Process	Catalyst	Others	Papers (sum)
ZEON	JAPAN	3	6		9
TU GRAZ	AUSTRIA	4	2		6
UNIV ILLINOIS	USA	4	1		5
EPFL	SWITZERLAND	3		2	5
ECUST	CHINA		5		5

Figure 6 Analysis in PDCPD polymerization areas

b) In-depth analysis: R&D strategy for novel polymeric catalysts

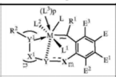
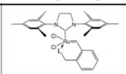
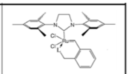
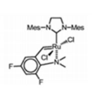
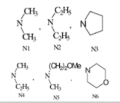
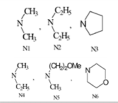
A technology tree was made in accordance with technological elements of PDCPD material development: polymer technology, property/composite materials, application technology, forming process technology, and other areas. After analyzing patent and paper information per components of the technology tree and reviewing the linkage between research and technology landscape, it was reconfirmed that catalyst technology was a cream of the crop in PDCPD manufacturing.

Catalysts for other metathesis polymerization process possessing same mechanism with the catalyst for PDCPD polymerization were explored, although no patent application has been filed for them. Based on this review, a strategy to acquire rights for novel use patent was established. As a result, thirty-seven ideas of metathesis polymerization composition were suggested for novel use candidates for PDCPD polymerization.

[Catalyst/Ligand on Patent]

Sector	Metal	Patents	Structure
Metal catalyst	Ru	77	-Deep dive analysis
	Os	44	-
	W	11	- $W(CHCMe_2Ph)(NArdiMe)(Me_2Pyr)_2$ - $\{W[O_2P(PhRn)_3]_2\}Cl_6$ - WCl_6 - WCl_6-ArOH-Et_2AlCl/Lp
	Mo	8	- $Mo[P(Ph)_2R]_2Cl_5$ - $\{MoO_2[L(PhRn)_3]_2\}Cl_2$
	Pd	3	- $[(Ph)_3P]_4Pd(0)$ or $[(cyclo\text{-}hexyl)_3P]_4Pd(0)$ - Pd(SIMes)(Cl)(COD) - $Pd(CH_3C(O)CHC(NCH_2CH_2CH_2OCH_3)CH_3)(PPh_3)Me$
	metall ocene	8	- Ti, metallocene complex - 4B transiion metal - lanthanoid, scandium

[Novelty Use and Catalyst/Ligand Structure]

Structure			
Regand			
Patent No.	CN104211735A	EP2452958A1	JP05314753B2
Applicant	ZANNAN SCITECH(CN)	LTD LIABILITY COMPANY UNITED RES AND DEV CT(RU)	LTD LIABILITY COMPANY UNITED RES AND DEV CT(RU)

[Catalyst/Ligand on Paper]

Sector	Metal	Papers	Structure
Metal catalyst	W	19	- $W(N\text{-}2,6\text{-}Me_2C_6H_3)(CHCMe_2Ph)$(rac-biphen) - [W(NPh)Cl(3)(L)] (L = chelating phenolate) - [W(diol)(2)(phe)(2)] and [W(diol)(2)(biphe)] (diol = aliphatic diolate dianion, phe = substituted phenolate, biphe = substituted biphenolate) - trans-$[WCl_2$(diol)(OAr)(2)] - (Ph4P)(2)[W-2(mu-Br)(3)Br-6] - WCl_6 and $WOCl_4$ - $W(=N\text{-}Ph)(Cl_4Et_2O)$-Et-.-$Et_2Al(OEt)$ - WCl_6-Et_2AlCl, (WCl_6-PhCOMe)-Et_2AlCl - W(=N-R)Cl(4)circle(Et_2O)(n) (R=Ph, 2,6-Me2Ph, alpha-naphthyl, 2,6-i-Pr_2Ph, Et, n-Bu, n-Hex, cyclohexyl, adamantyl; n=0 or 1) - $W(dNPh)Cl_4{\cdot}Et_2O$ - WCl_2(cat)(2) (cat=catecholato), WCl_4(cat) - (ArO)(6-x)WClx-Et_2AlCl (ArO: 2,6-ditertiarybutyl-p-cresoxy, x=3,4,6)
	Ru	14	- Deep dive analysis
	Mo	8	- MoO_3/MCM-41 - Mo(N-2,6-C6H3-i-Pr)(CHC(CH3)(2)Ph)(OCCH3(CF3)(2))(2) - [MO(2)(MeCN)(8)][BF4](4), $[Mo\text{-}2(mu\text{-}O_2CCH_3)(2)(MeCN)(6)][BF_4](2)$ - bis[1-(arylimino)ethyl]pyridine-$MoCl_3$/MMAO - $Mo(N\text{-}2,6\text{-}Me_2C_6H_3)(CHCMe_2Ph)$(rac-biphen), - MoO(rac-5,5',6,6'-Me-4-3,3'-t-Bu-2-2,2'-biphenolate) - MoO(rac-biphenolate)$_2$.C_7H_8
	Ti	6	- [2,4-'Bu-2-6-(2,3,4,5-Me-4-Cp)-PhO]$TiCl_2$ - $TiCl_4{\cdot}2L$[L=pyridine(1), 2-methylpyridine(2), 2,4,6-trimethylpyridine(3), 3-aminopyridine(4), 2-hyroxypyridine(5)] - $TiCl_4{\cdot}2L/CH_3Li$ system[where L is tetrahydropyran (I), dioxane, 2,5-dimethylfuran, or tetrahydrofurfyl alcohol] - Cp_2TiCl_2 - $MenTiCl_{4\text{-}n}$

Figure 7 In-depth integrated analysis of patents and papers on PDCPD catalyst composition

1.3 Commercialization Strategy via Patent-Market Analysis

a) Industrial environment and market trend analysis

DCPD (Dicyclopentadiene), a raw material for PDCPD is a useful byproduct gained from the process that extracts ethylene from crude oil through naphtha cracking (Figure 8). Asia, centering on China, accounts for 50% of its global production. Due to a greater demand than supply, analysis found that it is necessary to develop technology and products that can acquire new downstream business areas through high-purity DCPD. According to the QYResearch (2016), the global PDCPD market reached US $71.5 million in 2015, with transportation including truck and bus accounts for car body panel over 60%. Other segments include construction, agriculture, chemical industry, and medical equipment.

b) Link analysis of patent uses and industrial market

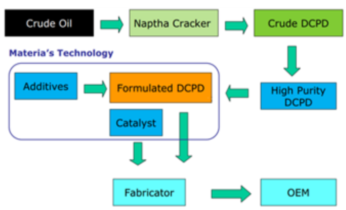
According to PDCPD market analysis, acquisition of future market share is deemed positive with low technology barriers. It is urgent to devise diverse exit strategies for exploring a market opportunity including diversification of products. The initial research plan established an exit strategy for developing lightweight materials for electric and hybrid vehicles, however, other areas of application should also be considered due to the uncertainty of industrial environment and technological sophistication in the said area. Considering the nature of patents that grant rights to technology with the aim of industrial use, efforts were made to acquire ideas for developing products by investigating the areas of utilization for PDCPD through the 'Use' field in the Derwent World Patent (DWPI) provided by the Thomson innovation DB.

Given that pressure vessel, solid electrolyte membrane, tire, optical film are not applicable in the market yet show very high rate of patent filings, they can be the first-round areas of application with immediate marketability. As illustrated in the Figure 8, areas of application for automobile witness patent applications of diverse uses, thus acquisition of physical properties that stress high-strength and lightweight for large, small automobile and electric vehicle in the future can be employed as mid to long-term strategy.

← Number of patent ↑

Pressure vessel	Car Body Panel	Tire	Bath	Electrical insulation	Sensible heat record	Railcar door
Solid electrolyde	Joint	Optical films	CNG tank	Protective portion	Ballistic	Smokestack
Septic tank	Micro-fluidic Device Carrier	Proppant	Imitation of marble	Building template	Fishing rod	Concrete form
Membrane	Rocket Fuel	Tunnel	Telephone pole	Dump-truck trunk	Underground Plastic	Adhesive
Putty	Electric vehicle	Enclosure for generator	Pipe	Manhole cover	Concreat floor	Sensor
Door assembly	Tube joint	Pump component	Film (press pack)	Medium-sized vehicle	Support plate of a stamping devic	Bonding jont for pipes
Chair	Aero part for vehicle	Roof panel or floor of vehicle	Wall structure	Light weight door	Films(optical)	Plant piping

[Use-application analysis on patent]



[PDCPD process Value-chain]

Production (MT)	2011	2012	2013	2014	2015	2016
Construction Mahinery	5515	5813	6048	6345	6651	6922
Agricultural Machinery	4236	4555	4728	4987	5265	5541
Medical Instruments	632	678	727	774	836	888
Transportation	23476	24478	25469	26521	27728	28895
Chemical Industry	5018	5267	5446	5664	5936	6176
Others	2060	2281	2335	2521	2688	2831
Global	40937	43072	44753	46812	49104	51253

[World market size by application]

Figure 8 A linkage analysis of PDCPD

1.4 Strategy for Preventing R&D Redundancy

Analysis of national R&D projects in the area of PDCPD for the past ten years via the NTIS Cloud system shows that eleven related projects are either completed or being conducted. Approximately US$17 billion have been dedicated to the projects in the PDCPD polymerization area for the past ten years (Figure 9). Among the projects, those funded by the Ministry of Trade, Industry and Energy have the highest proportion, and SMEs have a higher proportion in terms of research entities. To date, PDCPD-related national R&D projects tend to focus on the application for new products in terms of investment. If same degree of research effort is made for basic and application areas, technological competitiveness including IP acquisition will be further strengthened.

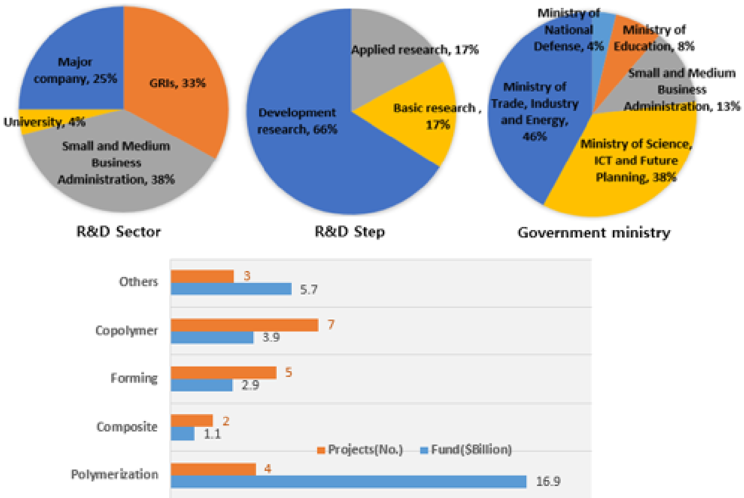


Figure 9 Analysis of national R&D projects in PDCPD areas

KRICT conducted PDCPD-related projects supported by the then Ministry of Science, ICT and Future Planning from 2010 to 2015, whose research funds amounted to US$9.15 billion. In terms of technology development, high-purity separation refining method of PDCPD has the core strength and is central to the value chain of PDCPD manufacturing. According to the analysis, KRICT has established a reliable roadmap on PDCPD manufacturing at the organizational level. The analysis also reveals that domestic PDCPD manufacturers, Dongsung TCS Co. Ltd. and Hutecs Co. Ltd. are now developing the PDCPD materials applicable for small boat, heavy-duty equipment, and agricultural machinery through national R&D programs. For strengthening the nation's industrial competitiveness, the areas of application suggested via patent and market analysis deserve due consideration; it will be desirable to develop them through national R&D programs in the imminent future.

1.5 Summary and Implications

A technology tree was developed and technological elements for polymerizing and commercializing PDCPD were redefined with a view towards ensuring objectivity and systemicity instead of personal intuition. On the basis of these, polymerization-catalyst technology was designated as core technology through a link analysis of patents and papers, and in-depth analysis was conducted for determining research direction for novel catalyst development. By presenting catalyst composition for avoidance and catalysts patentable for novel uses, a direction for planning that corresponds to IP strategy for commercialization was suggested. An exit strategy for applying to short-, mid- to long-term products was devised through a link analysis of patents for industrial use and market. When reviewing national R&D programs in the areas of PDCPD materials and DCPD-related fields, it turned out that KRICT is geared to systemicity in all-phase roadmap planning.

The 4P analysis employed in this case is meaningful in that it contributed to devising early-stage research planning and determining a research direction for technology commercialization.

2. Selection of Promising Technology

This sector introduces KRICT's successful research planning based on 4P analysis. KRICT took the initiative in selecting a promising technology area that led to winning a bid for national R&D projects, 'High value-added chemical conversion process through direct activation of alkane gas.' Korea is a producer of platform compounds for chemical industry based on naphtha, a byproduct of refinery process, and high-value fine chemistry products. Due to the uncertainty of oil price, a policy measure is required for diversifying base materials that use non-petroleum gas such as shale and natural gas. 4P analysis was conducted to explore promising technologies that can put gas-based materials such as alkane gas (methane) to industrial use in an economic way.

2.1 Patent Analysis

A patent review on direct conversion of alkane gas shows promising methods: pyrolysis, halogenation, OCM, selective partial oxidation, and plasma. Pyrolysis, halogenation, and OCM are the processes in which filings of patent application are active recently; they are designated as first-round candidates for promising industrial technologies (Figure 10).

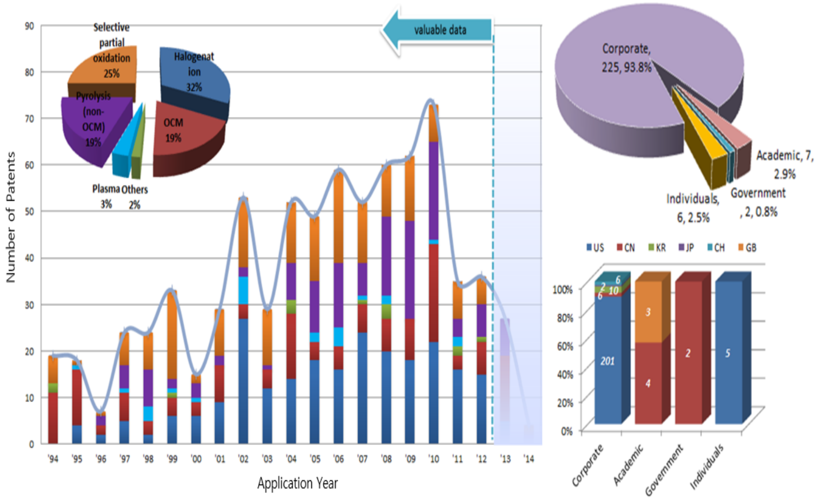


Figure 10 Patent application trends: direct conversion of alkane gas

Looking at the patent applications filed at the IP5 offices in terms of entities of technology development, companies account for 93.8% while universities and GRIs account for 3.7%. The number of domestic organizations' patent applications filed at the IP5 is 43, which accounts for a mere 5.6%.

For analyzing final outputs and main applicants of each candidate process, a themescape analysis on patent information including name, application abstract, claims, and detailed description was conducted via a text-mining method. Through a linkage analysis of patents and final outputs, it was ascertained that halogenation was useful for olefin conversion such as ethylene and propylene, decomposition method for aromatic compounds such as benzene and toluene, and OCM for fluid fuel conversion (Figure 11).

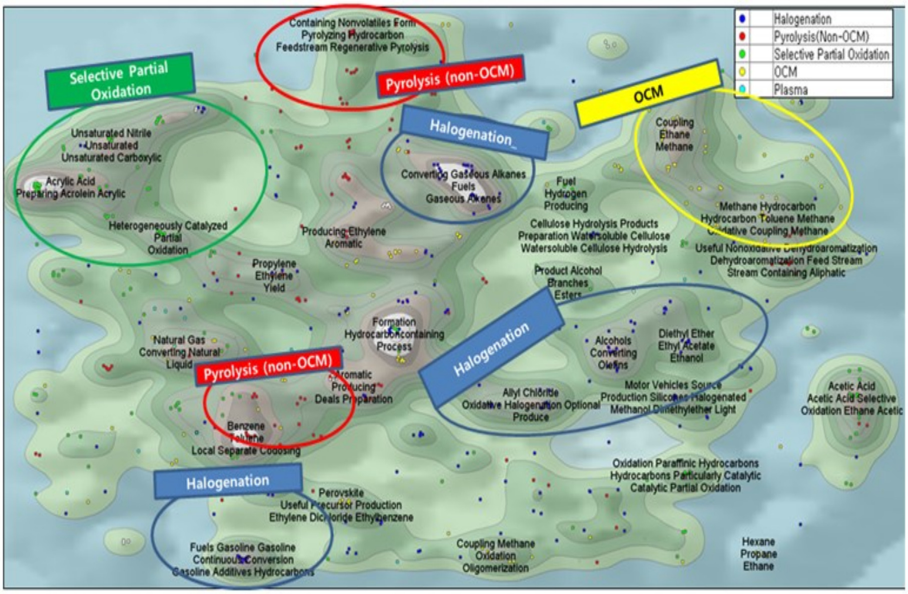


Figure 11 Positioning analysis: alkane gas direct conversion and final products

2.2 Paper Analysis

A review of SCI(E) papers on alkane gas direct conversion for the past twenty years demonstrates distinct changes of technology flow: OCM of phase I in pre-2000s; selective partial oxidation in phase II in mid-2000s; and pyrolysis in phase III in periods after mid-2000s (Figure 13). For halogenation, joint research activities are being made centering on its main applicants, GRT and UC Santa Barbara.

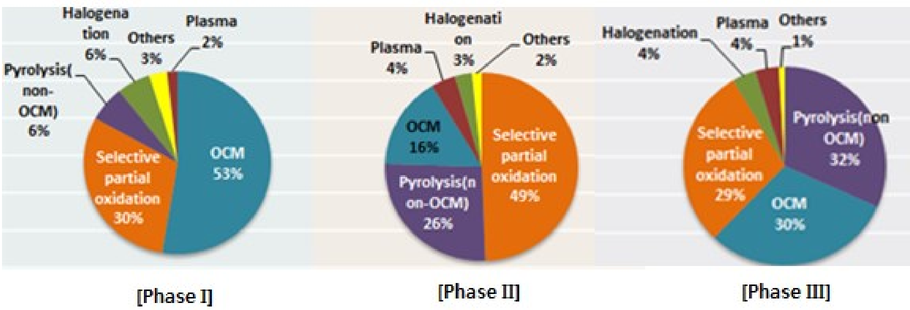


Figure 12 Paper analysis: alkane gas direct conversion

Looking into the distribution of technology through a text-mining method, photo-catalyst and plasma pyrolysis are considered as emerging technologies (Figure 14). It is not easy to draw implications in exploring promising areas of technology for industrial use when considering the nature of papers. Discovering ideas from papers, however, can significantly contribute to IP acquisition strategy.

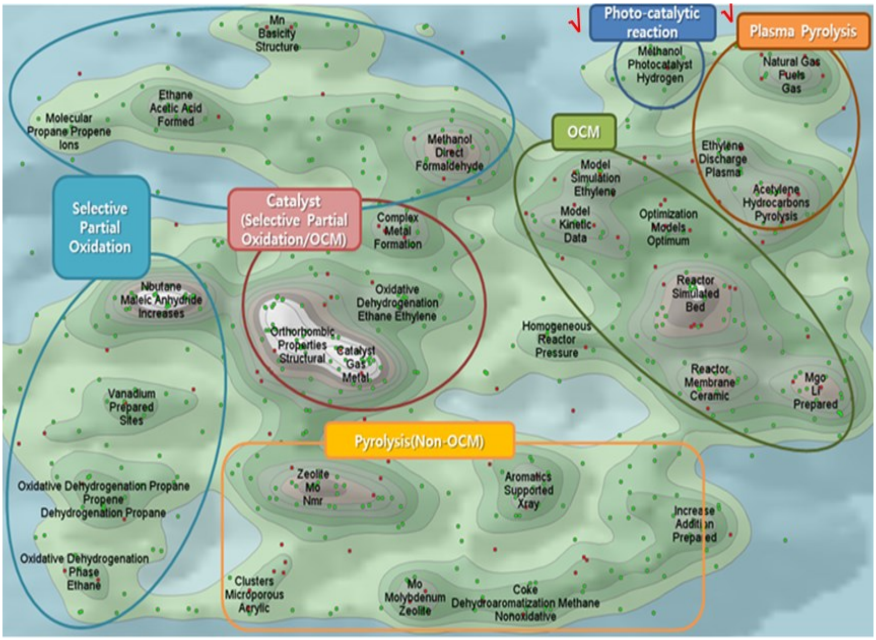


Figure 13 Exploring emerging technologies through text-mining papers

2.3 Industrial Market Analysis

Oil price fluctuations greatly affect the global economy, which gave rise to the increasing demand for developing liquid-phase conversion technology of natural gas that utilizes non-petroleum natural gas as an energy resource to guard against oil price fluctuations. Global natural gas market shows average annual percentage growth rate of 10% since 2010; it reached US$1.6 billion in 2016. Demands for shale gas are increasing as its economic feasibility is greatly strengthened. Apropos of markets per products for alkane gas, ethylene (olefin series) has been making 6.2% annual growth since 2012 and is expected to create a market size of US$17.78 billion by 2017. Hence, the development of olefin technology and the expansion of downstream market became the center of global attention.

The market for alcohol demonstrates a rapid growth as the consumption of alcohol fuel increases. Ethanol leads the world's alcohol market and reached US$59.6 billion in 2013 and ethanol is expected to create a US$46.9 billion market in 2018 with an average annual growth rate of 12.1% since 2013.

2.4 National R&D Project Analysis

With regards to creating high-value technology through direct conversion of alkane gas, a total of seven national R&D projects were conducted between 2003 and 2013: six projects in OCM and one in plasma. These projects were supported by the then Ministry of Education and the then Ministry of Trade, Industry and Energy, whose research entities include GRIs including KRICT, the Korea Institute of Energy Research and universities. It is noteworthy that there have been no projects in the areas of halogenation and pyrolysis, which draw rigorous attentions from patents and papers. Government-level supports on them are thus necessary for pursuing energy self-sufficiency and strengthening competitiveness of chemical industry.

2.5 Summary and Implications

Korea is heavily dependent on oil; over 95% of feedstocks required for energy and chemical products are from petroleum imports. It is not too much to overemphasize the importance of feedstocks diversification through strengthening technology development lest its industrial competitiveness should be dependent on oil price fluctuations. Gas-based energy resources such as natural gas and shale gas are abundant in supply. But technological barriers to utilizing these resources are quite high; hence technological innovation is necessary for tackling them. According to our patent analysis, major countries including the US and the EU have established strategies to utilize energy resources other than petroleum. Major oil and gas companies possess licenses but almost no Korean companies acquired any license. A government-led technology development in this area is thus urgent and it will be desirable to implement national R&D projects based on KRICT's technologies. The technology that directly converts alkane gas to high-value compounds is of great economic value for industrial use, but at the same time, there exist high technological barriers to entry. The patent information analysis revealed the recent rise of patent filings in the areas of halogenation, pyrolysis, OCM, and selective partial oxidation, whose processes gave birth to optimized products, olefin, aromatic compounds, and liquid fuel, respectively. It confirmed olefin's potential for a downstream product with the largest market share.

For the most promising realm for commercializing the direct conversion of alkane gas technology, halogenation process is designated through a link analysis of patents and markets. For mid- to long-term technology development model, the pyrolysis process, a popular subject matter in papers, is suggested. Since the OCM technology is being implemented through a national R&D project, it will not be given consideration for future project planning. The photo catalyst and pyrolysis were labeled as emerging technologies through paper analysis, which require additional research planning.

V. Conclusions

4P analysis relates results of independent analysis on patents, papers, markets and projects to types and characteristics of research planning and the realms of technology. It thus offers perspectives on developing ideas and opportunities. The landscape analysis linking research and technology facilitates an integrated analysis of emerging technologies and recent research trends. It provides perspectives on undeveloped areas of technology that deserve more attention. Through a landscape analysis, information on competitors and their core technology can be obtained, unbiased information that can diagnose organizational competences can be attained, and challenging and detailed objectives can be established. In particular, it is helpful to avoid patent infringement on prior arts and establish IP strategy that turns the ideas gained from papers into patents. Patent use analysis is a starting point for a link analysis of patent and product information. A linkage between technology and products can be made through analyzing industrial utilization of patents, and a value chain model composed of technology, products, and market can be created when industrial analysis is added. Hence this method offers perspectives on the analysis of the market-oriented feature of technology.

Through a link analysis of patents, papers and products, patents and papers of global issues can be understood, leading to efficient research planning for R&D projects. Another advantage is the review of redundancy of a given technology that can contribute to efficient use of national R&D investment. Moreover, it supports the establishment of more challenging technological and industrial objectives than existing national R&D programs. 4P analysis is most effective when it is conducted at the initial research planning stage as part of all-phase R&D process, rather than as a one-off activity. What is more important than 4P analysis per se is the establishment of an inner R&D structure in which 4P analysis can be made continuously and systematically.

Research planning at research sites is oftentimes regarded as lower conceptual part of policy or project planning. In many cases, research planning is conducted after themes and areas of research are determined to some degree. 4P analysis alone has some limitations in the exploration of important industry and policy for the future beyond the realm of research planning. Therefore, such measures as domestic and overseas policy analysis and life-cycle analysis on technology-based business should be added to 4P analysis for gearing towards the inception of drastic research planning method that creates value and prepares for the imminent and mid- to long-term future.

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