Annual Report 2019

Korea Research Institute of Chemical Technology

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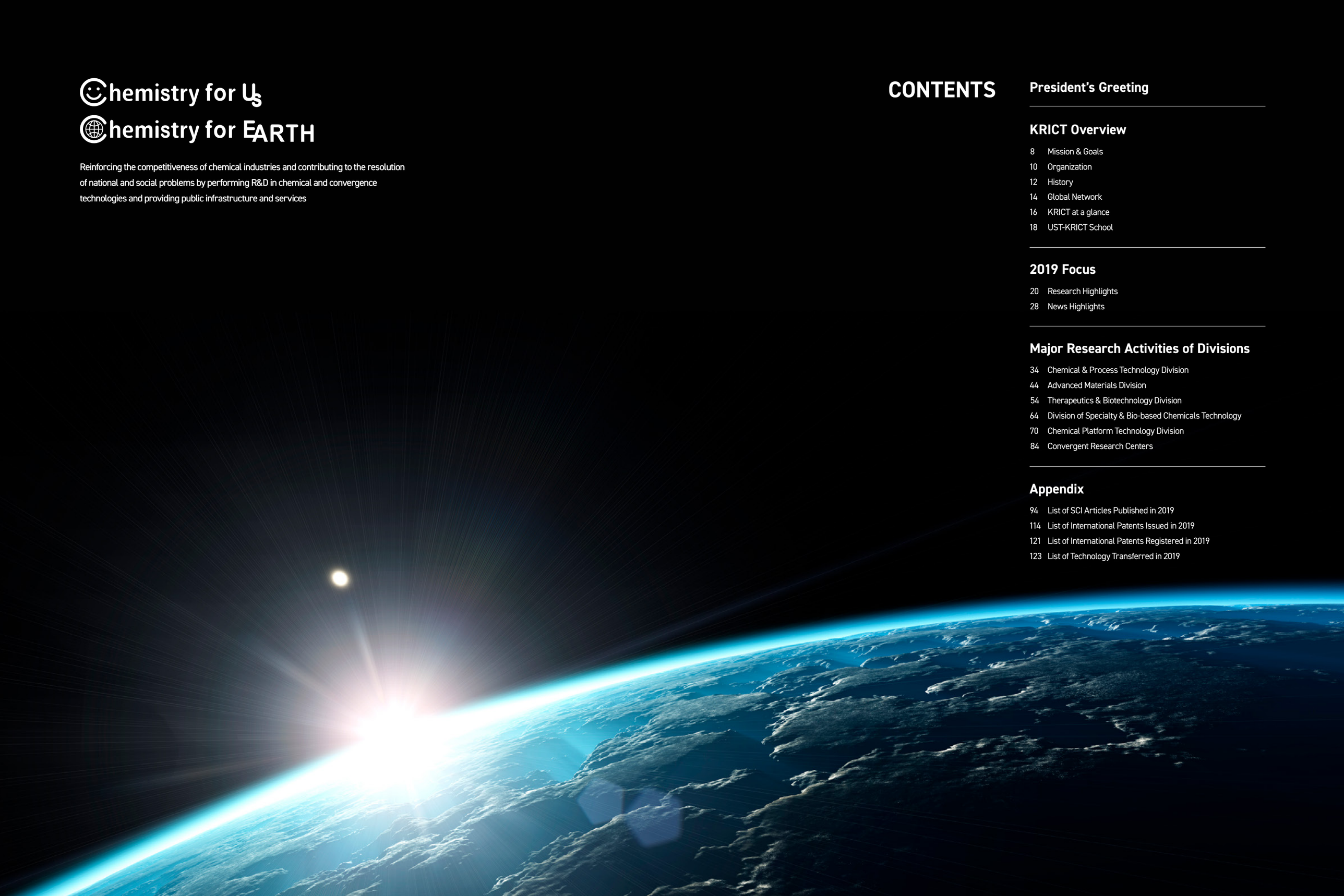
Chemistry for US

Chemistry for EARTH

Reinforcing the competitiveness of chemical industries and contributing to the resolution of national and social problems by performing R&D in chemical and convergence technologies and providing public infrastructure and services

CONTENTS



President's Greeting

KRICT, Towards a Sustainable Society

As one of Korea's major industries, the chemical industry has enhanced the quality of life and played a pivotal role in the advancement of civilization.

Since its establishment in 1976, KRICT has served as national leader of the chemical industry, making significant contributions to the development of chemical and transdisciplinary technologies, technology transfers, fostering of chemical experts, and various infrastructural services.

In 2019, KRICT received more public attention than in past years. I can say with confidence that KRICT embraced changes, implemented preemptive measures, and demonstrated its capacity as a government-funded research institute. Some highlights include our rapid response to Japan's export regulations, the establishment of KRICT's R&R, and the development of long-term plans for the next decade. With the advent of the fourth industrial revolution, the institute is developing plans to construct a next-generation soft chemistry research building to focus on big data research. This is expected to lay the foundation for KRICT to mature into a hub of big data for the field of chemistry.

In terms of research, KRICT achieved the most outstanding results in its history, elevating its status as a specialized research institute.

In particular, we developed perovskite solar cells with the world's best efficiency, entered phase 2 of a clinical trial for ulcerative colitis treatment, and completed technology transfers on MOF water adsorbents and biodegradable polymers. Four of KRICT's studies, namely, "Development of MOF water adsorbent with low temperature regeneration and dehumidification technology," "TNIK inhibitor technology transfer," "Development of new liquid organic hydrogen storage system with world's best efficiency," and "Development of ultra-high-purity N_2O collection/purification process for semiconductors from adipic acid waste gas," were included in the list of Korea National R&D Performance Evaluation Awards 2019. "Development of MOF water adsorbent with low temperature regeneration and dehumidification technology" was also featured in the list of outstanding research achievements by government-funded research institutes.

As a leading chemical research institute in Korea, KRICT will strengthen its competitiveness in chemical material research, concentrate resources on overcoming social issues, participate in research on eco-friendly and sustainable chemical technology, and utilize medicinal chemistry and AI web services in response to the fourth industrial revolution, thereby doing its part to support a sustainable society.

With best wishes,

Mihye Yi

Yi Mihye
President of KRICT

KRICT Overview

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Korea Research Institute of Chemical Technology

KRICT Overview

Mission & Goals

Mission

Chemistry for US
Chemistry for EARTH

* US: Utilization & Sustainability

Reinforcing the competitiveness of chemical industries and contributing to the resolution of national and social problems by performing R&D in chemical and convergence technologies and providing public infrastructure and services

Vision

E	A	R	T	H
Environment Energy	AI Analysis	Resource Recycle	Transport Telecommunication	Human Health
Responding to new climate system and achieving energy independence	Leading the fourth industrial revolution and establishing chemical platform infrastructure	Acquiring national strategic materials and properly distributing them	Driving innovation in smart materials for future society	Overcoming diseases and ensuring safety of citizens

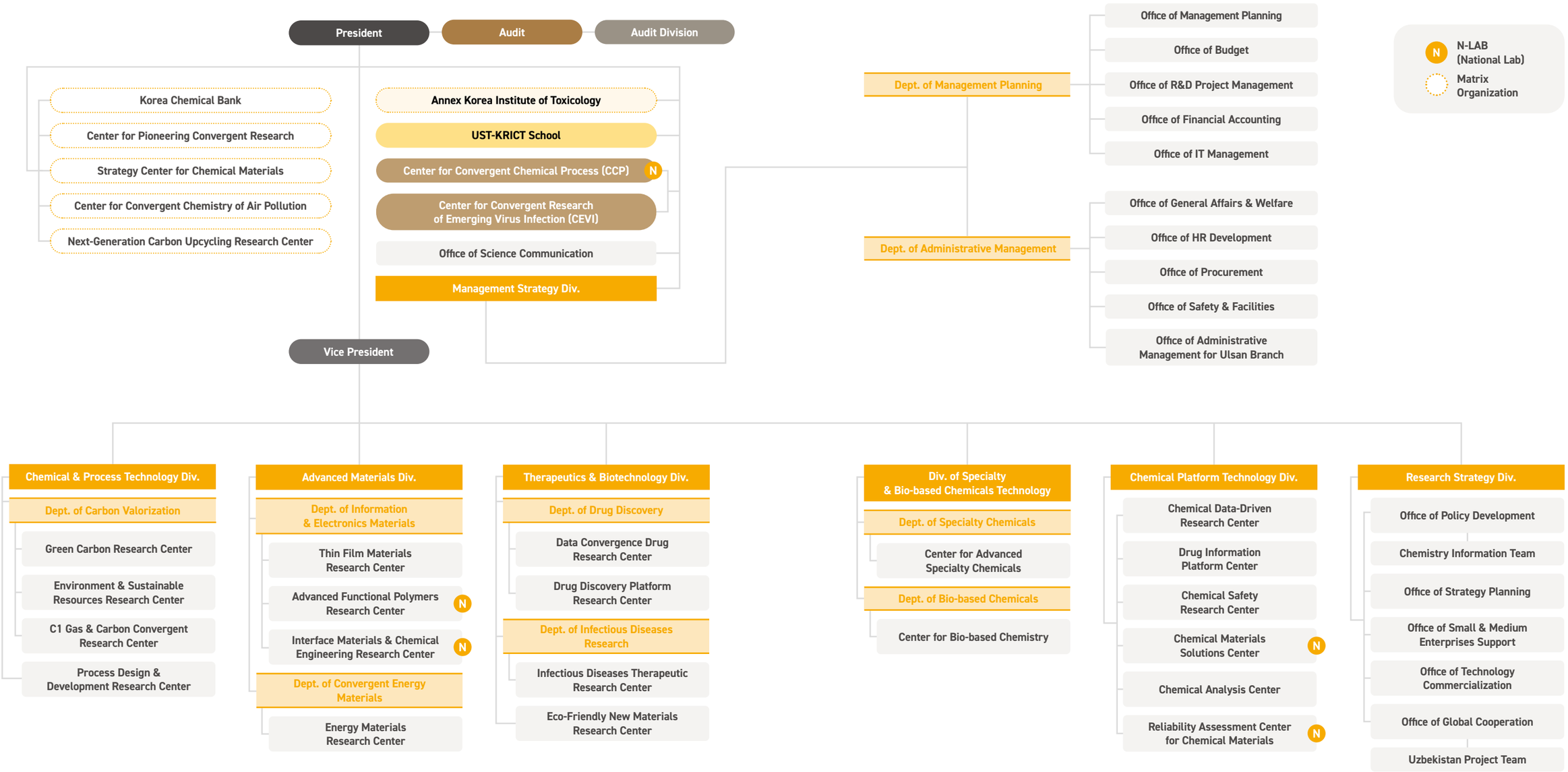
Management Goals & Essential Values

Excellence	Effectiveness	Publicness	Openness
· Acquiring future growth engines · Fostering outstanding talent	· Creating an optimal environment for research immersion · Strengthening mission-centered R&D	· Supporting innovative pursuits of the chemical industry · Strengthening R&D capacity to resolve social issues	· Strengthening internal/external communication · Expanding global cooperation

Performance Goals

Performance Goals	Final Goals
Driving innovation in integrated R&D system to fulfill R&R	Developing mid/long-term novel technology, strengthening R&D capacity to solve social problems, achieving institutional R&R through choices and focus
Fostering outstanding talent and creating envrionment for research immersion	Fostering outstanding talent, establishing a culture of safety consciousness, building environment for research immersion by relieving researchers' burden of administrative affairs
Stimulating chemical industry ecosystem for greater innovation	Strengthening competitiveness in chemical industry by supporting SME, commercializing technology based on IP strategies throughout business cycle, and supporting the growth of emerging industries
Strengthening global cooperation and internal/external communication	Enhancing global reputation of institute and improving awareness of chemistry-related issues by promoting strategic international cooperation and strengthening internal/external communication

Organization



History

1976

1976.09
Established as Korea Chemical Research Center

1999

1999.01
Change of affiliation to Korea Research Council for Industrial Science and Technology under the Prime Minister's Office

2000

2000.03
Established Korea Chemical Bank

2001

2001.01
Renamed as Korea Research Institute of Chemical Technology

2002

2002.01
Established Annex Korea Institute of Toxicology

2011

2011.12
Established Chemical Materials Solution Center

2012

2012.03
Established New Chemical Commercialization Research Center in Ulsan (currently Research Center for Advanced Specialty Chemicals)

2012.12
Named among World's Most Innovative Research Institutions by Thomson Reuters

2016

2016.03
Established Biochemistry Commercialization Center in Ulsan (currently Research Center for Bio-based Chemicals)

2016.09
40th anniversary of KRICT

2017

2017.07
Changed affiliation to National Research Council of Science and Technology under Ministry of Science and ICT

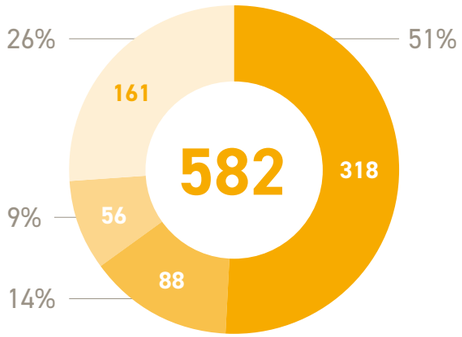
2019

2019.11
Dr. Yi Mihye inaugurated as 16th president

Global Network(Status of MOU Implementation)

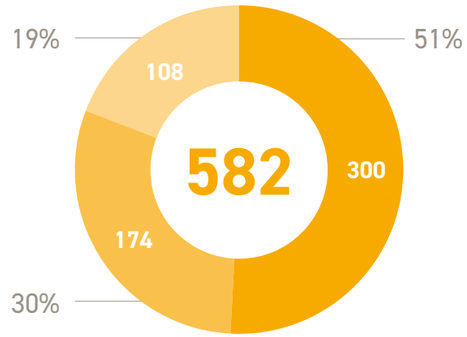
KRICT at a glance

Personnel



By Occupation

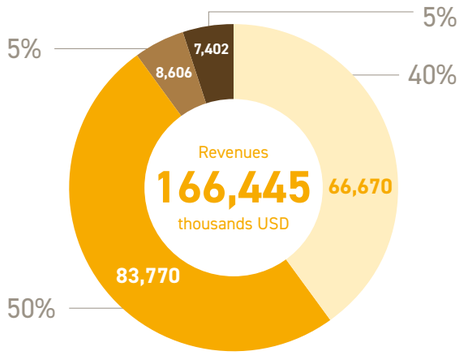
- Researcher
- Administrator
- Technician / Engineer
- Specialist



By Degree

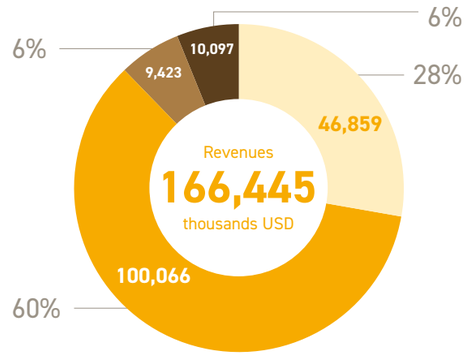
- Doctor's
- Master's
- Bachelor's

Budget



Revenues

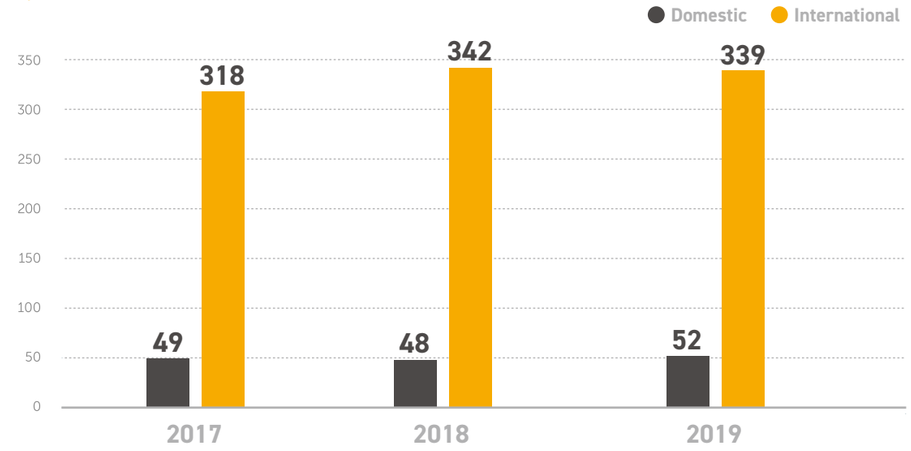
- Government Funded R&D
- Government Institutional Funding
- Private Sector Funded
- Others



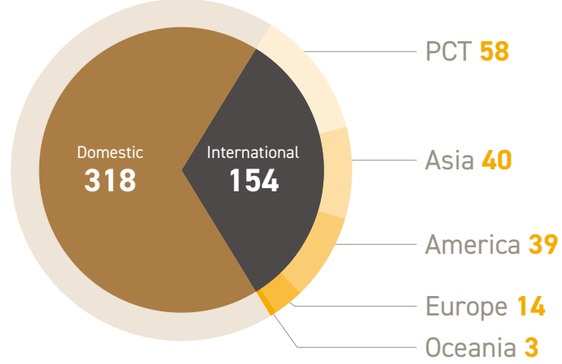
Expenditures

- Labor Cost
- R&D
- Operating Cost
- Others

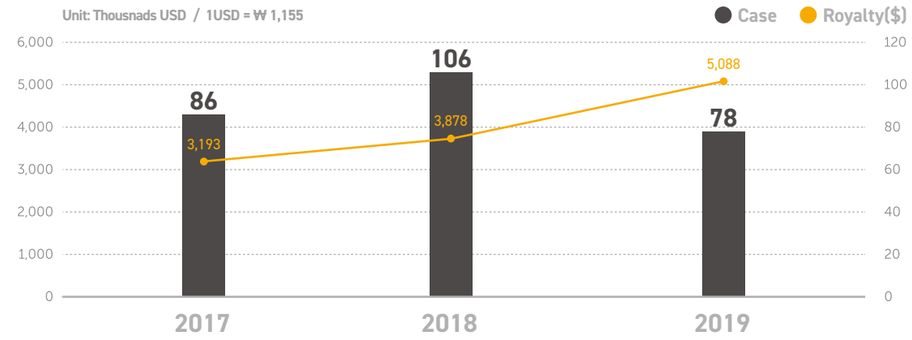
SCI Paper Publication



Patents Application



Technology Transfer



UST-KRICT School

KRICT offers various training programs to educate future professionals in the field of chemistry, the most notable being the UST-KRICT School. The UST-KRICT School is a joint education system between UST and KRICT. The UST-KRICT School offers a systematic educational approach centered around major and specialized fields of research.

At the UST-KRICT School, students are provided with a skilled teaching faculty, cutting edge research facilities, a unique academic curriculum, student welfare programs, and more. Through this, the UST-KRICT School strives to foster global professionals equipped with both knowledge and practical skills, who will become the leaders of tomorrow's chemical industry.

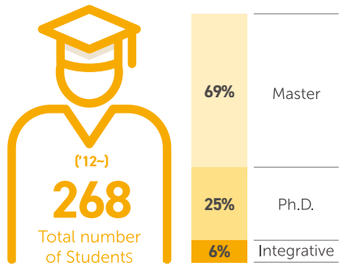
In 2019, 43 students successfully completed the UST-KRICT School program and received their degrees; 29 students in the master's program, 9 students in the Ph.D. program, and 5 students in the integrated program.

Majors Medicinal Chemistry and Pharmacology / Advanced Materials and Chemical Engineering

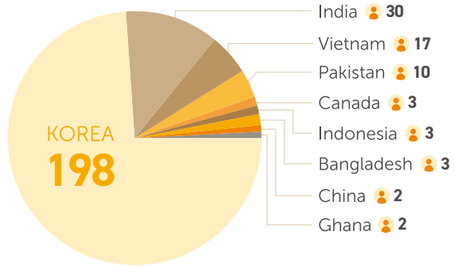
Programs Master / Ph.D. / Integrative program

Benefits Course Stipend, Welfare (health insurance, dormitory etc.)

Program Admission Stats



National Proportion



2019 Focus

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Korea Research Institute of Chemical Technology

Research Highlights

01

Non-oxidative direct conversion of methane: synthesis of hydrogen, ethylene, and aromatics through CO_2-free conversion process

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C1 Gas&Carbon Convergent Research Center

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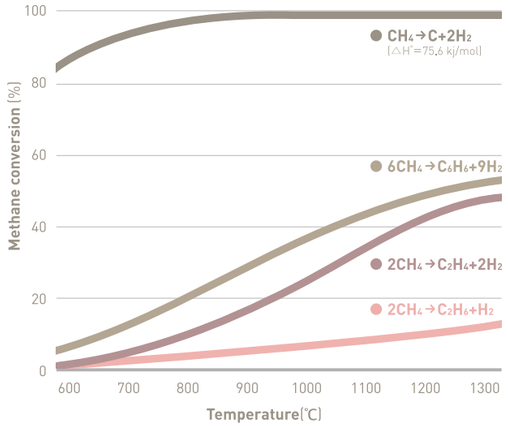
Chemical Data-Driven Research Center

We seek to develop chemical processes for the conversion of cost advantaged raw materials to higher margin performance chemicals. The advent of gas production technology has resulted in plentiful methane resources around the world. Rising concerns about methane emissions accentuate the need for an effective transformation to commodity chemicals. Catalysis in the non-oxidative direct conversion methane will be the workhorse of next chemical industry. We have proposed at the basic level catalytic reactor systems that works effectively in hydrocarbon pool and radical-chemistry.

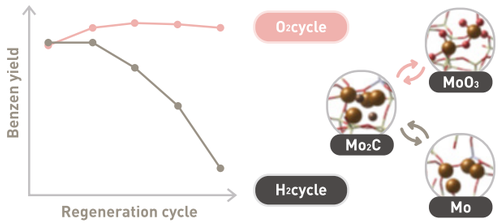
Methane has a strong C-H bond (425 kJ mol^{-1}), which limits the application of only 15% as a feedstock for the conversion process. Methane reforming based indirect routes (i.e. syngas conversions) such as methanol synthesis and gas-to-liquid (GTL) are just commercially available routes and must be mega-size plants to overcome thermal efficiency limits (≤60%). On the other hand, direct routes for the conversion of methane without oxidants can offer significant economic potential by improving process efficiencies and reducing facility capital investment. Ethylene and aromatics, mainly produced in petroleum, that has a potential capitalizing on methane advantage. This conceptual thermochemical route requires high energy (≥700℃) and it is important to ensure a narrow product distribution and increase product yield. Increasing the purity of co-produced hydrogen is another area that increases the economics of non-oxidative methane conversion.

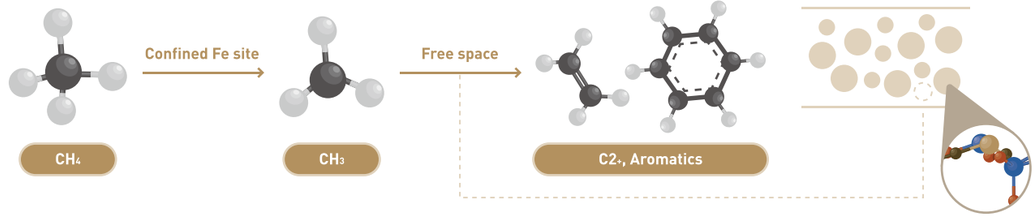
We have designed a bifunctional metal-acid catalyst (i.e. Mo carbides on H-ZSM-5 zeolite) for the production of benzene from methane. Detailed reaction mechanism studies show that the Mo carbide sites initially activate the C-H bonds of methane and the acidic sites catalyze the C-C coupling reaction to produce aromatic compounds. The main drawback of the catalytic system is stability in which zeolite acid sites undergo severe deactivation due to coke formation. We did comparative studies

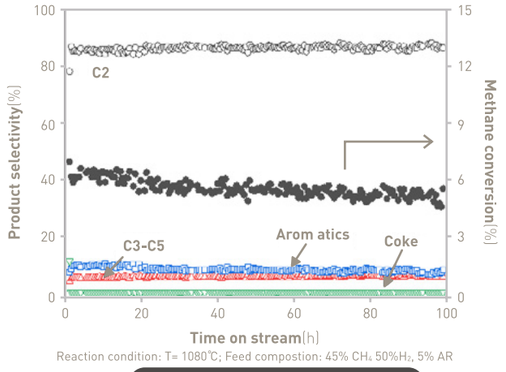


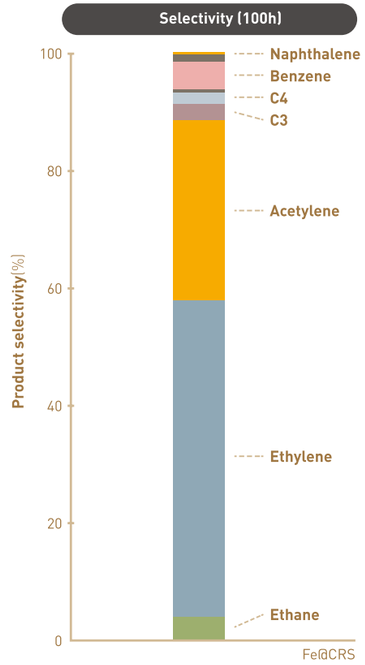
on the reaction-regeneration cycles under both oxidative and reductive conditions. What we learned from this systematic study is that the selective recovery of Brønsted acid sites near Mo sites other than isolated acid sites is sufficient to restore the catalytic activity in terms of benzene formation. Theoretical calculations indicated that partial oxidation of coke precursor (i.e. naphthalene) at 450℃ was more favorable than its partial hydrogenation at 850℃ on the Mo clusters in ZSM-5 channel.

We note that zeolite-based catalysts have limitations on thermodynamics and thermal stability, making it difficult to increase









the yield of benzene by 10% or more. Another issue in terms of kinetics is that the control of consecutive reactions of unsaturated hydrocarbons in zeolite pores is not easy. We have attempted to design surface active sites by optimizing variables such as site proximity to selectively produce ethylene and aromatics from methane. The non-porous iron confined cristobalite catalyst (Fe©CRS) prepared through the melt-fusing method is demonstrated to be effective for the non-oxidative direct conversion of methane. The Fe©CRS catalyst was proper to control radical chemistry where methane conversion is more advantageous on the catalytic surface than on the gas phase based on the reaction kinetics. The silica confined Fe species (Fe–Si bond) not only selectively promote the methane activation but also inhibit the coke formation on the silica surface by reducing its defect sites. Electronic structure calculations indicated that these confined Fe sites were more favorable for methyl radical formation and a high coke resistance than Fe_3C clusters. By optimizing reaction parameters, the Fe©CRS catalyst exhibited 6.9–5.8% methane conversion and 86.2% C2 selectivity for 100 h with co-feeding of 50% H_2 at 1080℃. We note that the Fe©CRS catalytic system requires further optimization using numerous ways to increase the product yield, especially ethylene by more than 20%. Detailed mechanism studies on radical chemistry for high-temperature conversion technologies would help to maximize the yield of target products.

Our key findings will facilitate researchers working in the field of catalysis to design catalytic surfaces with detailed characterization techniques as a global innovation technology. We hope that the methane will be a game changer in the petrochemical industry in the next few years.

Research Highlights

02

Efficient, stable, and scalable perovskite solar cells using poly(3-hexylthiophene)

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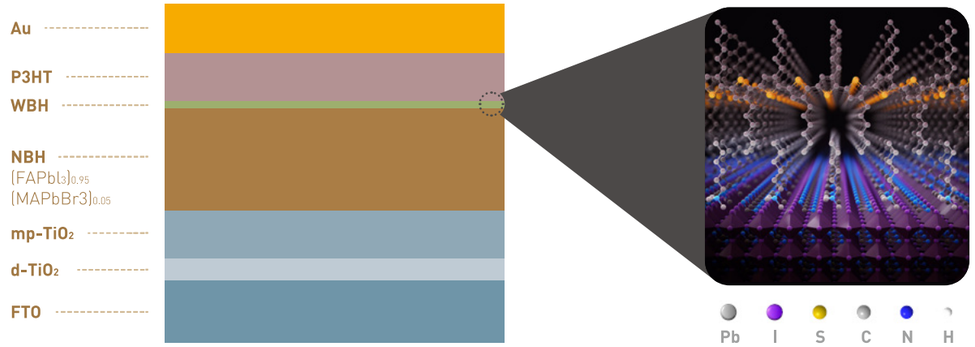
Energy Materials Research Center



Double-layered halide architecture of P3HT-based perovskite solar cells. Left, the structure of an n-i-p perovskite solar cell based on a DHA using P3HT as the hole-transport material. Right, schematic structure of the interface between the WBH and P3HT

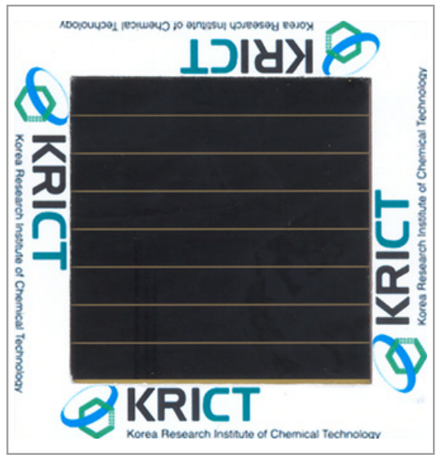
In the early stage, our team at KRICT had developed the fundamental core technologies including device structure, film fabrication, and materials composition to obtain highly efficient perovskite solar cells. So far, we have received world-record efficiencies in this area for 7 times, which were recorded in NREL's best cell efficiency chart.

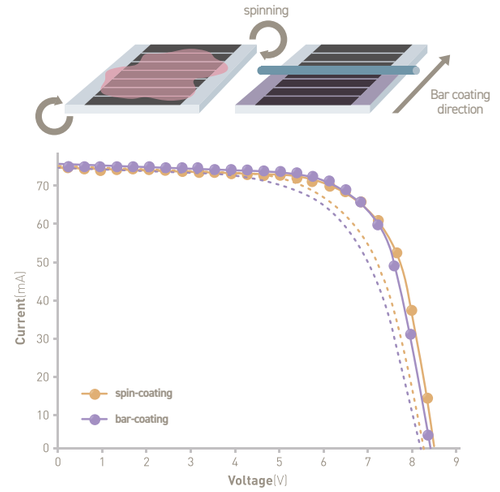
Based on key technologies from unit cells, we have focused on the development of large-area perovskite solar modules with good reliability towards commercialization. Furthermore, our research scope also covers flexible perovskite solar cells and silicon/perovskite tandem solar cells.

Perovskite solar cells typically comprise of electron- and hole-transport materials deposited on each sides of a perovskite active layer. So far, only two organic hole-transport materials, poly(triarylamine) (PTAA) and 2,2′,7,7′-tetrakis(N,N-di-p-methoxyphenylamine)-9,9′spirobifluorene (spiro-OMeTAD), have led to state-of-the-art performance in these solar cells. However, these materials have several drawbacks in terms of commercialization, including high cost, the need for hygroscopic dopants that trigger degradation of the perovskite layer, and limitations in their deposition processes.

Poly(3-hexylthiophene) (P3HT) is an alternative hole-transport material with excellent optoelectronic properties, low cost and ease of fabrication, but so far the efficiencies of perovskite solar cells using P3HT have reached only around 16%.

Here we propose a device architecture for highly efficient perovskite solar cells that use P3HT as a hole-transport material without any dopants. A thin layer of wide-bandgap halide perovskite is formed on top of the narrow-bandgap light-absorbing layer by an in situ reaction of n-hexyl trimethyl ammonium bromide on the perovskite surface.





method	direction	J_{sc}(mA/cm²)	V_{oc}(V)	FF(%)	η(%)
spin-coating	reverse	2.72	8.78	71.7	17.1
	forward	2.73	8.53	66.0	15.4
bar-coating	reverse	2.72	8.66	72.6	17.1
	forward	2.73	8.46	64.5	14.9

Large-scale fabrication of P3HT-based DHA solar cells. Left, Photograph of a 5 cm × 5 cm DHA-based solar module. The designated illumination area was estimated as 24.97 cm² according to the average of five separate area measurements. Right, Current–voltage (*J-V*) curves of the DHA-based solar modules formed by depositing the P3HT layer using spin-coating (orange) and bar-coating (purple) methods

Our device has a certified power conversion efficiency of 22.7 % with hysteresis of ±0.51%; exhibits good stability at 85% relative humidity without encapsulation; and upon encapsulation demonstrates long-term operational stability for 1,370 hours under 1-Sun illumination at room temperature, maintaining 95% of the initial efficiency.

We extended our platform to large-area modules (24.97 cm²)—which are fabricated using a scalable bar-coating method for the deposition of P3HT—and achieve a power conversion efficiency of 16.0%. Realizing the potential of P3HT as a hole-transport material by using a wide-bandgap halide could be a valuable direction for perovskite solar-cell research.

Research Highlights

03

Discovery of BBT-176

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Data Convergence Drug Research Center

Lung cancer is the most common cancer worldwide with 2.5 million new cases each year (more than 220,000 new patients in US alone 2016). Non-small cell lung cancer (NSCLC) accounts for almost 85 percent of all lung cancers. A five-year survival rate in advanced NSCLC patients is less than 20%. Many of NSCLC are caused by oncogenic driving mutation of related proteins. Epidermal growth factor receptor (EGFR) activating mutations account for 30-40% of NSCLC patients in East Asian population and 10-15% in European descendants.

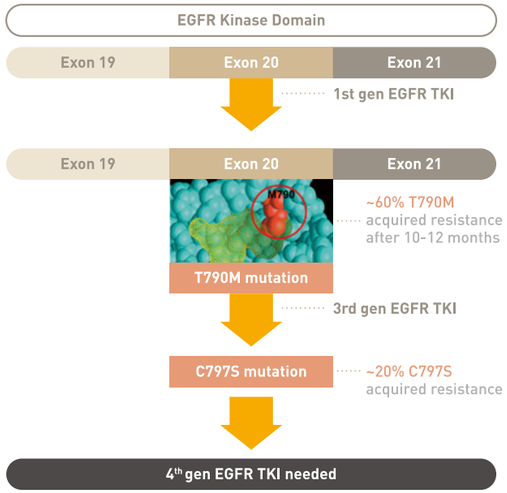
Iressa & Tarceva are clinical in-use first generation EGFR-tyrosine kinase inhibitors (EGFR-TKIs) featuring quinazoline-based reversible inhibition targeting the major EGFR driving mutations such as EGFR L858R and EGFR ex19 deletions. Osimertinib is a pyrimidine-based irreversible EGFR-TKI addressing Iressa & Tarceva-resistant EGFR T790M mutation while sparing wild-type EGFR activity.

Professor Byoung-Chul Cho at Yonsei University Hospital identified and reported EGFR C797S mutation resistant to Osimertinib for the first time. EGFR C797S mutants are resistant to currently available treatment.

So our research team has collaborated Yonsei University Hospital toward EGFR resistant mutants inhibition for unmet'first-in-class'lung cancer drug development. After 4 years, BBT-176 was identified as the first small molecule inhibitor with potent activity to EGFR C797S mutants with excellent oral drug properties.

BBT-176 was licensed to domestic biopharmaceutical company (BridgeBio Therapeutics) and recently finished its pre-clinical development study. In pre-clinical studies, BBT-176 showed anti-tumor efficacy against EGFR C797S triple mutations. It also demonstrated enhanced efficacy when combined with anti-EGFR antibodies.

BridgeBio Therapeutics submitted Investigational New Drug (IND) application for the treatment of patients with NSCLC who developed resistance to osimertinib (Tagrisso) to Korean Ministry of Food and Drug Safety (KFDS) and US Food and Drug Administration (FDA) at December 2019 and received IND approval from US FDA on January 2020. BBT-176 will initiate Phase 1 clinical trial on early of year 2020 in United States to find out BBT-176 safety and anticancer efficacy.



Scheme of development for 4th generation EGFR tyrosine kinase inhibitors to address evolving EGFR mutations and its frequencies; BBT-176 is a first-in-class 4th generation EGFR TKI currently under development

Following the IND clearance, BridgeBio Therapeutics plans to initiate a dose-escalation study to find the maximum tolerated dose (MTD) of BBT-176. The dose-escalation phase will be the first part of a phase I/II first-in-human study in Korea, which will evaluate the safety, tolerability, and anti-tumor efficacy of the drug in patients with advanced NSCLC. A dose-expansion study will be the second part of the study, which will re-evaluate the safety, tolerability, and efficacy of the MTD of BBT-176 in patients in the United States and Korea.

Research Highlights

04

Tough yet biodegradable plastic bag: Cellulose/chitosan nanofiber-reinforced polybutylene succinate (PBS)

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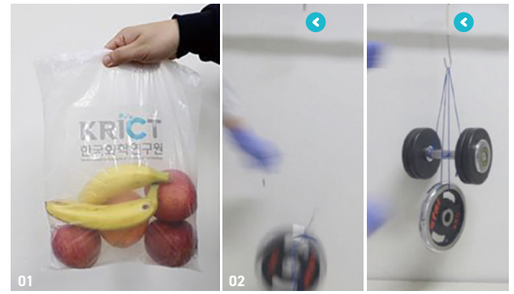
Center for Bio-based Chemistry

Polyethylene (PE) and polypropylene (PP) are sufficiently tough as materials for plastic bags; however biodegradable plastics including polylactic acid (PLA), polybutylene adipate terephthalate (PBAT), and polybutylene succinate (PBS) typically give poor mechanical properties. The reason is that biodegradability and mechanical property are mutually exclusive i.e. both pro perties have trade-off relationship. PLA and PBS show the tensile strength of 35-45 MPa and the tear strength of <1,000 N/cm. To address the mechanical property issue of bioplastics, many inorganic nano-particles are incorporated into bioplatics. Their mechanical reinforcement was not effective due to their poor dispersion in polymeric matrices. In addition, inorganic nano-particles create fine dust and are not degradable at all.

Cellulose and chitin (chitosan) nanofibers are emerging reinforcing materials for bioplastics. Their single fibers have an elastic modulus of 40-100 GPa, and they are biodegradable and renewable as well. Theoretically, the incorporation of cellulose and chitin nanofibers can improve the mechanical properties of bioplastics. However, it has been hardly realized mainly due to the poor dispersion of cellulose and chitin nanofibers in bioplastics. To address the homogenous dispersion cellulose and chitin nanofibers in bioplastics, high-cost and time-consuming process are necessarily required.

Cellulose and chitin nanofibers were extracted from wood pulp from crab shell, respectively. 1) The natural nanofibers are homogeneously dispersed in di-alcohol monomer i.e. ethylene glycol (liquid) of PBS via our know-how. 2) the nanofiber-dispersed monomer is in-situ polymerized. Through our method, the only 0.1 weight% (1000 ppm) of the incorporation of cellulose or chitosan nanofibers increases the mechanical properties of PBS: 1.6 times in tensile strength of 65-70 MPa and 2.3 times in toughness. The tensile mechanical properties are as high as those of Nylon 6. Our key technology is homogenous dispersion of cellulose nanofiber via a simple and cost-effective nanofiber modification. We have the whole original technologies for a series of processes from the nanofiber production to the plastic bag product. Our patents include 1) the production of natural nanofibers 2) the dispersion know-how of natural nanofibers 3) the plastic product of natural nanofiber-reinforced PBS, PBAT, and PLA.



01 The proto-type of plastic bag made of our new bioplastic (nanofiber-reinforced PBS)
02 A commercial PP film fails at 5 kg.
However, our bioplastic withstand a 20 kg weight.

This process is also reproduced in a pilot scale (50 kg). We have demonstrated the prototypes of tough plastic bag using our newly invented bioplastic. Also, It is the first case where the sufficient mechanical property, pilot production, and 3) full biodegradability (0.5-1 year) are achieved at the same time.

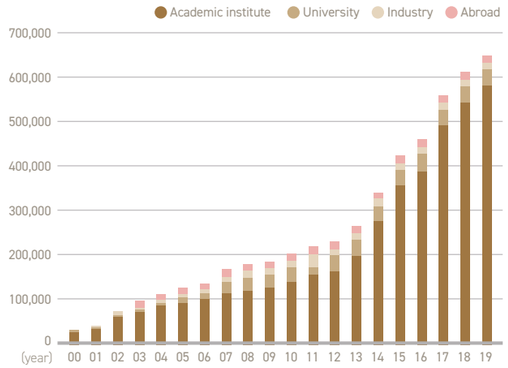
In addition, cellulose and chitin nanofibers can improve the gas barrier properties of plastic bags. Typically, oxygen permeates the plastic packaging, degrading foods. Improving the gas barrier usually requires metallic or halogenated polymeric coatings; however, both cause environmental concerns. Our researchers coated cellulose and chitin nanofibers on the biodegradable PLA films. This sustainable and biorenewable coating achieves the very low oxygen transmission rate of below 0.5 mL m^{-2} day^{-1}. This invention potentially can replace the current non-biodegradable and non-sustainable plastic packaging.

Research Highlights

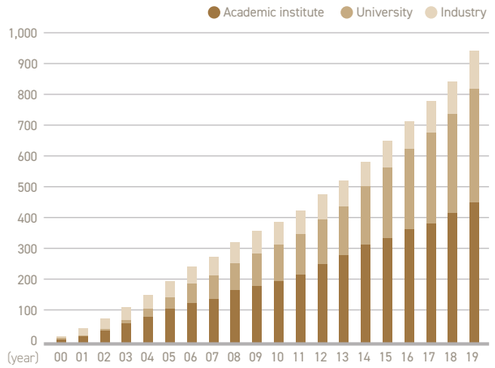
05

Establishment of Web based database platform for drug discovery

Dr. Lee, Sunkyung / leesk@krict.re.kr
Drug Information Platform Center



Numbers of Compound Libraries



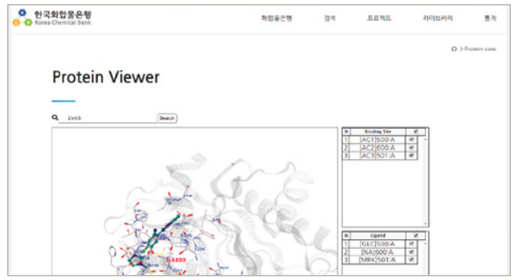
Numbers of Projects Using KCB Libraries

Korea Chemical Bank (KCB) was established in 2000 as a national platform for drug discovery and chemical biology through collection, management, and provision of biologically-relevant chemical libraries. KCB was designated as the Korea National Chemical Repository since 2010 by the Ministry of Science and IT (MSIT) of Korea.

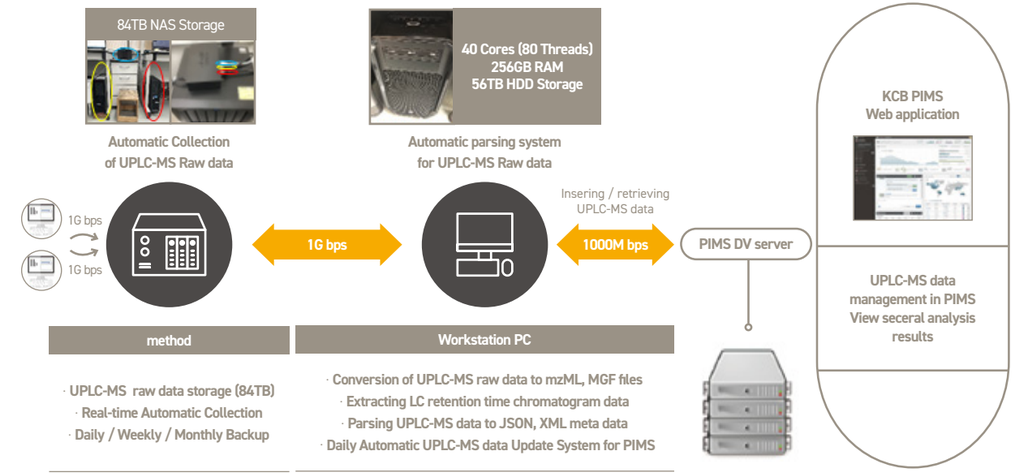
In 2019, around 40,000 compounds including research products deposited by Korean research scientists, were collected resulting in 640,000 cumulative compounds. KCB also supported 188 projects including 97 new projects, and provided 239,000 libraries to domestic researchers in 2019. During 20 years KCB collected around 6,500,000 biological activity data using 640,000 compounds on 937 different drug targets. Recently, there are many needs on data services for data-driven drug discovery research.

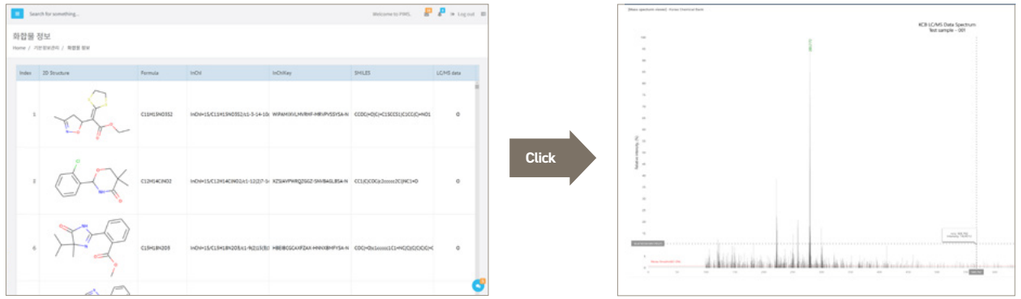
Then, integrated database platform for drug discovery has been established in 2019 for web based services. KCB database containing the information on 640,000 compounds' management and their 6,500,000 biological data cumulated for 20 years, was integrated with open databases such as ChEMBL, DrugBank, and PDB. Researchers can search sub-structure of chemical compounds with their analytical data (UPLC-MS, nmr), molecular descriptors, and biological activities. Additionally, they can get the information on drug targets, diseases, biological pathways, and prediction values on physicochemical properties and ADMET (absorption, distribution, metabolism, excretion, and toxicity) profiles of compounds.

Researchers can see 3D structures of proteins and ligands with crystal structures. As well as providing information, researchers can proceed the submission of compounds and requests on utilization of chemical libraries and data through this web service in the second half of 2020 after completion of security program.



KCB usually analyzes 30,000 ~ 40,000 compounds using UPLC-MS a year for qualifying libraries. The system on automatic collection of analytic data from instrument and transformation of data to image was also established. Researchers can monitor the analytical data of compounds in this web platform.





Automatic data collection / conversion / viewer from UPLC-MS

There are 21 publications with citation of KCB in 2019 including high impact journal "Cell". KCB contributes to technology transfer of preclinical candidate for HBV form academic to bio venture.

News Highlights

1

Completed development and technology transfer of anticancer drug candidate

On January 22, KRICT signed a technology transfer agreement with Bridge Bio for its newly developed anticancer drug candidate.

Jointly developed by the KRICT team led by Dr. Lee Kwangho and Yonsei Cancer Center, the new candidate material targets lung cancer and other types of cancer. The candidate drug inhibits specific genes or proteins and selectively kills cancer cells, thus presenting new possibilities in the treatment of lung cancer involving mutations.

In cooperation with Bridge Bio, KRICT will assess the effectiveness of the candidate drug against lung cancer and other types of cancer, and conduct pre-clinical studies, including a GLP toxicity test.

2

Completed development and technology transfer of new compound for colorectal cancer treatment

A team led by Dr. Lee Hyuk of KRICT and the Yonsei Cancer Center completed technology transfer of a new compound for colorectal cancer treatment to FutuRx, a global biotech incubator. The technology was used to launch a new Israeli startup, TNIK Therapeutics.

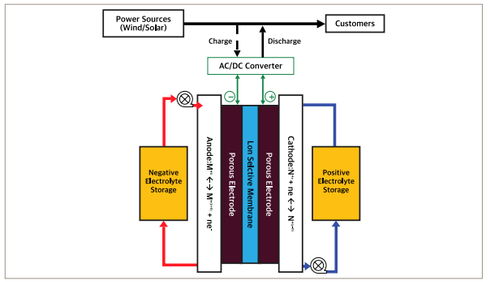
FutuRx, OrbiMed, J&J, Takeda, KRICT, and Yonsei University, the shareholders of TNIK Therapeutics, will share their experiences on new drug development and provide advice on future moves for the company.

The compound takes effect by inhibiting the binding of TNIK and β-Catenin in the body. The accumulation of β-Catenin promotes the growth and transfer of cancer cells by entering cell nuclei and binding with TNIK. As such, colorectal cancer can be treated by inhibiting the binding of TNIK and β-Catenin.

Through experiments, the team verified that the compound is effective at preventing the spread of cancer when administered alone or together with other anticancer agents. The material is expected to open new possibilities in the development of drugs for other types of cancer.

3

Commercialization begins for vanadium redox flow battery following development and technology transfer



A team comprised of Dr. Hong Young TaiK, Dr. Kim Tae Ho, and Dr. Lee Jang Yong completed technology transfer of poly(phenylene)-based membrane materials for use in vanadium redox flow batteries. The technology has now entered the early stage of commercialization. The team formed a multi-block copolymer of poly(*p*-phenylene) structure, containing a sulfonic acid group, and maximized durability by strengthening the connecting links and fabricating a reinforcing composite membrane. The new material maintained its durability and stable performance even under high current densities.

In November last year, KRICT transferred the technology to Standard Energy, a company specializing in vanadium redox flow batteries. The new ion membrane technology has undergone basic performance tests, including a battery life test. The results verified the high efficiency and stable capacity of vanadium redox flow batteries. The team plans to accelerate commercialization by cooperating with Standard Energy in safety evaluation and production optimization.

4

PVDF for secondary batteries to be commercialized

KRICT signed an agreement with Chemtros on the transfer of technology for the manufacturing of PVDF, an essential material of secondary batteries and solar cells.

The first stage of this manufacturing technology involves producing VDF monomers through pyrolysis and refinement of raw materials, and the second uses polymerization to turn VDF into PVDF. The KRICT team developed the VDF monomer process as well as the VDF-to-PVDF process.

The technology was just as outstanding as the world's leading pyrolysis-based VDF manufacturing process and produced VDF of high purity. The pyrolysis conversion rate was 99.5%, and purity levels of VDF and refined VDF were 98.5% and 99.97%, respectively. Meanwhile, the pyrolysis conversation rates achieved by Japan, the United States, and Germany fall in the range of 95 to 98%.

Previously, due to its lack of domestic manufacturing technology, Korea relied on imported PVDFs. The proposed technology is expected to reduce PVDF imports, which amount to an annual 4,000 tons.

News Highlights

5 On-site MERS diagnostic assay moves forward in commercialization

A team led by Dr. Kim Hong Gi of the Center for Convergent Research of Emerging Virus Infection (KRICT CEVI) transferred a 20-minute on-site MERS diagnostic technology to Wells Bio, a subsidiary company of Access Bio.

Dr. Kim's team succeeded in optimizing an antibody that binds to the MERS-CoV antigen, thereby facilitating the detection of MERS-CoV. The antibody was used to develop an on-site diagnostic kit that allows rapid detection (within 20 minutes) of persons affected with MERS in airports.

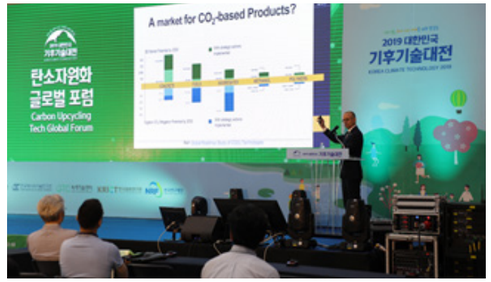
The two institutes plan to pursue commercialization based on KRICT's rapid MERS diagnostic technology and the company's high-sensitivity rapid diagnostic kit platform. They will also conduct clinical trials in UAE, and share experimental facilities in conducting joint research on the prevention of new/variant diseases.

6 World's largest R2R Asia Conference was held in KRICT for the first time

From May 28 to May 30, KRICT and the Association of International Metallizers, Coaters, and Laminators (AIMCAL) *held the 2019 R2R** Roll-to-roll (R2R): A high-tech process involving continuous coating of functional organic and inorganic materials on rolls of flexible plastic or foil
Asia Conference, the world's largest conference on R2R coating technology, at the Didimdol Plaza of KRICT in Daejeon.
This year's conference attracted more than 150 domestic and international experts in R2R equipment, materials, and coating processes. The three-day event was comprised of 11 sections, including coating and surface treatment, R2R sputtering, moisture barriers, and batteries.

* Established in 1970, AIMCAL is an association of laminators and metallizers who have gathered to enhance the quality of coated products. It organizes an annual R2R conference focused on functional coating and flexible devices.
** Roll-to-roll (R2R): A high-tech process involving continuous coating of functional organic and inorganic materials on rolls of flexible plastic or foil

7 2019 Carbon Upcycling Tech Global Forum was held



The 2019 Carbon Upcycling Tech Global Forum, which aims to strengthen international cooperation on carbon upcycling technology***, was held under the theme of "Climate Technology, the Key to a Better Future."
The forum attracted representatives and experts from around the world, including Europe, the United States, and China, and served as a platform for the sharing of the latest trends and projects related to Carbon Capture and Utilization (CUU) technology. Dr. Choi Ji Na, the head of the Office of Carbon Upcycling R&D Strategy(currently Environment & Sustainable Resources Research Center), said, "The forum, which is in its fourth year, attracted more than 600 participants during pre-registration alone. This shows that there is a growing interest in CCU technology. Since the goals of reducing greenhouse gases by 2030 and creating new industries through CCU technology can only be achieved through cooperation, I hope that this forum will be an opportunity for industries, universities, research institutes, and governments to share strategies and solutions for the greater good."

*** Carbon upcycling technology: Conversion of unused carbon (carbon dioxide, carbon monoxide, methane, etc.) in greenhouse gases and by-product gases into useful products.

8 Dr. Yi Mihye inaugurated as 16th KRICT president

On November 11, KRICT held an inauguration ceremony for Dr. Yi Mihye, its 16th president, in the auditorium of the Administration Building. President Yi, an expert in material development, has served as a KRICT researcher for more than 30 years. Since joining KRICT in 1985, she has made significant contributions to polyimide resin research, to which she devoted more than two decades of her career.

By re-establishing KRICT's R&R, President Yi hopes for KRICT to play a role in providing solutions to social issues through science and technology. She will concentrate resources on the development of material component technology, paving the way for Korea to acquire domestic technology and to strengthen its international competitiveness in new material development.

President Yi said, "KRICT will establish long-term strategies for material development, and actively pursue research projects to enhance domestic technology and explore possibilities in emerging markets."

News Highlights

9

Completed technology transfer of natural multi-functional material and super bioplastic

KRICT transferred its natural multi-functional material synthesis catalytic technology and eco-friendly super engineering plastic manufacturing technology to Activon and IlKwang Polymer, respectively.

The natural multi-functional material synthesis catalytic technology is a catalyst-based chemical transition technology used to produce 1,2-pentanediol with materials derived from plants. KRICT's Green Carbon Catalysis Research Center succeeded in developing 1,2-pentanediol manufacturing technology, which offers advantages such as a 75% decrease in manufacturing costs, higher yield, and improved reaction selectivity. The center will work with Activon in research on mass manufacturing and high-purity refinement for the purpose of technology commercialization.

For eco-friendly super engineering plastic manufacturing technology, KRICT's Bio-based Chemistry Research Center developed a strong, heat-resistant super bioplastic free of environmental hormones by using a phase transition catalyst to maximize the reactivity of isosorbide.

KRICT and IlKwang Polymer will conduct joint research to further develop the institute's eco-friendly super engineering plastic manufacturing technology.

10

Ultra-low power dehumidification/ air-conditioning system paves way to success in next-generation dehumidifier market

KRICT completed technology transfer of a hybrid solid desiccant material, essential for dehumidification and cooling, to AEOL Korea. The energy-saving dehumidification/air-conditioning technology developed by a KRICT team comprised of Dr. Chang Jong-San and Dr. Lee U Hwang uses a cylindrical rotor coated with MOF Metal-Organic Framework (MOF): A metal-organic framework formed from coordinate covalent bonds between metal cations and organic carboxylic acid anions desiccant material to remove moisture in air and facilitate air-conditioning. Compared to existing dehumidifiers, the proposed system saves power by more than 40%, and improves dehumidifying performance by at least 50%. KRICT was granted a U.S. patent for the MOF desiccant technology, which was also named by the Ministry of Science and ICT among the top 100 national research achievements of 2019 and the top 10 achievements by government-funded research institutes in 2018. If commercialized, the MOF desiccant rotor will not only replace imported desiccant rotors but also pave the way for KRICT to lead the next-generation dehumidifier market.

Metal-Organic Framework (MOF): A metal-organic framework formed from coordinate covalent bonds between metal cations and organic carboxylic acid anions

Major Research Activities

Annual Report 2019
Korea Research Institute of Chemical Technology

Major Research Activities of Divisions

Development of environment-friendly chemical technologies to deal with climate change and atmospheric environment issues

Chemical & Process Technology Division develops convergent technologies for utilizing carbon containing wastes (CO_2, byproduct gases, biomass wastes) as alternative chemical and fuel feedstocks and improving atmospheric environment.

Chemical & Process Technology Division

Department of Carbon Valorization
Green Carbon Research Center
Environment & Sustainable Resources Research Center
C1 Gas & Carbon Convergent Research Center

Process Design & Development Research Center

Green Carbon Research Center

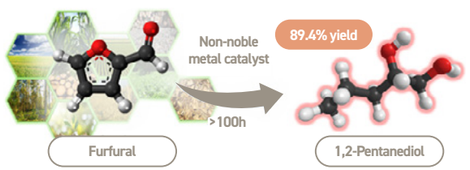
Director / Hwang Dong Won / dwhwang@krict.re.kr

- Development of eco-friendly process for green carbon into platform chemicals
- Development of eco-friendly process for plastic waste into valuable chemicals
- Development of porous nanomaterial and application technology
- Development of membrane technology to solve environmental and industrial issues

A highly efficient and robust catalyst for making value-added chemicals from sustainable biomass

The efficient catalytic conversion of renewable resources such as plant biomass into commodity chemicals is one of the alternate ways for production of petroleum based chemicals.

This valorization process usually involves the ring opening reaction of furan-based biomass platform chemicals such as furfural and 5-hydroxymethyl furfural. The current global production of furfural being > 5 million tons/year and it as a potential C5 biomass-based resource can be converted to high value-added alcohols and polyols, especially 1,2-pentanediol (1,2-PeD) via the hydrogenation and subsequent its ring opening reaction. 1,2-PeD has been widely used as a monomer in the production of polyester and an intermediate in the synthesis of fungicides and is also a component of disinfectants and printing inks. Especially in cosmetic industry, 1,2-PeD is a widely used cosmetic raw material with multifunctional properties. It is an excellent moisturizing ingredient for topical preparations. Besides it has very good antimicrobial and solubilizing properties. It also improves the water resistance of sunscreen formulations.



Highly efficient and robust catalyst for furfural to 1,2-PeD in a fixed-bed reactor

However, 1,2-PeD is conventionally produced from petroleum based n-pentene using mineral acid or formic acid by costly multistep reactions involving selective oxidation of pentene to pentene oxide and subsequent hydrolysis. Therefore, the development of a new synthesis route of 1,2-PeD is great important from the viewpoint of energy-efficient and eco-friendly process, and it can be realized by a single step reaction with biomass-derived chemicals.

Despite the extreme usefulness of furfural as a C5 resource, the transformation of furfural to 1,2-PeD has not been widely studied, and to date, a catalyst system with only novel metal components such as Pt, Pd, Rh, and Ag has been reported as an active catalyst for the selective synthesis of 1,2-PeD in a batch reactor.

Herein, we have developed a highly efficient and robust catalyst with non-noble metal components prepared by co-precipitation method for direct transformation of furfural to 1,2-PeD in a fixed-bed reaction system. The catalyst showed 100% conversion of furfural with 89.4% selectivity to 1,2-PeD at 250℃ and 40 atm hydrogen pressure. Notably, the catalyst exhibits unprecedentedly superior performance in the vapor-phase hydrogenation of furfural to 1,2-PeD for 100 h without deactivation. Recently, we have contracted with ActivON Co., Ltd. for a technology transfer of this technology.

Technology transfer to ActivON Co., Ltd.

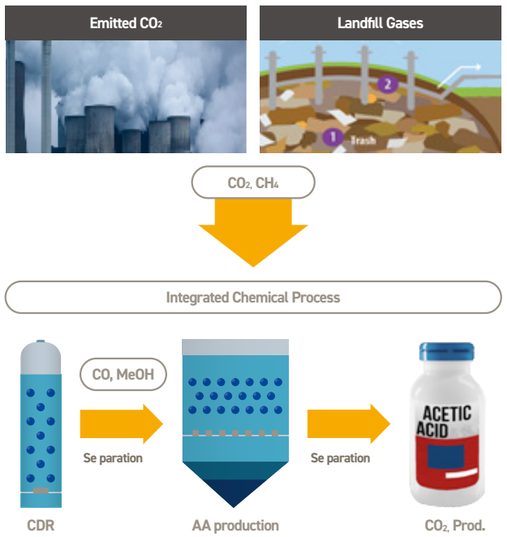
Environment & Sustainable Resources Research Center

Head / SHIN JIHOON / jshin@krict.re.kr

- Convergence technology for greenhouse gas resource recovery to respond to climate change
- Technology for reducing secondary fine dust sources to improve air quality
- Technology for sustainable resources-based high value-added compounds

Syngas and acetic acid production *via* CO_2 reforming

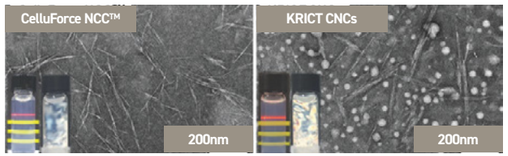
The pilot-scale CO_2 reforming system has been operating. The system demonstrates CO_2 conversion to syngas via catalytic reforming of CO_2 and natural gas; the CO_2 conversion efficiency reaches 95%, and 20 tons of CO_2 can be utilized in a year using our system. The demo-scale plant of current CO_2 reforming technology will be developed in following years. The ongoing research aims to establish an integrated process for CO_2 reforming, sequential CO conversion, and separation technology to manufacture CO_2 based chemicals(acetic acid, etc.). This project will provide an opportunity to substitute petroleum based chemicals to CO_2 based chemicals, which ultimately contributes to the greenhouse gas reduction.



Facile and eco-friendly extraction of cellulose nanocrystals (CNCs) via electron beam irradiation

An innovative system for extracting cellulose nanocrystals (CNCs) was proposed that uses a two-step process that combines short-time pretreatment by electron-beam irradiation (EBI) in the solid state and disintegration using high pressure homogenization (HPH) and was compared with the classic production by tedious acid hydrolysis (CelluForce NCCTM).

The resultant CNCs have a uniform width and tunable length rod-like shape, a reasonable crystallinity index, comparable negative surface charge, and improved thermal stability compared with those prepared by the conventional method. Consequently, the presented

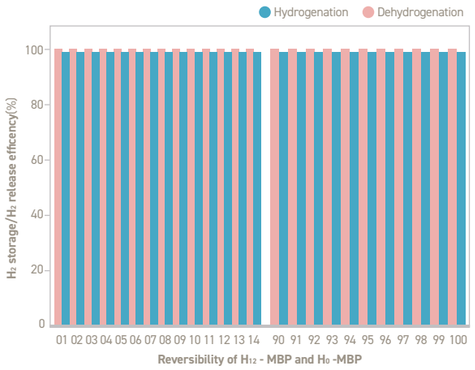


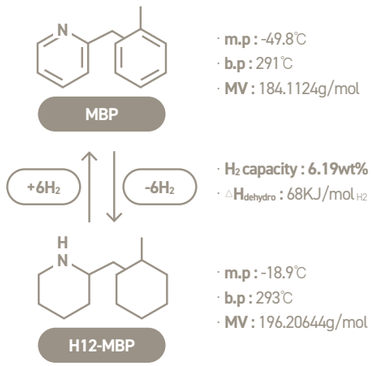
innovative approach makes green and sustainable production of renewable CNC possible for a variety of high value applications.

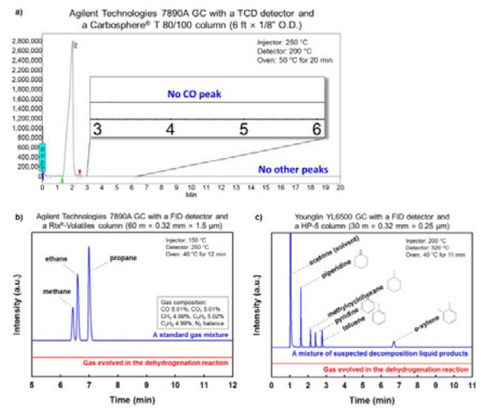
Hydrogen storage system based on innovative LOHC material(MBP)

Liquid organic hydrogen carrier (LOHC) is a promising solution for H_2 storage based on reversible hydrogenation and dehydrogenation. The well-known, typical LOHC materials had serious drawbacks for practical applications.

Our developed new LOHC 2-(n-methylbenzyl)pyridine (MBP) with an H_2 storage density of 6.19 wt% satisfied fairly well the







requirements for chemical reversibility in consecutive cycles, chemical and thermal stability, handling properties. Additionally, H12-MBP was fully dehydrogenated at lower temperatures with faster rates by reducing the dehydrogenation enthalpy owing to the presence of N atom, indicating excellent potential for efficient H2 storage.

Recently, our result was listed in the 2019 National R&D Excellence Top 100 and Best Performance title in the Energy & Environment area.

World's first identification of electron-transfer mechanism on the COF photocatalyst

We directly observed the ultrafast dynamics of phonon-assisted, PDI-to-porphyrin hole transfer through the splitting of excitons in 2D COFs photocatalyst using femto-second optical spectroscopy and NA-MD simulation.

From this result, we suggested a mechanism of phonon-assisted charge transfer which is highly important for future developments in artificial photosynthesis. The generation of electron on the 2D COF photocatalyst by photo-excitation was measured for the first time in the world. These experimental and theoretical fundamental results will be greatly useful for development of the high-performance photocatalyst with highly improved photocatalytic properties. The result was published in Nature Communications, and selected as the article of Editors' Highlights (2019, 10:1873)

C1 Gas & Carbon Convergent Research Center

Head / Lee Yun Jo / yjlee@krict.re.kr

- Membrane separation technologies for recovering greenhouse gases and chemical raw material gases from by-product gases
- Chemical process technologies to produce clean liquid fuels and industrial basic chemicals from C1 gases
- Catalytic processes for utilization of shale gas and small-sized gas resources
- Development of technologies to manufacture petroleum residue-based carbon materials
- Development of technology to manufacture activated carbon to remove fine dust and hazardous gases

Nonoxidative direct conversion of methane on silica-based iron catalysts: effect of catalytic surface

Methane, a principal component of natural gas, is an abundant resource that is mainly utilized as fuel because of its large heat of combustion. However, many methane reserves are located far from the accessible range of industrial and household demands, and transportation is limited owing to liquefaction difficulties. Therefore, catalytic conversion of methane to liquefied hydrocarbons such as paraffins, olefins, and aromatics is required for its efficient utilization. For a stable methane to olefins, aromatics, and hydrogen (MTOAH) reaction without oxidants, we designed Fe-containing silica catalysts through various preparation methods and tested.

The presence of Fe species in SiO_2 mixtures increased the true and apparent densities of the catalysts during the melt-fusing process at 1700℃ . The Fe©CRS catalyst, prepared from fayalite and quartz by the melt-fusing method, maintained highly dispersed Fe carbides at sizes of approximately 7 nm under the reaction conditions (1020℃ and 1 bar) for 50 h. The Fe©CRS catalyst was more selective in producing C2 (ethane, ethylene, and acetylene), C3–C5 olefins, and aromatics than pure CRS and other Fe catalysts. At a steady state, the Fe©CRS surface was most suitable for methane conversion, being 2.3 times more efficient than without a catalytic surface.

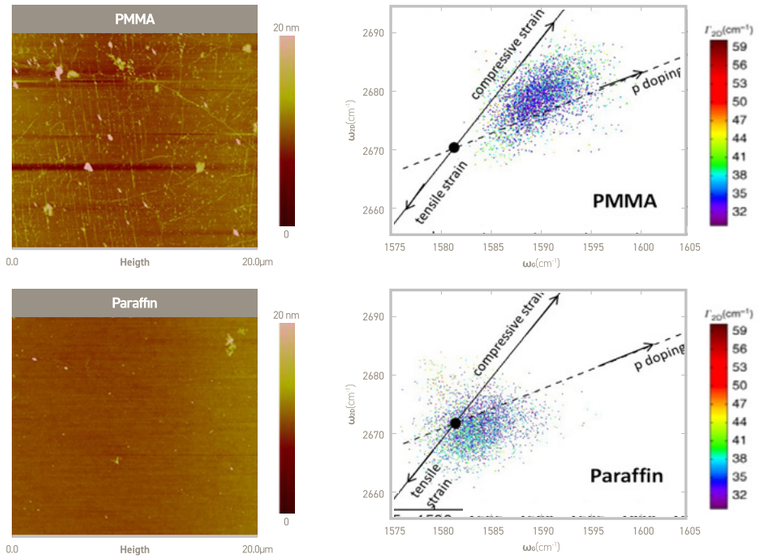
The iron confined cristobalite catalyst prepared through the melt-fusing method is demonstrated to be effective for the nonoxidative direct conversion of methane. The silica confined Fe species (Fe–Si bond) not only selectively promote the methane activation but also inhibit the coke formation on the silica surface by reducing its defect sites.

Characterizations showed that highly dispersed Fe carbide with Fe–Si coordination was formed in the Fe©CRS catalyst, and electronic structure calculations indicated that these confined Fe sites were more favorable for methyl radical formation and a high coke resistance than Fe_3C clusters.

By optimizing reaction parameters, the Fe©RS catalyst exhibited 6.9–5.8% methane conversion and 86.2% C2 selectivity for 100 h with cofeeding of 50% H_2 at 1080℃ .

Smoothing out the wrinkles in graphene

Graphene is an atom-thin material that holds promise for making next- generation electronics. Researchers are exploring



The image at the bottom shows a graphene sheet coated with wax during the substrate-transfer step.
This method drastically reduced wrinkles on the graphene's surface compared to a traditional polymer coating (top).

possibilities for using the exotic material in circuits for flexible electronics and quantum computers, and in a variety of other devices.

But removing the fragile material from the substrate it's grown on and transferring it to a new substrate is particularly challenging. Traditional methods encase the graphene in a polymer that protects against breakage but also introduces defects and particles onto graphene's surface. These interrupt electrical flow and stifle performance.

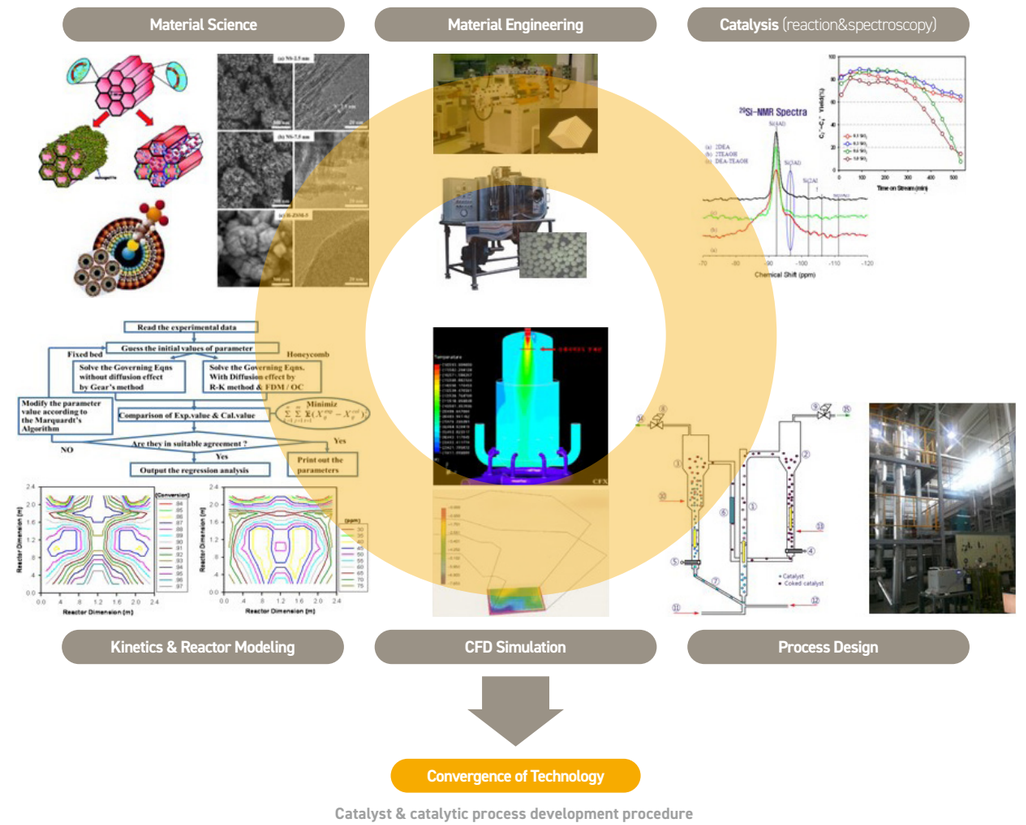
In a paper published in Nature Communications (Nature Communications, 2019, 10, 867), the researchers describe a fabrication technique that applies a wax coating to a graphene sheet and heats it up. Heat causes the wax to expand, which smooths out the graphene to reduce wrinkles. Moreover, the coating can be washed away without leaving behind much residue. In experiments, the researchers' wax-coated graphene performed four times better than graphene made with a traditional polymer-protecting layer. In this paper, the researchers show microscopic images of a small area of the paraffin-coated and PMMA-coated graphene.

Paraffin-coated graphene is almost fully clear of debris, whereas the PMMA-coated graphene looks heavily damaged, like a scratched window (Figure). Next, the researchers aim to further minimize the wrinkles and contaminants left on the graphene and scaling up the system to larger sheets of graphene.

Process Design & Development Research Center

Head / Chae Ho Jeong / hjchae@krict.re.kr

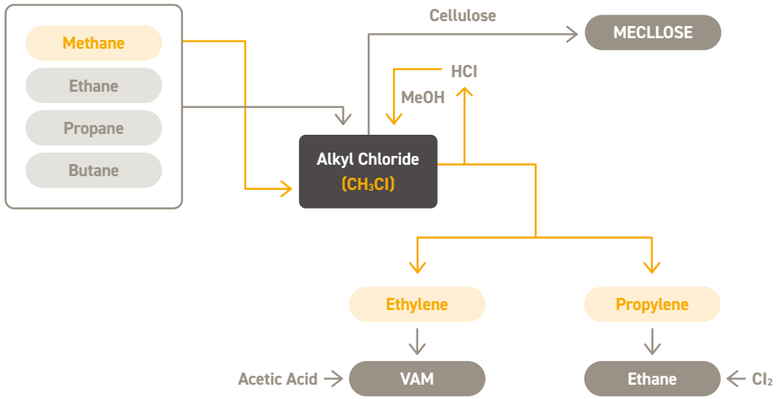
- Development of chemical process technologies for the production of high value-added chemicals from low-carbon resources
- Process system engineering to develop energy conservative olefin production/separation process
- Design & development of catalytic process for sustainable hydrogen supply using ammonia-based hydrogen carrier
- Design & development of environmental catalytic process for the removal of air pollutants in stationary and non-stationary emissions

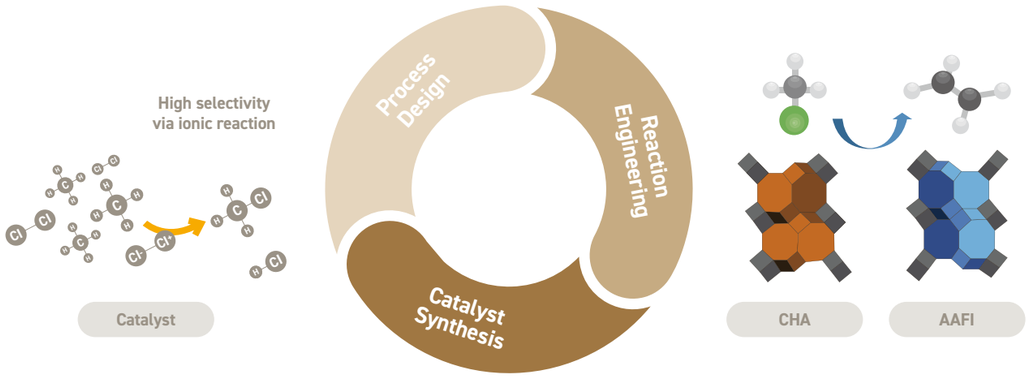


Catalyst & catalytic process development procedure

New catalytic process development for eco-friendly, energy-efficient chemical industry & energy application

In our research center, we have developed new catalytic process technology for eco-friendly, energy-efficient chemical industry &





Platform technology for the production of valuable chemicals based on natural gas

energy *application*. The new catalytic process development can be completed via the optimization and convergence of all steps such as catalyst design/synthesis/shaping, reaction performance test, kinetic/reaction modeling, and process simulation/design (Figure). This is the role & responsibility of our research center.

We have a various lab & bench scale reaction system. In particular, a circulating fluidized bed (CFB) reactor that can continuously regenerate the catalysts for catalytic reactions with severe deactivation is useful for various reaction processes. Using the CFB system, we did develop the high performance micro-spherical catalysts and processes for the production of light olefins from alcohol. Especially, MTO (methanol to olefins) will be promising as an alternative petrochemical process, For MTO reaction, we developed not only the chabazite(CHA)-structured SAPO-34 catalyst with appropriate shape selectivity and acid properties, but also the micro-spherical catalyst with excellent mechanical strength and optimized shape & size for smooth circulation in CFB process.

Moreover, we could obtain the process operation conditions to maintain high yield of light olefins via appropriate monitoring, controlling, and reaction & regeneration methods.

Development of a high performance catalyst & process for methane conversion reaction

The direct conversion of methane (CH_4) to value-added products under mild conditions with much less energy has been a subject of great importance in economical methane utilization. Despite the large number of disparate approaches for direct CH_4 transformation, none of them has been developed into an industrial process. One of the biggest problems is the very low selectivity to desired product with reasonably high CH_4 conversion.

The chlorination of CH_4 is an attractive route to convert CH_4 into more valuable chemicals. The selective formation of methyl chloride (CH_3Cl) is a key process, but it is rather difficult to achieve with high selectivity due to a radical reaction. Catalytic ionic processes can be a solution.

In this work, sulfated tin oxide (STO) was employed in the gas-phase catalytic chlorination of CH_4. The STO catalyst exhibited high selectivity to CH_3Cl (>96%) even at high CH_4 conversion (Figure).

By applying a suite of physicochemical characterizations, it is shown that the strong Lewis acid sites on STO generated by the interaction of Sn and surface sulfate groups are mainly responsible for the highly selective CH_4 conversion. DFT calculations further revealed that STO surface can activate more Cl_2 molecules in a heterolytic manner, leading to better catalytic performances compared to SnO_2 and sulfated zirconia catalysts. Therefore, the highly selective CH_4 chlorination over STO catalyst has the potential to advance the commercialization of the direct methane transformation process. This work was published in the ACS Catalysis in 2019. Kim & Chae et al. ACS Catalysis 2019, 9, 9398-9410.

Development of the cutting-edge technologies for indispensable chemical materials to lead the 4th Industrial Revolution

Advanced Materials Division develops novel smart chemical materials for the IoT device materials, high-stability emerging energy materials, and high-performance materials for the environment and separation processes.

Advanced Materials Division

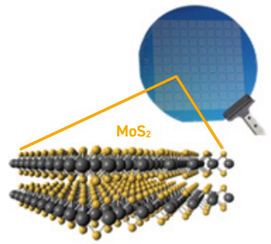
Department of Information & Electronics Materials
Thin Film Materials Research Center
Advanced Functional Polymers Research Center
Interface Materials&Chemical Engineering Research Center

Department of Convergent Energy Materials
Energy Materials Research Center

Thin Film Materials Research Center

Head / Lee Sun Sook / sunsukl@krict.re.kr

- Development of electronic materials and devices for next-generation semiconductors
- Development of new materials and processing techniques for 2D/3D printed electronics and energy devices



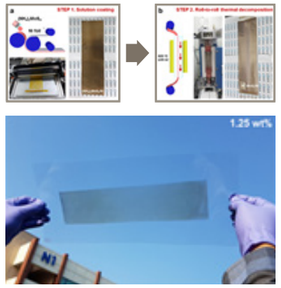
$(NH_4)_2Mos_4$ precursor > wafer-scale MoS_2 sunthesized at low temperature (450℃)

> At low temperature (450℃)

Low-temperature Synthesis

Uniformity optimization

Adv. Mater,
2016, 25, 5025

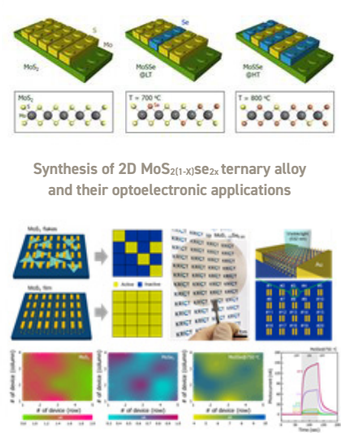


Roll-to-roll production of 50cm-long layer-controlled MoS_2

Low-temperature Synthesis

Uniformity optimization

Adv. Mater,
2018, 30, 1705270



Synthesis of 2D $MoS_{2(1-x)}Se_{2x}$ ternary alloy and their optoelectronic applications

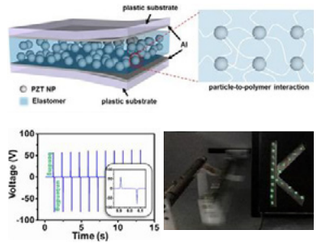
Atomic level customizing in 4 in. van der Waals semiconductors for photodetectors

Adv. Mater,
2019, 1901405

Large-scale production and atomic-level manipulation of molybdenum disulfide: Prerequisites for two-dimensional semiconductor-based industrial applications

Layered two-dimensional transition metal dichalcogenides (TMDs) have opened new prospects for their potential applications owing to their distinctive physical properties that differ from their bulk counterparts. Despite many encouraging properties of two-dimensional TMDs, a central challenge in the realms of industrial applications based on TMDs materials is to connect (i) the direct synthesis of large-scale TMD materials on plastic substrates for applications in flexible nanophotonic devices, (ii) the mass production of TMD materials with a spatial homogeneity associated with compatibility of the conventional semiconductor manufacturing processes and device-to-device performance variation, and (iii) the atomic-level engineering of TMD materials for realization of high-performance nanophotonic devices. Intriguing properties of TMD materials can be manipulated by altering the combination of heteratoms, bonding configuration, and surface/interface states.

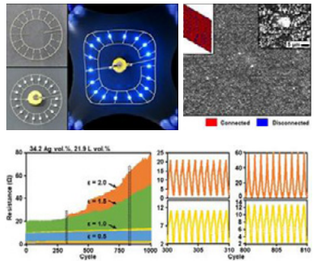
Energy Nanogenerator



High-Performance Piezoelectric Nanogenerators Based on Chemically-Reinforced Composites

Energy Environ. Sci.,
2018, 11, 1425-1430

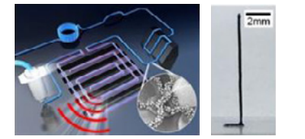
Stretchable Conductor



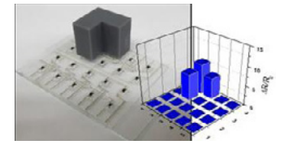
Lubricant-Added Conductive Composite for Direct Writing of a Stretchable Electrode

ACS Appl. Mater. Interfaces
2019, 11, 48459-48465

3D Printable Composites



3D-printable, highly conductive hybrid composites



3D-printable pressure seoncor arrays

RSC Adv.,
2019,9,3993-4002

We primarily aim to resolve the three issues through (i) the solution-based large-area compatible, low-temperature synthetic approach using $(NH_4)_2MoS_4$ single source precursor, (ii) a simple coating of the precursor with subsequent roll-to-roll-based thermal decomposition, and (iii) the synthesis of 2D ternary alloys with customizable bichalcogen atomic ratio *via* atomic-level substitution.

The substitution of heteratoms with relatively different atomic radius and electronegativity is able to create internal strain and bandgap modulation in the alloy system, which dictate diverse physical properties of the 2D alloys with target functionalities. Our synthetic approaches will become the predominant choice of modern nanophotonic applications in the simultaneous pursuit of high photoresponsivity and the realization of photodetector arrays with identical responses from all devices.

Development of composite materials and 3D printing processes technologies for the implementation of untethered IoT devices

In order to realize a hyper-connected society, untethered IoT devices are essential, and for this, it is necessary to develop original materials, high-resolution patterning process, and integrated device application technology.

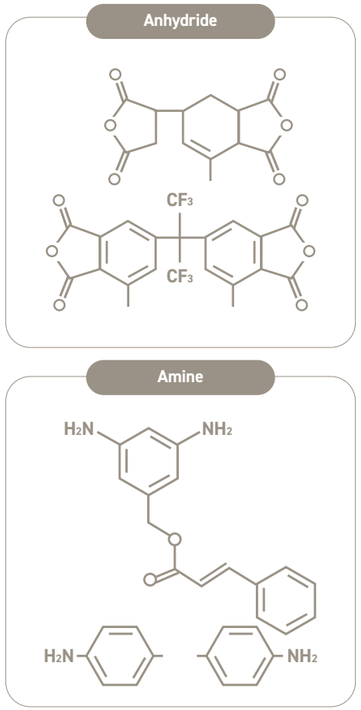
Our PIM (Printable Innovative Materials) group has developed i) energy nanogenerator, ii) stretchable conductor, iii) stretchable substrate, iv) sensor arrays based on the 3D printing process. And in the future, we will use it to implement integrated devices for IoT that can be operated independently by integrating logic operation, wireless communication, self-power, and human body monitoring modules.

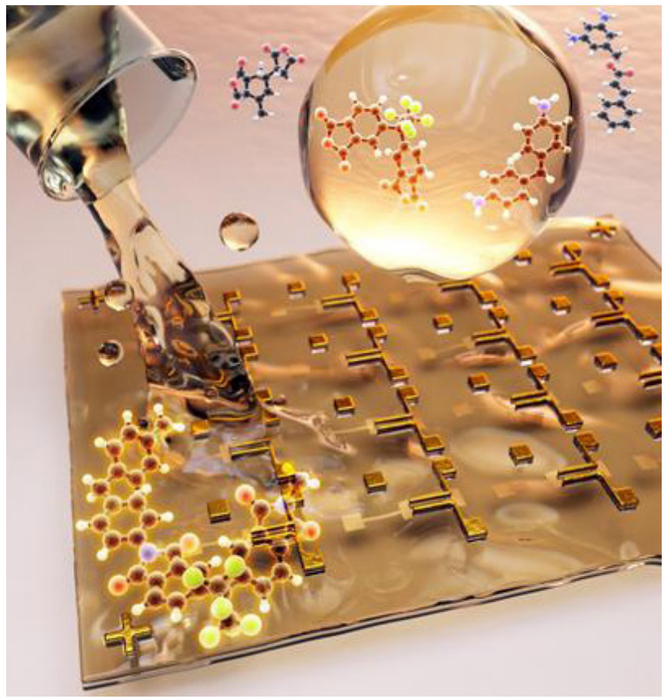
i) Energy nanogenerator : We developed a high-performance piezoelectric nanogenerators (PNGs) device based on a chemically reinforced composite system. By incorporating amine-functionalized lead zirconate titanate (PZT) NPs and a thermoplastic triblock copolymer grafted with maleic anhydride, homogeneous dispersions with well-distributed PZT NPs were obtained without using dispersion enhancers.
ii) Stretchable conductor : Lubricant-added stretchable conductive composite of a polydimethylsiloxane-based elastomer containing silver flakes has reported. The added lubricant minimizes changes in conductivity during stretching and maximizes elastic durability by re-ducing friction.
iii) Stretchable substrate : We developed a RMI process that can adjust the adhesion force, softness, and stretchability of the elastomer. The location and influence of the inhibitor were adjusted by the RMI process in order to modify the mechanical properties of the film.
iv) Sensor arrays : We formulated the 3D-printable composite pastes for the facile fabrication of piezoresistive pressure sensor arrays. It was demonstrated that the pressure sensor array exhibits the sensitivity of 0.31 kPa^{-1} in a linear trend up to a pressure level of 30 kPa.

Advanced Functional Polymers Research Center

Head / Kim Yong Seok / yongskim@krict.re.kr

- Development of smart polymers for IoT applications
- High performance chemical materials for the next-generation energy and display industry
- Lightweight polymers and composites for transportation industry





Low-temperature solution-processed soluble polyimide gate dielectrics for flexible organic transistors

Aromatic polyimides (PIs) have been widely used in organic field-effect transistors (OFETs) as gate dielectric layers due to their promising features such as chemical resistance, thermal stability, and mechanical flexibility. However, high thermal annealing temperatures for imidization reactions limit the use of inexpensive plastic substrates. In this work, aromatic soluble PI is presented as an alternative to low-temperature processable gate dielectric layers. Low-temperature processability of soluble PI is demonstrated by comparing dielectric and electrical properties with conventional PI at various annealing temperatures. The chemical structure effects of aromatic dianhydride and diamine monomers on device performance are then systematically investigated by evaluating four soluble PIs based on 4,4'-(hexafluoroisopropylidene)diphthalic anhydride (6FDA) and 5-(2,5-dioxotetrahydrofuryl)-3-methyl-3-cyclohexene-1,2-dicarboxylic anhydride, in which monomeric precursors containing different backbones, side groups, and linkages. The results indicate that 6FDA-based soluble PI is the most promising gate dielectric candidate due to its high field-effect mobility, near-zero threshold electric-field, and excellent electrical stability.

Finally, room-temperature solution-processed OFETs are successfully integrated with ultrathin flexible substrates and they exhibit no significant electrical performance loss after mechanical flexibility tests. This work presents a step forward to the development of soluble PI gate dielectrics for flexible electronic devices with high device performance. It was published in ACS Applied Materials & Interfaces and was introduced in various media.

Park & Yoo et al. ACS Applied Materials & Interfaces, Low-Temperature Solution-Processed Soluble Polyimide Gate Dielectrics: From Molecular-Level Design to Electrically Stable and Flexible Organic Transistors

Sulfur based poly(phenylene polysulfide) networks: stretchable, healable, and reprocessable polymers for infrared optical applications

The synthesis and characterization of poly-(phenylene polysulfide) networks (PSNs) with controlled average sulfur ranks, from elemental sulfur (ES) and pdiiodobenzene (DIB), are investigated. The PSN films, prepared via simple hot pressing, are found to possess large extensibility up to around 300% and complete recovery of shape and mechanical properties after deformation, which are attributed to the loosely cross-linked network structures mainly consisting of linear poly(phenylene polysulfide) chains.

The covalent polysulfide linkages in the PSNs also exhibit dynamic behaviors under ultraviolet (UV) or thermal treatment, thus, enabling self-healing and reprocessing of the films when scratched and broken, respectively. Combined with the unique mechanical properties of the PSNs, their high refractive index and excellent infrared (IR) transparency contribute to the preparation of stretchable, healable, and reprocessable IR transmitting materials for potential deformable and stretchable optical applications.

This work was published in ACS Macro Letters and was introduced in various media. Lee et al. ACS Macro Letters, 2019, 8, 912-916

Interface Materials & Chemical Engineering Research Center

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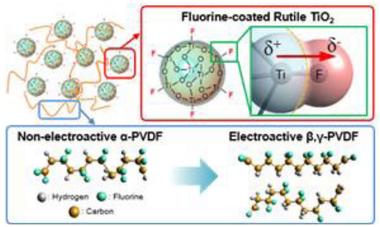
- Development of technologies to manufacture and apply environment-friendly fluorine-based polymers
- Development of technologies to reduce non-CO_2 green-house gas emission and to synthesize alternative materials
- Development of highly efficient photoresponse materials

Fluorinated titania nanoparticle-induced piezoelectric phase transition of PVDF



Piezoelectric phase transition of PVDF

We prepared F-coated rutile titanium dioxide nanoparticles (r-TiO_2 NPs) via simple thermal annealing of titania nanoparticles in poly(vinylidene fluoride) (PVDF), and demonstrated that the F-coated r-TiO_2 NPs doped composite film could efficiently induce the piezoelectric phase transition of the non-electroactive PVDF due to highly electronegative F bonds on the surface of these nanoparticles. In the case of a 2.0 wt.% composite film, 99.20% of the non-electroactive PVDF was transformed into the electroactive phase. Additionally, utilizing the F-coated r-TiO_2 NPs for a piezoelectric device lead to an enhancement of the piezoelectric performance. With the 5.0wt.% composite film, the resulting piezoelectric device exhibited voltage generation of 355 mV, whereas a device with the innate r-TiO_2 NPs exhibited voltage generation of only 137 mV. Furthermore, due to optical inactivity of F-coated r-TiO_2 NPs, the piezoelectric films exhibited high stability under 64 h of photoirradiation at an intensity of 0.1 W/cm^2. These results indicate that the F-coated r-TiO_2 NPs doped composite films could be useful for various applications, including outdoor energy-harvesting, self-powered wearable devices, and portable sensors.

Kang et al. 2019, Langmuir, Volume 35, pp. 8816-8822

Development of PVDF manufacturing process

The technology transferred to Chemtros is a process technology for manufacturing PVDF. PVDF is widely used in a variety of industrial fields such as cathode binder for Li-ion battery, solar cell film, and water intake separator membrane, because of its excellent weather resistance and stain resistance. transfer the technology of PVDF manufacturing process.

We developed i) manufacturing technology to produce VDF monomer through pyrolysis; ii) purification of a raw material and iii) polymerization technology that makes VDF monomer to PVDF. In particular, the technology allows manufacture of VDF with a high purity of 98.5% by preventing most of the impurities in the pyrolysis process of producing VDF from the raw material.
We announced on March 13, 2019 that it has signed a contract to transfer the technology of PVDF manufacturing process.

KRICT 15th president Kim Sung-Soo(right) and Chemtros CEO Lee Dong-Hoon(left) after signing an agreement on transfer of PVDF manufacturing process

Energy Materials Research Center

Head / Suk Jung Don / jdsuk@krict.re.kr

- Development of core materials for highly efficient, stable inorganic/ organic hybrid solar cells and technologies to improve stability
- Development of core materials for highly efficient organic solar cells and technologies to improve stability
- Development of core materials for next-generation secondary lithium batteries and technology to improve battery capacity and stability

High performance lithium-oxygen battery electrolyte derived from optimum combination of solvent and lithium salt

Due to the ever-growing demand for the high efficiency energy storage devices, developing post Li-ion batteries with high performance are needed urgently. In this regard, diverse energy storage systems including lithium-oxygen, lithium-carbon dioxide, lithium-sulfur and solid-state lithium batteries have been intensively studied as candidates for the next-generation Li-ion batteries. Specifically, lithium-oxygen battery has been regarded as the most promising high energy density battery because its new electrochemical reaction mechanism results in the extremely high energy density as ~3500 Wh kg^{-1}. To fabricate a sustainable lithium-oxygen battery, it is crucial to identify an optimum electrolyte. Herein, it is found that tetramethylene sulfone (TMS) and lithium nitrate ($LiNO_3$) form the optimum electrolyte, which greatly reduces the overpotential at charge, exhibits superior oxygen efficiency, and allows stable cycling for 100 cycles. Linear sweep voltammetry (LSV) and differential electrochemical mass spectrometry (DEMS) analyses reveal that neat TMS is stable to oxidative decomposition and exhibit good compatibility with a lithium metal. But, when TMS is combined with typical lithium salts, its performance is far from satisfactory. However, the TMS electrolyte containing $LiNO_3$ exhibits a very low overpotential, which minimizes the side reactions and shows high oxygen efficiency.

LSV-DEMS study confirms that the TMS-$LiNO_3$ electrolyte efficiently produces NO_2^-, which initiates a redox shuttle reaction. Interestingly, this NO_2^-/NO_2 redox reaction derived from the $LiNO_3$ salt is not very effective in solvents other than TMS. Compared with other common Li-O_2 solvents, TMS seems optimum solvent for the efficient use of $LiNO_3$ salt. Good compatibility with lithium metal, high dielectric constant, and low donicity of TMS are considered to be highly favorable to an efficient NO_2^-/NO_2 redox reaction, which results in a high-performance Li-O_2 battery. (Adv. Sci. 2017, 4, 1700235)

01

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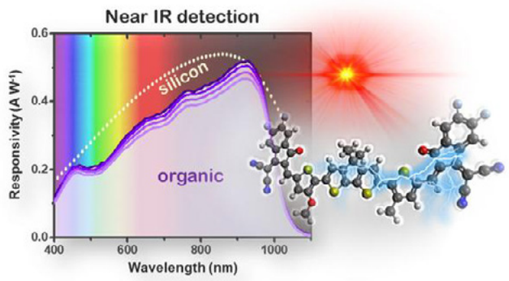
01 A redox shuttle reaction of NO_2^-/NO_2 molecules with a toroid shape lithium peroxide in the lithium oxygen battery for a possible application in electric vehicles.

02 Macroporous carbon nonofiber decorated with platinum nanorodes as free standing cathodes for Li-O_2 battery

Side chain engineering of non-fullerene acceptors for near-infrared organic photodetectors and photovoltaics

Narrow bandgap n-type molecular semiconductors are relevant as key materials components for the fabrication near-infrared organic solar cells (OSCs) and organic photodetectors (OPDs). We thus designed nearly isostructural non-fullerene electron acceptors, except for the choice of solubilizing units, which absorb from 600 nm to 1100 nm. Specific molecules include CTIC-4F, CO1-4F and COTIC-4F, whose optical bandgaps are 1.3 eV, 1.2 eV and 1.1 eV, respectively. Modulation of intramolecular charge transfer characteristics was achieved by replacing alkoxy



groups with alkyl groups on thiophene spacers that connect an electron rich cyclopentadithiophene core to peripheral electron poor fragments. OSCs incorporating CTIC-4F and CO1-4F with PTB7-Th achieve power conversion efficiencies of over 10% with short-circuit current densities as high as ~25 $mA{\cdot}cm^{-2}$. More importantly, efficient OPDs were demonstrated with responsivities of 0.51 A W^{-1} at 830 nm and 0.52 A W^{-1} at 920 nm for CTIC-4F and CO1-4F, respectively. Notably, CO1-4F is one of the few electron acceptor materials featuring narrow bandgap (<1.3 eV) and high photoresponse in the NIR portion of the spectrum. The side-chain design strategy is likely to prove general and may be applied to fine tune the properties of other NFA conjugated frameworks. These findings high light outstanding opportunities to tune further molecular design so that OPDs may ultimately compete with their silicon counterparts. This work was published in ACS Energy Letter in 2019.

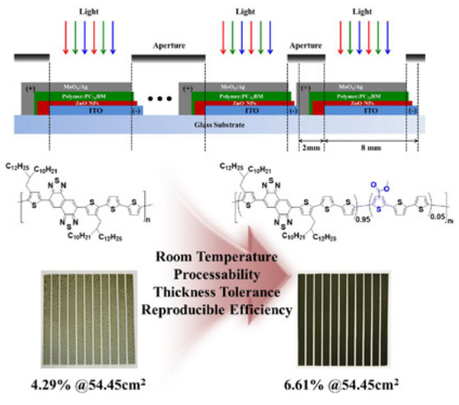
Freely shapable and 3D porous carbon nanotube foam using rapid solvent evaporation method for flexible thermoelectric power generator

A rapid solvent evaporation method based on the triple point of a processing solvent is presented to prepare carbon nanotube (CNT) foam with a porous structure for thermoelectric (TE) power generators. The rapid solvent evaporation process allows the preparation of CNT foam with various sizes and shapes. The obtained highly porous CNT foam with porosity exceeding 90% exhibits a low thermal conductivity of 0.17 $W{\cdot}m^{-1}{\cdot}K^{-1}$ with increased phonon scattering, which is 100 times lower than that of a CNT film with a densely packed network. The aforementioned structural and thermal properties of the CNT foam are advantageous to develop a sufficient temperature gradient between the hot and cold parts to enhance TE output characteristics. To improve the electrical conductivity and Seebeck coefficient further, p- and n-molecular dopants are easily introduced into the CNT foam, and the optimized condition is investigated based on the TE properties. Finally, optimized p- and n-doped CNT foams are used to fabricate a vertical and flexible TE power generator with a combination of series and parallel mixed circuits.

NIR organic photodetector

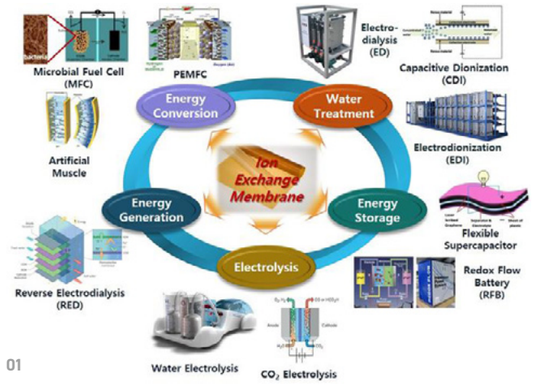
The maximum output power and output power per weight of the TE generator reach 1.5 μW and 82 μW g^{-1}, respectively, at a temperature difference of 13.9 K. Our approach demonstrates that the use of bulk and porous CNT foam allows the fabrication of a vertical and flexible TE generator with various shapes with high TE output power. This work was published in Advanced Energy Materials in 2019.

Room temperature processed highly efficient large-area polymer solar cells



Large-Area PSCs

The room temperature (RT) processability of the photoactive layers in polymer solar cells (PSCs) from halogen-free solvent along with their highly reproducible power conversion efficiencies (PCEs) and intrinsic thickness tolerance are extremely desirable for the large-area roll-to-roll (R2R) production. However, most of the photoactive materials in PSCs require elevated processing temperatures due to their strong aggregation, which are unfavorable for the industrial R2R manufacturing of PSCs. These limiting factors for the commercialization of PSCs are alleviated by synthesizing random terpolymers with components of (2-decyltetradecyl)thiophen-2-yl)naphtho[1,2-c:5,6-c′]bis[1,2,5]thiadiazole and bithiophene substituted with methyl thiophene-3-carboxylate (MTC). In contrast to the temperature-dependent PNTz4T polymer, the resulting random terpolymers (PNTz4T-MTC) show better solubility, slightly reduced crystallinity and aggregation, and weaker intermolecular interaction, thus enabling PNTz4T-MTC to be processed at RT from a halogen-free solvent. Particularly, the PNTz4T-5MTC-based photoactive layer exhibits an excellent PCE of 9.66%, which is among the highest reported PCEs for RT and ecofriendly halogen-free solvent processed fullerene-based PSCs, and a thickness tolerance with a PCE exceeding 8% from 100 to 520 nm. Finally, large-area modules fabricated with the PNTz4T and PNTz4T-5MTC polymer have shown 4.29% and 6.61% PCE respectively, with an area as high as 54.45 cm^2 in air. Our finding provides insight into random terpolymers and provides a guideline for those involved in the further design of highly efficient and stable polymer donors processable at RT.



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01 Ion exchange membrane technology applications

02 Commercial anion conducting binder based on KRICT AEM technology

Design and development of ion exchange membranes and membrane-electrode assembly (MEA) for electrochemical energy conversion devices

Ion-exchange membranes are semi-permeable membranes that transports certain dissolved ions, while blocking other ions or neutral molecules. Important examples of ion-exchange membranes include the proton-exchange membranes (PEMs), that transport H^+ cations, and the anion exchange membranes (AEMs) to transport OH^- anions. We have investigated various hydrocarbon-based PEMs and AEMs, which are PBI-based and poly(*p*-phenylene)-based ionomers, with high electrochemical performance, chemical stability, and low gas permeability for fuel cell, vanadium radox flow battery, and water electrolysis applications. The electrochemical energy conversion devices using AEMs, which could efficiently convert chemical energy to electrical energy or electrical energy to chemical energy, have been considered as attractive technology with the potential advantages of utilizing low-cost catalysts based on non-precious metals and less expensive metal hardware as well as superior conversion reactions at electrodes under alkaline environment conditions. Typically, among various components, which have an effect on the performance and durability of device, solid electrolyte used as anion conducting membranes (AEMs) and anion conducting binders (AEBs) are regarded as core components to play a major role. Recently, although several kind of AEMs and AEBs, such as Fumasep®, AemionTM, Sustainion®, and Xion®, are released for commercial use, there are still no reliable ACMs to be utilized under harsh operating conditions. Therefore, development of ACMs with outstanding performance and chemical stability is still remained as a major concern.

Recently, we developed anion conducting ionomer material (QPC-TMA) consisting of ether-free backbone incorporating trimethylammonium-terminated flexible alkyl side chain for fuel cell and water electrolysis. Moreover, in spite of moderate IEC value as low as 2.0 meq g^{-1}, state-of-the-art performances of water electrolysis cell as well as excellent performances of fuel cell, where QPC-TMA is introduced as membrane and electrode binder, are released. The performance of QPC-TMA-based water electrolysis (3.5 A cm^{-2} at 1.9 V) is higher than that of commercial PEM water electolysis (2.2 A cm^{-2} at 1.9 V). We contracted technology transfer contract with SDB corporation in 2019, and SDB corporation began commercial sale of the AEMs as electrode binder (AnioMer CB-X) in 2020.

Development of drug discovery and biotechnologies to lead better life

Therapeutics & Biotechnology Division secures new drug pipelines for healthy life and develops technologies to respond infectious diseases in society. The division also establishes new drug and diagnosis infrastructure for innovative medical services and seeks eco-friendly new materials to protect environment.

Therapeutics & Biotechnology Division

Department of Drug Discovery
Data Convergence Drug Research Center
Drug Discovery Platform Research Center

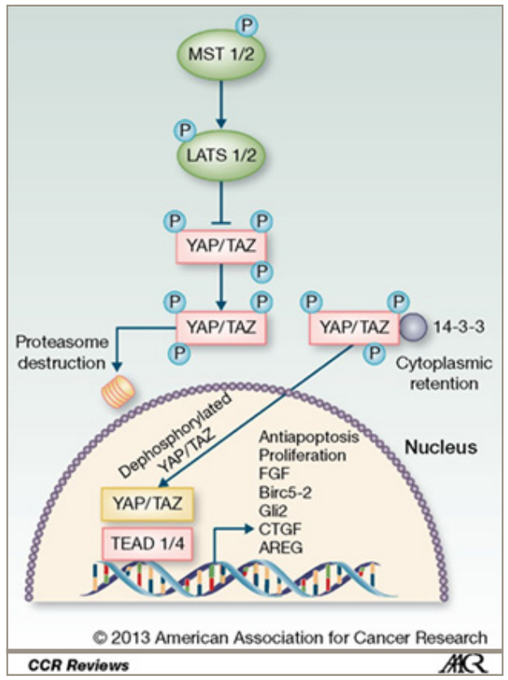
Department of Infectious Diseases Research
Infectious Diseases Therapeutic Research Center

Eco-Friendly New Materials Research Center

Data Convergence Drug Research Center

Head / Lim Hwan Jung / indium@krict.re.kr

- Development of deep neural network algorithms for predicting activity, toxicity, and druglikeness based on molecular structures
- Development of novel drug targets and validation solutions through drug-target interaction(DTI) big-data analysis
- Development of new drug candidates for existing medical unmet needs in cancers and immune related diseases
- Development of new modalities for drug discovery using the chemically induced proximity of proteins such as proteolysis targeting chimera(PROTAC) and molecular glue



Overview of the Hippo pathway (Clin. Cancer. Res. 2014, 20, 557.)

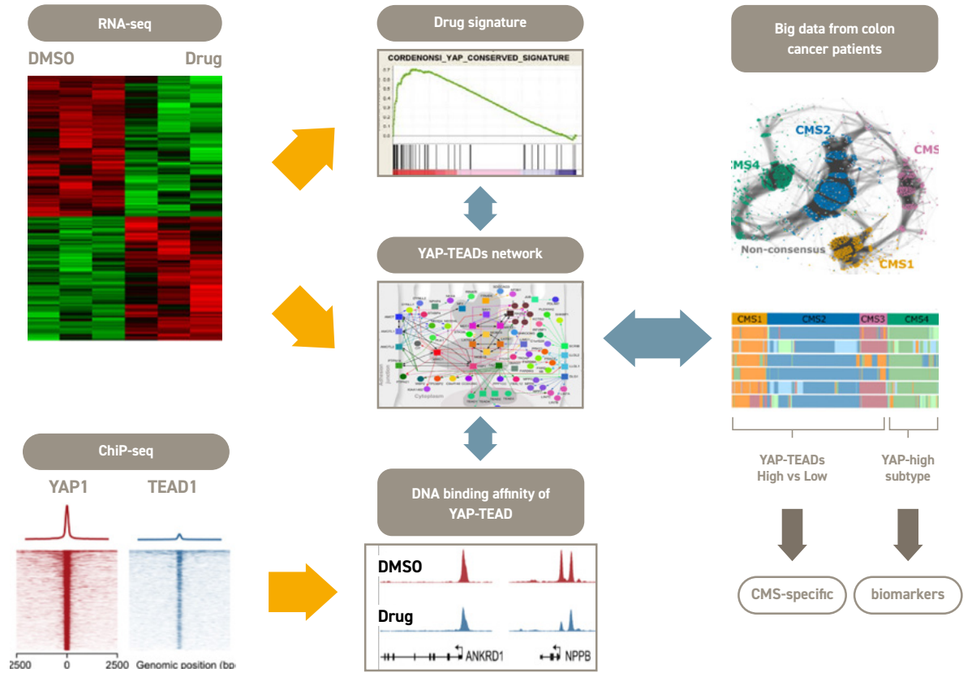
Development of YAP-TEAD inhibitors for a novel anti-cancer treatment

The Hippo pathway, highly conserved signaling pathway across higher-order vertebrates, is known as a key regulator of organ size and tissue homeostasis. The pathway is mainly consisted of kinase (MST1/2 & LATS1/2) and transcriptional modules (YAP/TAZ and TEAD1-4). Deregulation of the Hippo pathway would be related to oncogenesis and resistance of current anti-cancer chemo-therapies through various mechanisms. Moreover, its transcriptional coactivators, Yes-associated protein (YAP) and PDZ-binding motif (TAZ), are highly amplified in many human cancers. Multiple groups are under investigations in order to develop a novel anti-cancer drug that can restore the Hippo pathway's tumor suppression ability. Among druggable biological targets in the pathway, the binding of YAP/TAZ with TEA DNA-binding proteins (TEADs) is known as one of the promising anti-cancer targets. Initiated from biological studies related to the pathway and the molecular target by Dr. Heicheul Chung's group in Gangnam Severance hospital, a drug-like hit was identified by professor Kyoung Tai No in Bioinformatics and Molecular Design Research Center (BMDRC) in Yonsei university. We have been developing small-molecular inhibitors for selectively and efficiently inhibit YAP/TAZ-TEAD interaction.

The key findings and major achievements in our journey are :

1. Drug-like hits were identified by fragment molecular orbital (FMO) calculations and docking studies
2. Developed small-molecular lead compounds showed solid structure-activity-relationship (SAR) and promising anti-cancer activities in animal models with almost no side-effects (KRICT, Dr. Hwan Jung Lim and Dr. Seong Jun Park)
3. Selective binding of an inhibitor with TEAD protein was confirmed through various biochemical analyses such as SPR, ITC, and STD-NMR (Daegu-Gyeongbuk Medical Innovation Foundation, Dr. Eunmi Hong), and X-ray structure of hTEAD1 were obtained (Korea Research Institute of Bioscience and Biotechnology, Dr. Bon-su Koo).
4. The structures of major metabolites of a lead compound were analyzed by LC/MS/MS, and the proposed structures were confirmed by independent syntheses (KRICT, Dr. Sunjoo Ahn)
5. Selective TEAD-dependent transcriptional modulation through lead compounds was confirmed by RNA sequencing (KRICT, Dr. Byung Ho Lim). Using these omics data, searching potential biomarkers of colon cancer patients for YAP/TAZ-TEAD inhibitors is ongoing.

In 2019, the results were licensed-out to Samjin Pharm. (CEO, Mr. Hong Soon Chang) and also funded by National Research Foundation in Korea (NRF-2019M3E5D5066177) for further development. Currently, the development of an orally available preclinical candidate is underway.

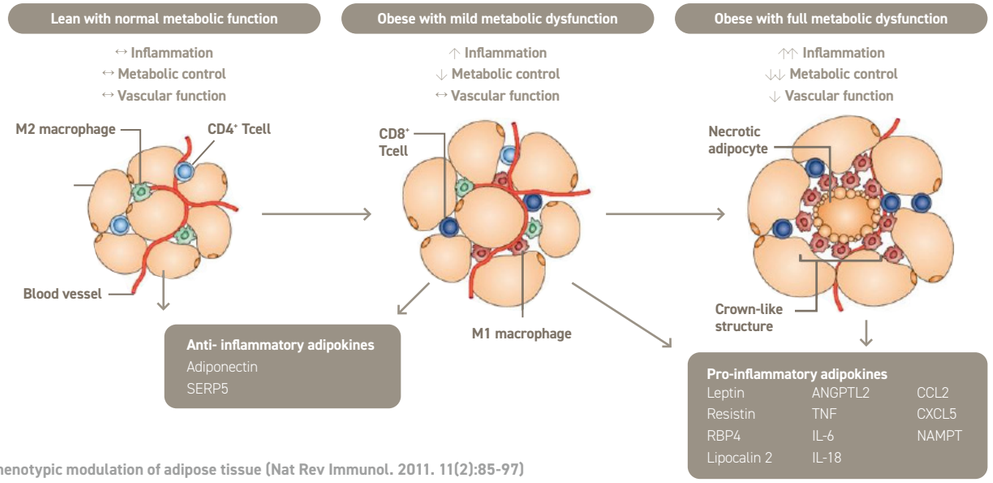


Multi-omics data analyses for searching potential biomarkers of CRC patients

Drug Discovery Platform Research Center

Head / Kim Ki Young / kykim@krict.re.kr

- Development of drug discovery platform technologies based on 3D cells/organoids and zebrafishes
- Development on treatment of customized rare diseases connecting clinical medicine
- Establishment of drug screening system using animals with various diseases
- Development of technologies to increase biological efficiency of innovative target candidate materials



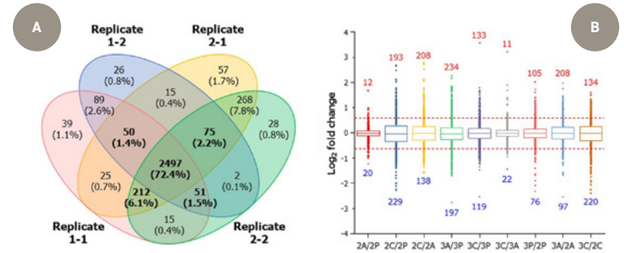
Phenotypic modulation of adipose tissue (Nat Rev Immunol. 2011. 11(2):85-97)

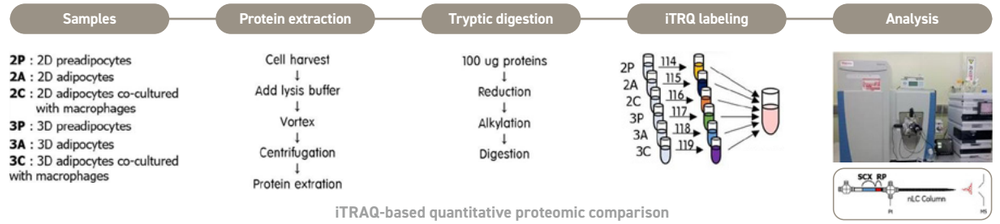
Development of in vitro three-dimensional co-culture system for metabolic syndrome therapeutic agents

There are many obstacles to overcome in the development of new drugs for metabolic diseases, including efficacy and toxicity problems in later stages of drug development. To overcome these problems and predict efficacy and toxicity in early stages, we constructed a new model of insulin resistance in terms of communication between 3T3-L1 adipocytes and RAW264.7 macrophages by three-dimensional (3D) culture.

Metabolic syndrome is a combination of mutually related risk factors for diabetes. These factors are typically abdominal obesity and insulin resistance. Many studies have reported that abdominal obesity is the form of obesity most strongly associated with metabolic syndrome. However, many other researchers have placed more priority on insulin resistance rather than obesity in pathogenesis. Insulin resistance generally increases with increasing body fat mass, consequently leading to abdominal obesity. Obesity contributes to hypertension, high-serum cholesterol, less high-density lipoprotein cholesterol, and hyperglycaemia. It is widely considered that a state of chronic low-grade inflammation contributes to insulin resistance. White adipose tissue (WAT) is the anatomical term for loose connective tissue composed of adipocytes. WAT contains several cell types such as fibroblasts, macrophages and endothelial cells in addition to adipocytes. Adipose tissue is associated with type 2 diabetes mellitus, obesity, hypertension, and cardiovascular disease. The traditional role of adipose tissue is energy storage and release of fatty acids when energy is required. WAT is now recognized as an endocrine organ that secretes hormones and cytokines. It is associated with energy balance, immune response and

3D scaffold fabrication





iTRAQ-based quantitative proteomic comparison

cardiovascular disease and is involved in a range of functions beyond simple fat storage. The cell types involved in inflammatory response in obesity are not yet fully delineated. Recently, attention has been paid to adipose tissue macrophages as a mediator of inflammatory responses in adipose tissue. Inflammatory cytokines are associated with increased numbers of adipose tissue macrophages in obese and diabetic patients. An increase in macrophage recruitment related to fat mass has been accepted as scientific dogma. Macrophages generate inflammatory cytokines and induce nitric oxide synthesis, which may impair insulin-stimulated phosphoinositide 3-kinase (PI3K)/protein kinase B (AKT) activation and, directly or indirectly, play a role in obesity-related insulin resistance in adipose tissue.

Thus, in this study, results focused on the functional resemblance between 3D co-culture of adipocytes and macrophages and adipose tissue in diabetic mice. The 3D mono-culture preadipocytes showed good cell viability and induced cell differentiation to adipocytes, without cell confluence or cell-cell contact and interaction. The 3D co-cultured preadipocytes with RAW264.7 macrophages induced greater insulin resistance than two-dimensional and 3D mono-cultured adipocytes. Additionally, we demonstrated that 3D co-culture model had functional metabolic similarity to adipose tissue in diabetic mice. We utilized this 3D co-culture system to screen PPARɣ antagonists that might have potential as therapeutic agents for diabetes as demonstrated by an in vivo assay.

Furthermore, we performed global quantitative proteomic profiling of three 3D-cultured 3T3-L1 cells (preadipocytes, adipocytes and co-cultured adipocytes with macrophages) and their 2D-cultured counterparts using 2D-nanoLC-ESI-MS/MS with iTRAQ labelling. A total of 2,885 shared proteins from six types of adipose cells were identified and quantified in four replicates. Among them, 48 proteins involved in carbohydrate metabolism (e.g., PDHα, MDH1/2, FH) and the mitochondrial fatty acid beta oxidation pathway (e.g., VLCAD, ACADM, ECHDC1, ALDH6A1) were relatively up-regulated in the 3D co-culture model compared to those in 2D and 3D mono-cultured cells. Conversely, 12 proteins implicated in cellular component organisation (e.g., ANXA1, ANXA2) and the cell cycle (e.g., MCM family proteins) were down-regulated. These quantitative assessments showed that the 3D co-culture system of adipocytes and macrophages led to the development of insulin resistance, thereby providing a promising in vitro obesity model that is more equivalent to the in vivo conditions with respect to the mechanisms underpinning metabolic syndromes and the effect of new medical treatments for metabolic disorders. Therefore, this in vitro 3D co-culture system could serve as a next-generation platform to accelerate the development of therapeutics for metabolic diseases. This study was jointly studied by KRICT and KRISS and published in the "Diabetes, Obesity and Metabolism" and "Scientific Reports" in 2019.

Infectious Diseases Therapeutic Research Center

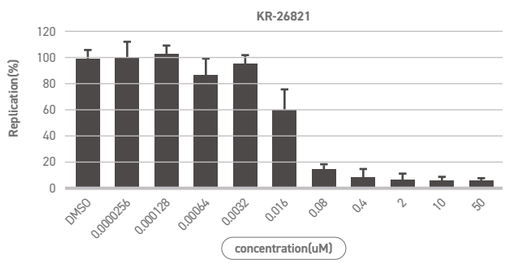
Head / Yun Chang Soo / csyun@krict.re.kr

- Development of new antivirals based on small-molecules against highly pathogenic viruses
- Drug target discovery for the development of first-in-class innovative antivirals
- Discovery of hit-, lead-, and candidate-compounds according to the development stage of new antivirals
- Development of antibiotics for multi-drug resistant bacterial infections
- Development of the small-molecule antibiotic pipelines for Gram-negative pathogens
- Novel target discovery and validation for developing new antibiotics against superbugs

Anti-rhinoviral drug candidate

The human rhinovirus (hRV), a member of the Enterovirus genus in the Picornaviradae family, is a persistent threat to public health. It is known to cause ~60% of upper respiratory tract symptoms such as the common cold. Moreover, recent studies conducted with improved detection methods suggest that hRV infections can aggravate inflammatory illnesses such as asthma, chronic obstructive pulmonary disease (COPD), and otitis media. Analyses of viral specimens from pediatric patients with asthma exacerbations identified a high prevalence of hRV.

More than 160 hRV serotypes have been identified and grouped into three species, hRV-A, B, and C, that are each divided into various subspecies. Like other picornaviruses, hRV has a positive-sense, single-stranded RNA genome packaged in an icosahedral capsid composed of four viral proteins (VP1 to VP4). Several drug candidates have been developed to combat hRV infections. However, because of insufficient efficacies or side effects observed during their clinical studies, none of these substances has been developed into drugs approved for the treatment of these viral infections. Therefore, a new small-molecule inhibitor that shows broad-spectrum inhibition of the replication of these enteroviruses is highly desired. KRICT developed a series of highly potent and broad-spectrum inhibitors of hRV replication. A representative analog, KR-26821, is a low-molecular compound and shows ~nM concentrations activity in vitro antiviral tests with >1,000 selectivities (CC50/EC50). To identify the viral target, EV71 replicon test was run and 23 nM of EC50 was obtained which suggests that KR-26821 is not an inhibitor of capsid binding. Given the broad-spectrum anti-rhinovirus activity, this class of molecules has the potential to be used for prophylaxis and treatment of rhinovirus induced exacerbations of COPD and asthma.

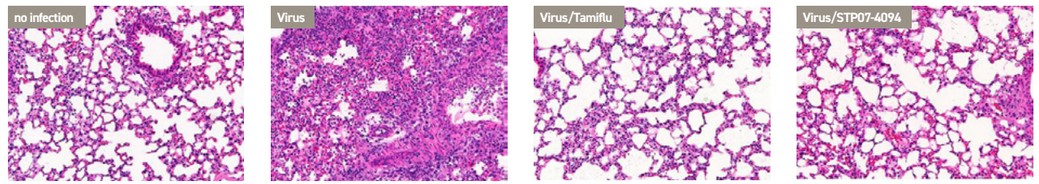


EV71 replicon test of KR-26821

Anti-influenza viral drug candidate

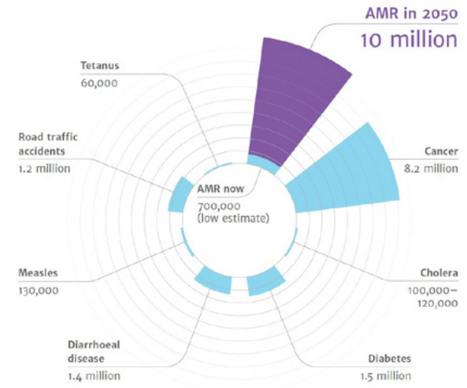
Influenza virus belonging to the family of Orthomyxoviridae is one of human respiratory pathogens that causes seasonal or zoonotic epidemics and unpredictable global pandemics. Its genome is composed of eight single-stranded negative-strand RNA segments.

Currently, there are three classes of antivirals that tharget influenza viral proteins NA, M2 and PA, approved by the U.S. Food and Drug Administration. Although vaccines and antiviral drugs are available to prevent or treat influenza viral infection, it still causes 300,000 to 500,000 deaths worldwide every year. Most of all, the emergency of drug-resistant viruses harboring mutations in the target proteins has been a major concern. Through a collaboration with ST Pharm Co Ltd., a company providing manufacturing service for active pharmaceutical ingredient (API), KRICT developed a nucleoside analogue, STP07-4094, that inhibits viral RNA-dependent RNA polymerase activity. As a pro-drug, its active form has been evaluated to have antiviral activity against influenza A (including H1N1 and H3N2) as well as B viruses with 50% effective concentrations between 1 to 10 μM. Using a mouse model susceptible to influenza A virus, we proved that STP07-4094 alleviates viral infection-mediated body weight decreases as well as lung inflammation, resulting in increases in mouse survival rates.



Lung histopathology. Normalization of viral infection-mediated lung inflammation by STP07-4094.

The compound is on the preclinical studies to investigate its pharmacokinetic properties or to analyze its mebatolites. It is expected that like favipiravir, an influenza viral RdRp inhibitor, STP07-4094 could be applicable to treat Ebola or coronaviral infection.

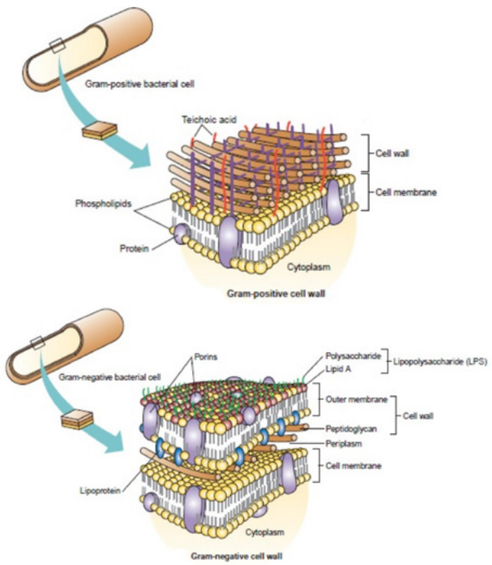


Development of drugs for multidrug-resistant Gram-negative bacterial infections

Global antibiotic resistance has reached critically urgent levels, as expected in the AMR (antimicrobial resistance) reports*, warning that it could cause 10 million annual deaths by 2050 in the absence of actions to tackle AMR.

WHO also drew up a list of antibiotic–resistant "priority pathogens" in 2017 - a catalogue of 12 families of bacteria with the highest priority needs for new antibiotics. The list particularly highlights multidrug-resistant Gram-negative bacterial pathogens such as Enterobacteriaceae, Acinetobacter baumannii, and Pseudomonas aeruginosa, posing the greatest threat to human health.

Although there is an urgent medical need for novel Gram-negative agents, a protective barrier, the outer membrane has been a significant challenge to discover a new antibacterial drug. In addition to promiscuous efflux pumps, the additional cell membrane of Gram-negative bacteria incorporating lipopolysaccharide (LPS) prevents small molecules from penetrating the cellular envelope (Figure).
In accordance with the danger of AMR especially for Gram-negative pathogens and the difficulties to discover a new agents to treat them, now we target to develop efficient antibiotics based on small molecules against Gram-negative bacterial infections.



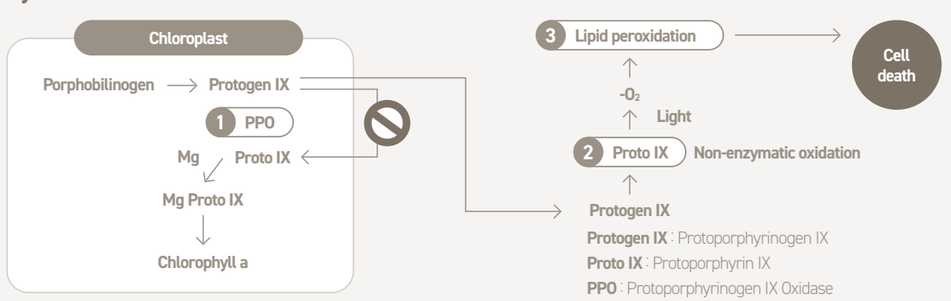
Gram-positive (left) and
Gram-negative (right) cell wall structures

* J. O'Neill, Tackling Drug-Resistant Infections globally: final report and recommendations. The Review on Antimitrobial Resistance. 2016.

Eco-Friendly New Materials Research Center

Head / Lee Ill Young / iylee@krict.re.kr

- Development of new herbicides to control resistant weeds
- Development of new insecticides with MoA
- Development of bio- and synthetic fungicides
- Establishment of pathological testing technologies for development of resistant cultivars and implementation of relevant support projects
- Development of new materials to replace environmentally hazardous materials



Terrad'or mode of action (PPO-inhibitor)

Launching of Terrad'or Gold and Terrad'or ME in Korea and Sri Lanka (2019)

Terrad'or(ISO name : tiafencil) is a noble, post-emergence, contact, non-selective herbicide. It was discovered and developed by a joint research program of KRICT and FarmHannong. The technology including new active ingredient and metabolite analysis at the KRICT was transferred to FarmHannong in 2015.

It is one of the most powerful PPO(Protoporphyinogen IX oxidase)-inhibiting herbicide to control both broad-leaf and grass weeds simultaneously with excellent toxicological profiles. Terrad'or inhibits chlorophyll formation in weeds and generates active oxygen, which destroys cells and shows quick herbicidal effects with a necrotic symptom, 2~3 days after application. Terrad'or drives burndown activity faster than Glyphosate and Glufosinate and provides broad spectrum by variable usage rate(25~250 g ai/ha). Above all, it features the excellent control against Glyphosate-resistant weeds such as Amaranthus spp, ragweed(Ambrosia spp), hophombeam copperleaf(Acalyphaostr yifolia), dayflower(Commelina communis), etc.

In recognition of the technological excellence, the discovery of the "tiafenacil" was selected as one of the 100 Best National R&D Excellence in 2016.

The Terrad'or Plus and Gold were successfully launched in domestic market in 2018 and 2019, respectively. On April 2019,

Terrad'or global field test(vs. Glyphosate)

Terrad'or Plus, Gold, and Me based on the tiafenacil

Terrad'or has taken its first step into the overseas market; Terrad'or ME was launched in Colombo, Sri Lanka, with local partner "Lankem" that is a leading agro-company in Sri Lanka. In addition, the registration dossier of Terrad'or was already submitted to the major target countries such as US, Canada, South America(Brazil and Argentina), and Australia to tap into the world's non-selective herbicide market.

Development of future convergent technologies to create new chemical industries and increase added value of chemical industries

Division of Specialty & Bio-based Chemicals Technology develops sustainable environment-friendly material technologies for future vehicles as well as novel-function high-value-added fine chemical material technologies.

Division of Specialty & Bio-based Chemicals Technology

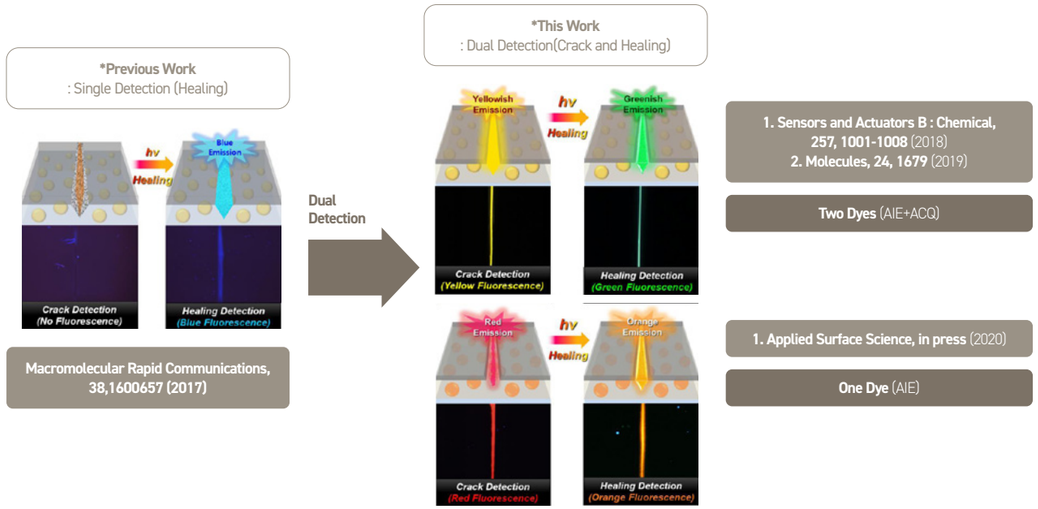
Department of Specialty Chemicals
Research Center for Advanced Specialty Chemicals

Department of Bio-based Chemicals
Research Center for Bio-based Chemistry

Research Center for Advanced Specialty Chemicals

Director / SEO BONG KUK / bksea@krict.re.kr

- Research on smart coatings technology
- Research on stimuli-responsive polymer material chameleon technology
- Research on advanced adhesives technology
- Technical support for analysis and verification of pilot production

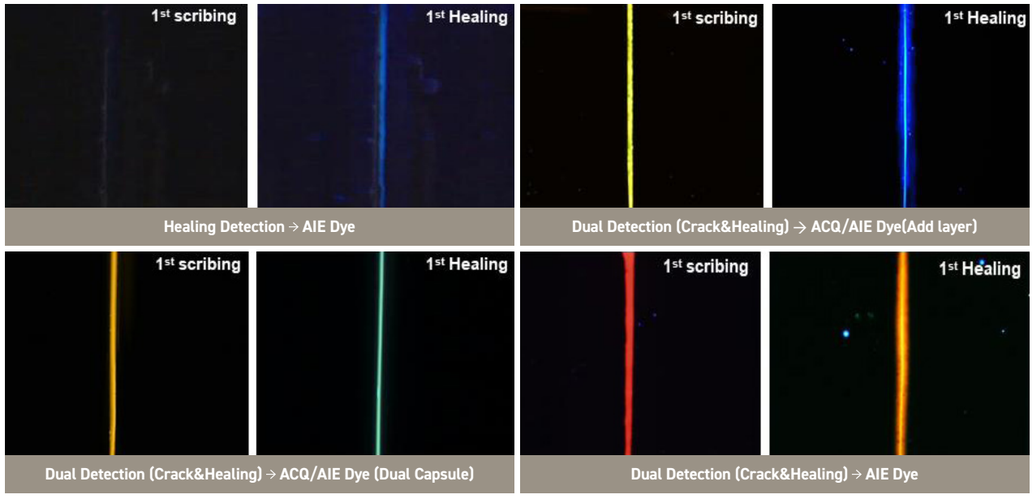


Schematic diagram of self-healing detection

Monitoring of cracking and healing in self-healing/self-report coatings using microcapsules loaded with AIE dyes

A self-healing coating technologies may potentially be useful for autonomously repairing surface damage caused by an outside impact, thereby extending the lifetimes of substrate materials in a variety of fields.

The self-healing of cracked regions formed under an external impact involves surface recovery solely at the cracked position. It is important to determine when surface cracks have been completely healing, because the self-healing capacity tends to deteriorate over time, and rehealed damaged surfaces may not restore the full coating integrity. Thus, detecting the degree of self-healing, the presence of cracks/healing, and the presence of healed positions is important for guiding spot-repair processes. Crack/healing sensing using fluorescence effects is readily achieved using noncontact, highly sensitive, and visualization-based detection methods.



Fluorescent Detection of Self-Healing

An extrinsic self-healing coating system containing tetraphenylethylene (TPE) in microcapsules was monitored by measuring aggregation-induced emission (AIE). This results suggested that this formulation might be useful as a self-healing material and as an indicator of the self-healing process due to the dramatic change in fluorescence during photocuring. To examine the ability of the healing agent to repair damage to a coating, a self-healing coating containing embedded microcapsules was scribed with a razor.

As the healing process proceeded, blue light fluorescence emission was observed at the scribed regions. This observation suggested that self-healing could be monitored using the AIE fluorescence. To our knowledge, no previous report has described the use of AIE fluorescence in self-healing applications.

As a follow up studies as mentioned, a crack and crack healing were both detectable with a microcapsule-based dual-reporting self-healing coating system developed using a single aggregation-induced emission (AIE) fluorophore. This selected and synthesized two type (AIE/ACQ) or single AIE dye was tested for changes in its fluorescence color and fluorescence intensity following a solution/solid-state phase change. These unique AIE-fluorophore-embedded microcapsules were successfully synthesized, and a crack/healing dual-reporting self-healing system with a top coating and an epoxy matrix resin was prepared. The prepared self-healing coating system was indicated by optical microscopy (OM) and scanning electron microscopy (SEM) after a scratch was created with a razor. The self-healing coatings showed and the fluorescence color changed from orange to green or red to orange as healing occurred via photocuring.

The fluorescence intensity also dramatically increased at the healing region soon after the scratch was inflicted. The fluorescence color changed according to the crack/healing process, and the fluorescence intensity also dramatically increased.

This work was published in the form of Macromolecular Rapid Communications, 38, 1600657 (2017), Applied Surface Science, 434, 1327-1335 (2018), Sensors and Actuators B: Chemical, 257, 1001-1008 (2018), Molecules, 24, 1679 (2019), Applied Surface Science, in press.

Research Center for Bio-based Chemicals

Director / Hwang Sung Yeon / crew75@krict.re.kr

- Development of technology to engineer plastics for environment-friendly vehicles
- Research on industrial biotechnologies to manufacture bio-based fine chemical materials
- Development of sustainable technology for functional materials using nonedible biomass

Transparent bio-polycarbonate film

Sustainable tough engineering thermoplastics from biorenewable monomer

We developed sustainable tough engineering thermoplastics including bio-polycarbonates and bio-poly(aryl ether)s. Bisphenol-A(BPA) is a petrochemical substance and an environmental hormone that causes endocrine disruptions and metabolic complications. BPA is mostly used in polycarbonates and polysulfones. The usage of this substance is prohibited in nursing bottles and cosmetics in Korea as well as worldwide. It is also used in receipt papers and the coating materials of canned foods.

For above reasons, bio-polycarbonate has received attention as an alternative to BPA-based polycarbonate. However, it is difficult to simultaneously satisfy both economic feasibility and high mechanical performances of biomass-derived plastics. we overcame it with the combination of biorenewable isosorbide and nanocellulose, and succeeded in producing bio-polycarbonate that surpasses the petroleum polycarbonate. Isosorbide, an eco-friendly compound derived from glucose, not only improves the mechanical properties of the incorporated polymer, but also possesses good optical and UV-resistive properties due to its unique molecular structure.

We applied the principle of "like dissolves like" where similar compounds mix together better. Isosorbide well mixed together with nanocellulose as a bio-derived reinforcing agent because both substances are hydrophilic and a similar structure. Then, the polymerization process of the nanocomposite plastic was carried out. The well dispersed nanocellulose acted like a metal rebar in the concrete and thus maximized the strength of the bioplastic.

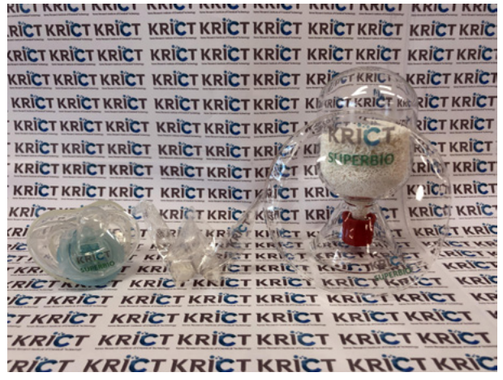
The developed bio-polycarbonate exhibited a tensile strength of 93MPa. This is the highest measurement to date amongst all existing petroleum and bio-polycarbonate. The tensile strength of petroleum polycarbonate ranges from 55~75MPa while the tensile strength of the bio-polycarbonate of the Japanese firm is 64~79MPa.

The light transmittance, which represents the transparency of the plastic, was measured as 93%. This result is very superior to commercially available petroleum polycarbonate, which was due to the suppressed crystallinity through the dispersed nanocellulose. This is an amazing because most nanocomposites have a reduced transparency because nonuniform aggregates scatter light. In addition, there is no risk of discoloration even after extended exposure to ultraviolet rays since there are no benzene ring in bio-polycarbonate, unlike petroleum polycarbonate.

Consequently, bio-polycarbonate can be used as an industrial material for applications including automobile sunroofs, headlights, transparent highway noise barriers, and exteriors of electronics such as smartphones. The material is thus expected to be a viable alternative to the existing polycarbonate.

In addition, we solved the problem of low reactivity of isosorbide by using a phase transfer catalyst to prepare biomass-derived super engineering plastics, poly(aryl ether)s. As a result, the strength per unit weight of super bioplastics was 69 KN·m/kg, higher than steel (63KN·m/kg) at the same weight. It is the strongest bioplastics ever published in academia. The tensile strength was 80MPa. This is higher than most petroleum plastics. It also has excellent heat resistance to withstand high temperatures. It did not expand or deform at temperatures as high as 300℃ in vacuum and withstands 212℃ under oxygen and physical stress conditions. In fact, in the chemical process of making OLED transparent substrates, it has surpassed the high temperature of over 300℃. The coefficient of thermal expansion is also about 25 ppm/℃, which is at least 2 to 10 times better than petroleum plastics. This means that when used as a component of electronic products, problems such as material expansion due to temperature rise can be minimized.

These research achievements entitled 1) "Preparation of synergistically reinforced transparent bio-polycarbonate nanocomposites with highly dispersed cellulose nanocrystals" was featured on the front cover of Green Chemistry of the Royal



Transparent bio-super engineering plastics

Society of Chemistry, which is the highest authority in the field of green chemistry, and simultaneously selected as a Hot Article of 2019; 2) "Sustainable and recyclable super engineering thermoplastic from biorenewable monomer" was featured on Editors' Highlights of Nature Communications published in June 2019.

Development of chemical platform technologies in response to social and industrial demand

Chemical Platform Technology Division develops a data-driven chemical research platform, drug information platform, technology platform for chemical materials industry, chemical analysis platform and advances chemical safety technology.

Chemical Platform Technology Division

Chemical Data-Driven Research Center

Drug Information Platform Center

Chemical Safety Research Center

Chemical Materials Solutions Center

Chemical Analysis Center

Reliability Assessment Center for Chemical Materials

Chemical Data-Driven Research Center

General Director / Chang Hyunju / hjchang@krict.re.kr

- Development of research data acquisition and management platform
- Development of data-based material property prediction platform

Identifying PB-free perovskite for solar cell by machine learning

Identifying optimal materials in applications research is a time-consuming step due to the vast scope of possible materials composed of three-dimensional networks of elements. Data-driven research has recently received attention as a new route to accelerating this step. This approach uses a materials' database and statistical tools that efficiently screen candidates in a search for optimal materials. The availability of open-access databases of material properties, along with machine learning (ML) techniques, has rapidly advanced research in this area. Over the last decade, ML has been applied to materials science problems in a variety of directions.

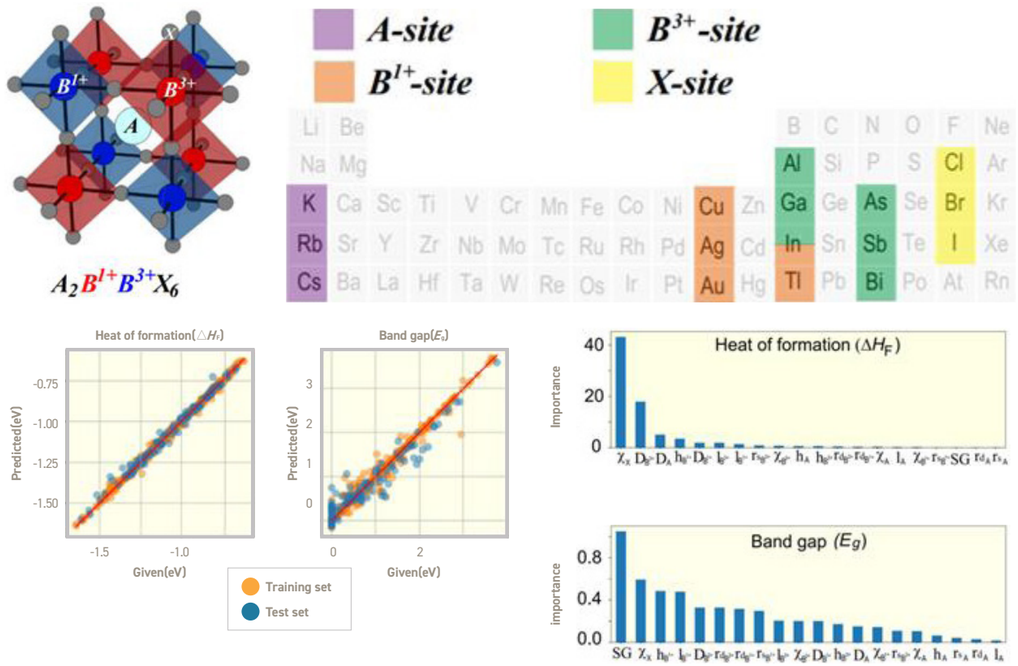
The use of ML in materials science, however, has been hindered by the accuracy and interpretability of predictive models. Complex interaction among compositions of materials leads to highly nonlinear relationships between material features and target properties. To accurately describe such relationships, nonlinear ML algorithms have been utilized due to their flexible forms. However, lack of interpretability of most nonlinear ML predictive models prevents further mechanistic understanding such as finding key ingredients for target properties. Thus, finding ML algorithms that can achieve both accurate prediction and interpretability is crucial to the further advance of data-driven materials research.

Tree-based learning algorithms can be one candidate due to their advantages in both accuracy and interpretability. Utilizing tree-based algorithms, we here focus on finding optimal candidates for double perovskite solar cells. While recent solar cell technology has been prompted by the development of hybrid lead perovskites having an increase of power conversion efficiency and low-cost manufacturing, the inclusion of lead ion raises environmental issue preventing commercialization. Alternatively, a new strategy using mixed mono- and tri-valent cations, in the form of the double perovskite has been introduced to replace lead-based perovskite solar cell materials. In this approach, sizable combinations of double perovskites can be possible, and thus a combination of high-throughput computations and the ML technique can be a powerful tool to explore the large combinatorial space.

In this research, employing the gradient-boosted regression tree (GBRT) algorithm and a dataset of calculated electronic structures of A2B1+B3+X6, we present an ML-based investigation, which can be ultimately used to identify Pb-free double perovskite solar cell materials. The GBRT method allows us to obtain highly accurate predictive models for the heat of formation (ΔH_F) and bandgap (E_g), with importance scores for each feature of materials.

Based on the scores, we extract crucial features to determine the values ΔH_F and E_g of halide double perovskites, enabling an overall understanding of the relationships between features and properties. Finally, we discuss the relevance of extracted features to the chemical and physical aspects of ΔH_F and E_g, and practical approaches of the ML model toward finding optimal candidates of Pb-free halide double perovskites solar cell materials.

Jino Im et al., npj Comput. Mater. 5, 1-8 (2009)



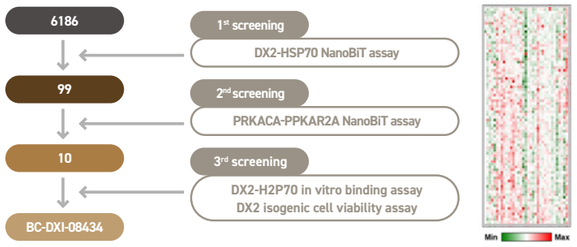
Drug Information Platform Center

Head / Lee Sunkyung / leesk@krict.re.kr

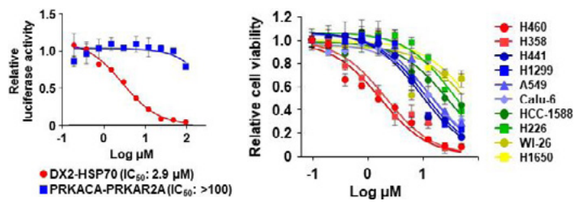
- Establishment of national platform on chemical libraries and big data for drug discovery
- Collection and management of chemical libraries and support for library utilization

Molecular dynamic simulation to prove the suppression of protein-protein interaction *via* conformational change induced by chemical

Since many physiological and pathological cellular events are controlled by protein-protein interactions (PPIs), modulating PPIs promises attractive ways to develop drugs for many diseases. Although disease-causing protein-protein interactions (PPIs) have been emerged as attractive therapeutic target space, identification of chemicals effectively inhibiting PPIs remains challenging. Our previous report demonstrated that AIMP2-DX2 is stabilized by its interaction with HSP70 and that inhibition of this interaction between the two proteins reduces DX2-mediated cancer proliferation. Then, we searched for an inhibitor of the interaction between DX2 and HSP70 to suppress DX2-dependent cancer progression using a luciferase-based complementation assay system. In a primary screen using 6,186 compounds from the Korea Chemical Bank (KCB), 99 compounds showed over 60% inhibition at 5 μM. The specificity of these 99 compounds for DX2 was determined using the binding pair protein kinase A catalytic subunit (PRKACA) and protein kinase A type 2A regulatory subunit (PRKAR2A), and 10 compounds were found to specifically suppress the binding of DX2 and HPS70 but not PRKACA-PRKAR2A. An *in vitro* pull-down assay using the purified HSP70 and glutathione S-transferase (GST)-DX2 proteins demonstrated that BC-DXI-08434 significantly inhibited the interaction of the two proteins. Furthermore, BC-DXI-08434 suppressed DX2-dependent cell proliferation in a DX2-inducible system.

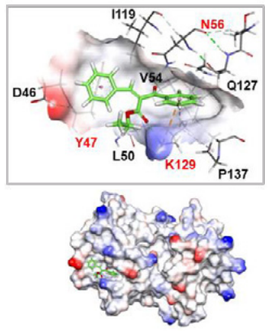


Identification of hit by HTS using KCB Libraries

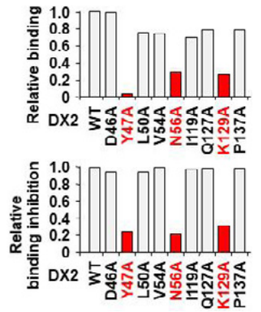


Efficacy of BC-DXI-08434

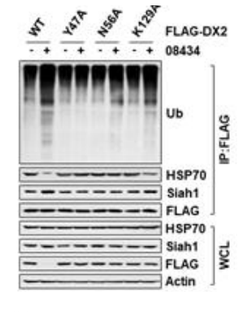
To investigate the binding mode of BC-DXI-08434 with DX2, we performed a molecular modeling study because the disordered NFR was not visible in other structural assays. Due to the disordered nature of the NFR, a series of relaxation procedures was conducted by molecular dynamics (MD) simulations. The representative structure obtained from the MD simulation, including the well-relaxed conformation of the NFR, was used as the initial structure of DX2 for the docking of BC-DXI-08434. The carbonyl group of benzoyl and ester moiety on BC-DXI-08434 interacts with side chain of amine of N56 and K129, respectively, by H-bonding. There was π-π interaction of styrene in BC-DXI-08434 with Y47 of DX2. To validate the results from the MD simulation, we generated alanine substituents of the DX2 amino acids suggested to be critical for binding BC-DXI-08434. We checked the binding of alanine mutants to chemicals using biotin-08434 *via* an in vitro pull-down assay. Wild-type DX2 (DX2 WT) and most of the mutants tested showed strong binding, but the binding of DX2 Y47A, N56A and K129A mutants to biotin-08434 was significantly reduced. Because Y47, N56 and K129 are critical residues of DX2 for binding with BC-DXI-08434, we tested the BC-DXI-08434-mediated ubiquitination of the selected DX2 mutants, resulting in a decreased level of DX2, but DX2 ubiquitination and DX2 protein expression of the tested mutants were not affected by treatment with BC-DXI-08434.



Binding mode of compound with DX2

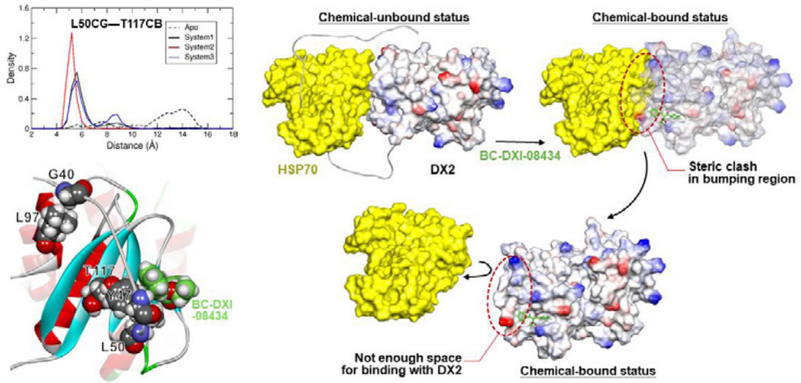


Relative binding of BC-DXI-08434 and DX2 mutants



293T cells expressing each FLAG-tagged DX2 mutant were subjected to ubiquitination assay

Further analysis using MD revealed that the interaction of BC-DXI-08434 in the pocket of DX2 surrounding Tyr47, Asn56 and Lys129 induces a steric clash against HSP70 by direct binding-interference and a conformational change of DX2, resulting in turnover of the DX2 protein.



Determination of Mode of action of BC-DXI-08434

Chemical Safety Research Center

Head / Kim Jong Woon / jkim@krict.re.kr

- Development of technology for human health risk assessment and reduction
- Chemical safety information research

MRA Toolbox Prototype: Mixture Risk Assessment Toolbox

MRA toolbox : mixture risk assessment toolbox

Chemical risk assessment has mainly focused on single substances rather than mixtures although living organisms may be exposed to different chemicals simultaneously. Scientific findings have shown that toxicity can be caused by cocktail effects of mixture components presenting even at or below their no observed effect levels (NOELs). These studies make chemical regulations (e.g. EU REACH/CLP, BPR, etc) consider mixture toxicity.

In Winter 2019, Chemical Safety Research Center developed a web-based mixture risk assessment toolbox (MRA Toolbox) as a prototype web tool which provides different predictive models for calculating mixture toxicity, estimating exposure concentrations, and determining risk characterization ratios of chemical products including consumer products. The current version of MRA Toolbox has two major conventional prediction models for assessing additive toxicity as a mixture toxicity effect: concentration addition (CA) and independent action (IA) models. Those models have been frequently used as default methods under related global chemical regulations. The MRA Toolbox will be published in 2020 and continuously updated with integrated additive toxicity models, exposure assessment models, and combined risk assessment models. The toolbox ultimately pursues supporting the industry to develop safer chemical products in product design.

· MRA Toolbox will be launched on https://chemsafety.krict.re.kr/ in 2020.

The bead type neutralizer and absorber

ERCAR App on Google Play

Bead-type neutralization/sorbent agents for hazardous materials

Chemical Safety Research Center carried out a 5-year-project for solving the problem of inaccessibility in emergency response of mass spill of acidic, basic and hydrocarbon chemicals. Through the project, three types of first bead-typed control agents with ensuring long-distance spraying, excellent neutralization and absorbing functions were successfully developed, and three patents were registered. The bead-typed smart control agents has been developed with apparent neutralization calories analysis and neutralization of control agents and indicator functions for chemical spills. We expect that these techniques highly contribute to prevent fight fighters, the public, and the environment from chemical accidents.

Ryu et al., 2019, Proceedings of KSIEC Fall Meeting, Development of neutralization/sorbent agent for hazardous materials,

ERCAR App: a mobile application of emergency response for chemical accident risks

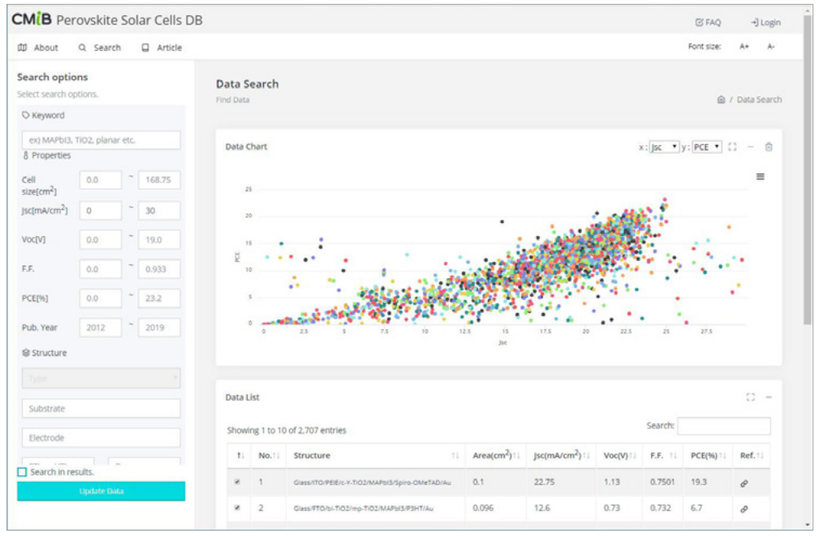
ERCAR app was developed by Chemical Safety Research Center as a mobile application to provide emergency response guideline against chemical accident risks. Through the app, users can easily get the information on major physico-chemical properties, hazards, response measures, etc. for preventing possible risks from chemical accidents. In addition, ERCAR helps the users select proper chemical controls agents and calculate their required doses as emergency response to chemical accidents. ERCAR was released in winter 2019 and it can be freely downloaded from Google Play.

· Download website of ERCA: https://play.google.com/store/apps/details?id=com.ideainfo.krictapp

Chemical Materials Solutions Research Center

Head / Choi Woo Jin / wjchoi@krict.re.kr

- Development and support of advanced coating process technologies based on pilot-scale roll-to-roll coating facilities and expertise
- Development and support of pilot-scale synthesis, purification, and dispersion process



Web-based search system of PSC-DB (www.perovskite.info)

KRICT opened database of perovskite solar cells (PSC-DB)

As a global research institute of perovskite solar cells (PSCs), we opened the database of perovskite solar cells (PSC-DB). PSCs have attracted great attention due to their high power conversion efficiency (PCE) compared with other solar cells. Since the performance of PSCs depends on materials, processes, and layered structures, providing the information of PSCs will be helpful to researchers. To built the database of PSCs (PSC-DB), we has extracted experimental results of 2,711 PSCs from 688 articles published between 2013 and 2019. The PSC-DB is designed for users to easily access, search, and utilize. The PSC-DB is now available through a web-based system (URL: www.perovskite.info). The providing information is as follows: the type and structure of the PSCs, the materials and processes applied to each layer, the active area and basic characteristics of solar cell (Jsc, Voc, F.F, PCE), article's bibliographic information (title, journal, published year, author, country, abstract, DOI).

KRICT and AIMCAL held the first R2R Asia Conference 2019

The world's largest roll-to-roll coating conference was held at Korea Research Institute of Chemical Technology(KRICT) in Daejeon for the first time in Asia. KRICT and AIMCAL(Association of International Metallizers, Coaters, and Laminators) held '2019 R2R Asia Conference' at the Didimdol Plaza of KRICT from May 28-30, 2019.

The 'R2R Conference' is an international meeting for roll-to-roll experts to exchange technical information and form network. We and AIMCAL have been discussing for several years to hold the 'R2R Conference' in Asia, signed an MOU to host the conference in 2018, and finally held the '2019 R2R Conference Asia' for the first time in Asia this year. About 150 experts in domestic and foreign roll-to-roll equipments, materials and coating processes participated in this conference, and in particular a large number of Korean businessmen participated to exchange information on recent trends in technology development.

The conference was held over three days with 11 sessions, including coating and surface treatment technologies, roll-to-roll sputtering, moisture barrier and batteries. The keynote speeches were presented by In-Sung Son, executive director of Innox Advanced Materials, and the Oliver Chen, head of display & optical solutions at Applied Materials. In-Sung Son presented 'Polymeric films in electronics packaging and display industries', and Oliver Chen introduced 'R2R technology for emerging flexible products'.

In an oral session presented by more than 40 experts, Dr. Nicolas Schiller of the Fraunhofer FEP presented 'Ultrathin flexible glass: Potentials and challenges for vacuum thin film coating'. Sang Kyun Kim, a senior researcher at Kolon Industries, introduced 'Current research on the colorless polyimides for foldable display'. In addition, Dr. Andreas Nilsson of the Von Ardenne and Dr. Seong-Keun Cho of the KRICT presented 'R2R technology and equipment for barrier applications' and 'Chemical and mechanical structures of SiN films as gas barrier layer', respectively.

We both agreed on continued exchanges in the future so that the 'R2R Asia Conference' could be reborn as the place for exchanges of Asia's top roll-to-roll industry. In addition, through this conference, the Chemical Materials Solutions Center of KRICT laid the foundation for growth as a world-class roll-to-roll hub institution.

Chemical Analysis Center

Head / Rho Ye Cheol / rhoyc@krict.re.kr

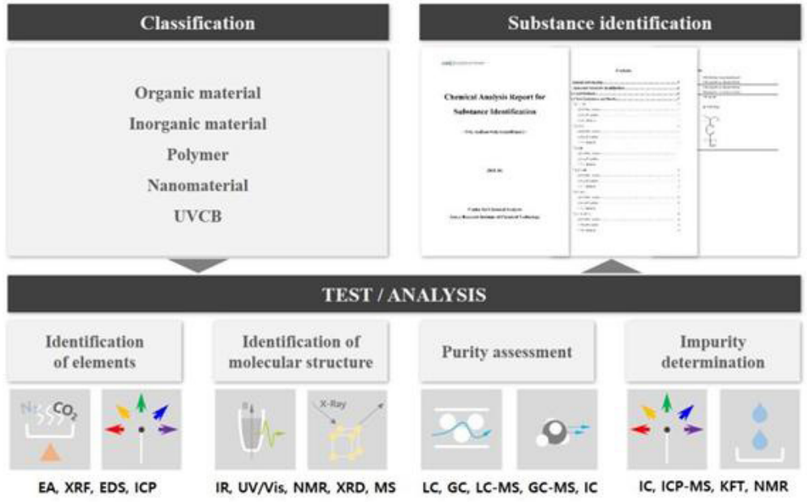
- Providing chemical analysis technology
- Developing technological grounds for chemical analysis

Analysis Platform for chemicals and their products against REACH*

REACH is a regulation to enhance public health and protect the environment from the risks posed by chemicals by providing hazards and risks data of chemical substances. EU(European Union)-REACH and K(Korea)-REACH have been in effect since 2007 and 2015, respectively. REACH established procedures for collecting and assessing information regarding the properties and hazards of chemical substances. Therefore, manufactures or importers are obligated to complete the EU/K-REACH registration.

The Chemical analysis center has built a platform to serve detailed information required for chemical registration. The platform has focused on the substances identification and physicochemical properties of chemicals. The platform technology is based on guidelines of SIP (substance identity profile) and SPP (substance physicochemical profile) established by the type of the chemical substance, such as organic/inorganic material, polymer, nanomaterials and UVCB (Unknown or Variable Composition, Complex Reaction Products and Biological Materials). The products are substance identity and substance physicochemical reports that can be registered with chemical agency. Moreover, instruments and analytical methods in accordance with OECD guidelines for physicochemical characterization were built. The Chemical analysis center can provide one-stop service of joint-utilizable test/analysis against regulation of chemicals and their products through 60 integrated instruments for substance identification and physicochemical property test.

The Chemical analysis center has a various equipment for substances identification and physicochemical properties of chemicals, and supports activities for research and development and technical improvement.



Registration, Evaluation, Authorization and Restriction of Chemicals

X-ray Electron microscope

SEM-EDS, Cryo-FE-SEM-EDS
XRD, HR-XRD, HT-XRD,
XRC(X-ray Crystallograph)
ED-XRF, WD-XRF

Spectrometry-Organic·thermal analysis

700Mhz NMR, 500Mhz w/CryoProbe,
IR, Vacuum-Microscope-IR, Near-IR,
FT- & dispersive-Raman
EA(Elemental analyzer)
TGA, DSC

Chromatograph/MS

GC, GC-MSD, HR GC-TOF-MS,
GC×GC-TOF-MS
LC, LC-MS, HR LC-Q-TOF-MS
HR-MS, MALDI-TOF-MS

Inorganic·moisture analysis

ICP-AES, ICP-MS, AAS, IC
KF(Karl Fischer titrator)

Physicochemical properties

Colorimeter, Dissolution system,
MP/BP testor, VP testor,
Gas Pycnometer, Oscillating
densitometer, PSA, Viscometer

Reliability Assessment Center for Chemical Materials

Head / Heo Kyu Young / kheo@krict.re.kr

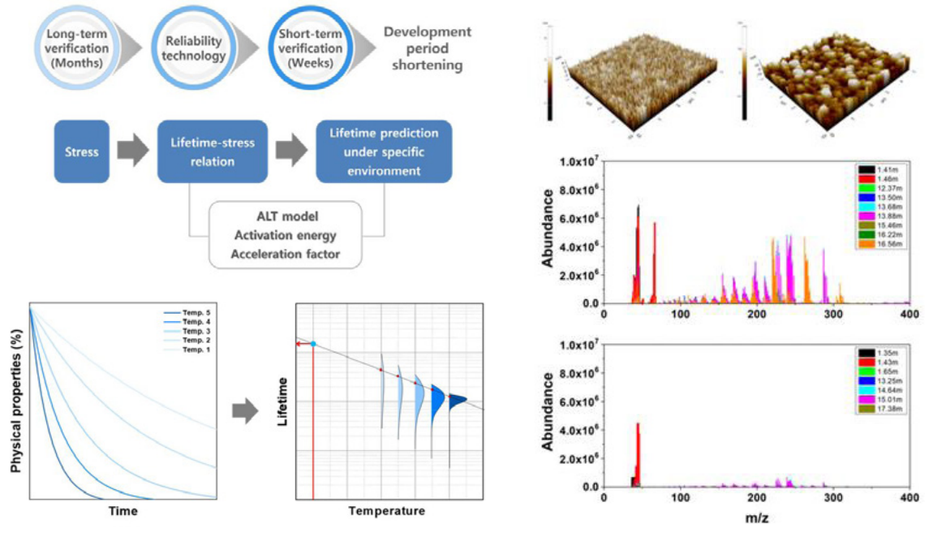
- Development of technologies for material reliability and accelerated weathering tests
- Operation of platform for chemical material failure analysis and accelerated degradation test

Development of reliability assessment techniques for chemical materials

The reliability assessment center for chemical materials is specialized in assessment on material reliability and failure analysis. We are devoted to the quality improvement of chemical materials by establishing a reliability assessment (performance, environment, and durability) system that is world class and providing technical support. Reliability refers to the basic quality over time, and the ability to maintain the initial quality of the product satisfactorily during the target life.

Reliability assessment is a core technology area that assesses environmental resistance to confirm how long the product will withstand the environment, and predicts and verifies durability or failure rate in advance. Since 2000, we are a leading research center in Korea for developing reliability evaluation standards and new test evaluation techniques, evaluating accreditation, and supporting failure analysis. Furthermore, we provide total solution to improve the quality and reliability of chemical materials based on reliability experts, advanced analysis, and test infrastructures. (Advanced weathering test infrastructures and test method standardization)

	evaluation standard	intellectual property	failure analysis	company standard	technology transfer
outcome	36	14	246	10	25
example	accelerated weathering test method simulating actual climate	apparatus for weathering using light emitting plasma	noise mechanism of vehicle link part in cold region	weathering test method for 5G LTE repeater enclosure	weathering test method using light emitting plasma



Lifetime assessment of chemical deposition materials for semiconductor and display

We pursued the installing the weathering evaluation equipments and supporting the related chemical industries. Also, we have developed accelerated weather evaluation equipment and related testing method based on the simulated reality. (Accelerated test method for chemical deposition materials) We have developed lifetime assessment of chemical deposition materials for the semiconductor and display devices which need extremely high reliability over processing period and storage. Also, we have found that purity can be predicted by using viscosity properties that can be measured quickly and easily in solution phase of deposition precursor.

This technique is expected to be useful for predicting the expiration of deposition materials in a real process environment or for diagnosing current state of the materials.

7th KRICT Weathering School (2019.12.04)

KRICT held the 7th Weathering School

KRICT Weathering School is annual seminar for introducing new weathering technology. Over 150 technicians from various industries have been participating in every year since 2013.

Weather resistance refers to the property of chemical materials and products to withstand the climatic environment such as sunlight, heat and moisture, which is an essential infrastructure technology for the automotive, home appliance, and construction industries. In particular, the surface properties of chemical materials such as transparency, hydrophilicity (water-binding properties), water repellency, and heat and gas barrier properties are becoming more important.

In addition, interest in the emotional quality of the material like maintaining gloss, color, and texture is gradually increasing. Our center is promoting domestic weathering assessment research by educating the current state of chemical weathering test.

Convergent Research Centers

Enhanced national Competitiveness through acquisition of novel technology for petrochemical and energy industry

The CCP contributes to sustainable growth of the nation's key industries and to climate change adaptation by developing novel technology for the economic production of basic chemicals and stable energy supply.

Development of convergence solution for new virus infection

The CEVI aims to develop the convergent solution for preventing a rapid spread of emerging virus by developing a highly sensitive detection method, a preventive vaccine, an anti-viral drug, and a preventing system for high-risk emerging virus(i.e. MERS-Cov. Zika, etc.)

Center for Convergent Chemical Process(CCP)

Center for Convergent Research of Emerging Virus Infection(CEVI)

Center for Convergent Chemical Process(CCP)

Director / Park Yong Ki / ykpark@krict.re.kr

Process Technology Research

- Development of process design package for reaction and separation processes in petroleum refining and petrochemical industries
- Development of thermal management technology for petroleum refining and petrochemical process

Olefin Separation Research

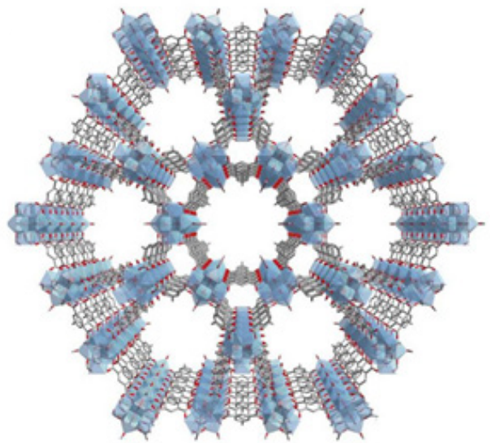
- Development of new porous adsorbents and technology for energy-efficient olefin/paraffin separation
- Development of technology for high-performance hollow fiber membranes for olefin/paraffin separation

Heavy Oil Upgrading Research

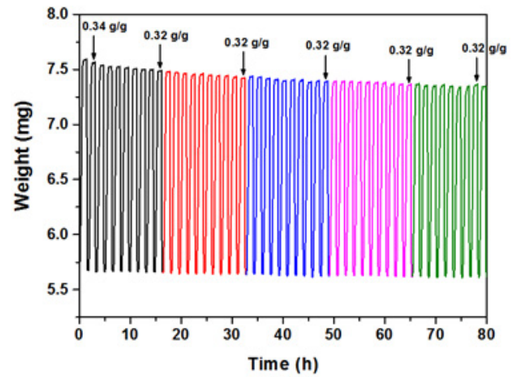
- Development of highly efficient new hydrocracking catalysts for Heavy oil upgrading technology
- Development of highly efficient hydrocracking reactor and process technology for upgrading of heavy oils
- Development of technology to produce hydrogen from steel industry by-product gases

Olefin Synthesis Research

- Development of catalysis for naphtha and methanol-to-olefin (NMTO) catalytic cracking process
- Development of technology for olefin inter-conversion (ethylene-to-propylene) allowing olefin supply control
- Development of fluidized propane dehydrogenation (FPDH) technology for continuous reaction-regeneration fluidized bed process



3D structure of MIP-200 viewed along the c-axls with larger hexagonal and smaller trlangular channels.



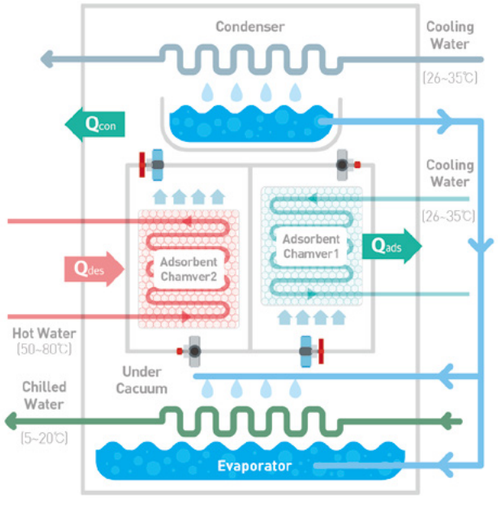
A robust large-pore zirconium carboxylate metal-organic framework for energy-efficient water sorption-driven refrigeration

Global energy consumption for heating and cooling in residential areas has increased steadily during the past decades and is forecasted to accelerate in the coming years, especially for cooling purposes1. The current systems and adsorbents used in heating and cooling processes rely mainly on non-sustainable energy resources and this is strongly against the recent global agreement aiming to reduce energy generated using fossil fuels.

Therefore, the development of alternative materials and systems involving clean and renewable energy resources has attracted considerable attention over the last few years.

Among them, green adsorption-driven heat pumps and chillers have aroused a great interest over the last few years. They exhibit many advantages including the use of clean energy sources, such as solar and industrial waste heat, the low driving and regeneration temperatures, as well as the involvement of environmentally friendly working fluids, such as water and ethanol.

In particular, for the cooling application, facile regeneration at low temperature (< 70℃) is a critical requirement to develop advanced water adsorbents since commercial adsorption



chillers based on LiBr/water show very poor cooling capacity below 75℃. The use of advanced water adsorbents which outperform commercial silica gel and SAPO-34 adsorbents in terms of working capacity and regeneration temperature paves the way towards the next generation of adsorption-driven heat reallocation systems, thus making them more cost- and energy-efficient. Therefore, the discovery of new MOFs water adsorbents that could be regenerated and cycled at low temperatures for the refrigeration purpose is highly expected. However, it remains a great challenge to date.

We present a large-pore MOF constructed from a Zr_6 oxocluster and tetracarboxylate linker (3,3′,5,5′-tetracarboxydiphenylmeth ane; H4mdip), denoted as MIP-200 (MIP stands for the Materials of the Institute of Porous Materials from Paris), that possesses water-adsorbent properties and overcomes the limitations outlined above.

This material features large one-dimensional (1D) hydrophilic channels in its crystal structure, which leads to outstanding water sorption properties including a high uptake of water in a low relative pressure range, facile desorption at fairly low temperatures (< 70℃ and a very high COP for refrigeration.

Because of the combined advantages of its cooling performance, along with its cost-effective, green and scalable synthesis and good chemical and mechanical stability, this MOF material, to the best of our knowledge, is one of the most promising water adsorbent materials developed so far in comparison with commercial benchmarks and previously reported MOFs.

Therefore, MIP-200 appears to be a promising candidate for adsorption-driven refrigeration that is compatible with the shaping process required for large-scale utilization. This work provides the promise of developing highly stable MOFs for applications in next-generation adsorption-driven chillers, heat pumps and dehumidifiers to achieve more efficient energy consumption.

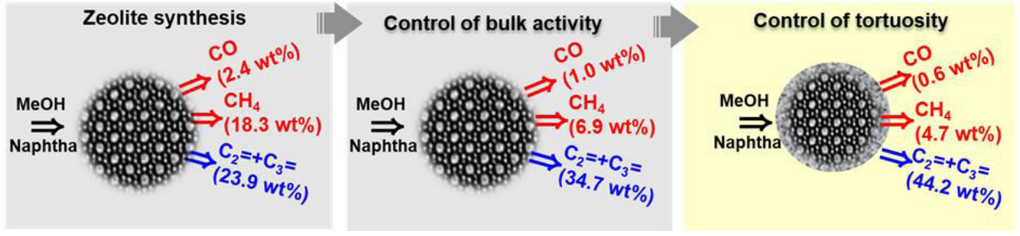
Naphtha-methanol hybrid catalytic cracking(NMTO), an energy-saving olefin production technology

Light olefins such as ethylene and propylene are valuable raw materials in the petrochemical industry for the production of various polymer products, including but not limited to, polyethylene, polypropylene and co-polymers. The conventional process for light olefin production is steam cracking of naphtha which proceeds at high temperature in the range of 800-900℃. The process is highly endothermic, which results in high energy consumption and excessive byproduct production. Besides, in the current steam cracking process, it is difficult to control the ratio of propylene to ethylene, as the reaction occurs via a free radical mechanism.

As an alternative to steam cracking, the naphtha catalytic cracking process in fluidized reactor(K-COT™ process) has been developed by KBR, SK Innovation, and KRICT to produce light olefins at lower reaction temperature (<700℃). In this process, phosphorus modified ZSM-5 is used as a commercial catalyst to give almost equal ratio of propylene/ethylene with increase of 30% of light olefin yields at the lower reaction temperature(600~650℃), compared to the conventional steam cracking. Using the acid catalyst like a zeolite may achieve the

cracking of naphtha at a relatively low temperature, but there is still the problem of system heat supplying. In order to develop an energy-saving process, we have tried the hybridization of endothermic catalytic naphtha cracking (NTO) with exothermic methanol-to-olefins (MTO) reaction. To carry out the NTO and MTO reactions simultaneously, relatively high reaction temperature is required. However, if the catalyst is not prepared properly, a lot of low-valued by-product such as CO and CH_4 are produced. According to our recent study, the controlling of physical and chemical properties of catalyst is quite important to hybridize the NTO and MTO reactions successfully.

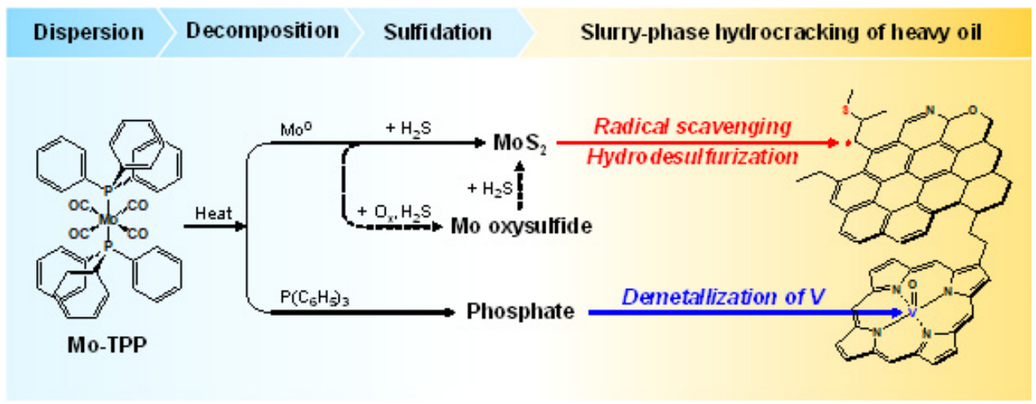
Based on the kinetic diameter of naphtha and methanol, zeolite with hydrothermal stability was selected and then the catalyst for hybridized naphtha and methanol reaction was synthesized by controlling the acidity. When performing the NMTO reaction under high temperature condition, not only did the synthesized catalyst produce 15% higher olefins yield than conventional commercial catalyst, but it also reduced energy consumption by 30% compared to the conventional steam cracking process in fluidized reaction system.



Catalyst design for reduction of byproduct in NMTO reaction

Slurry-phase hydrocracking of heavy oil over Mo precursors

A practical approach for enhancing the performance of dispersed catalysts during slurry-phase hydrocracking is the modification of the ligand structure of the catalyst precursor. In this regard, an oil-soluble Mo precursor with triphenylphosphine ligands (Mo-TPP) was prepared and further applied to the slurry-phase hydrocracking of vacuum residue (VR). The Mo-TPP precursor resulted in a better catalytic performance than a commercial precursor (Mo-octoate) in a semi-batch reactor at 410℃ and 110 bar. In particular, the use of Mo-TPP enhanced the radical scavenging and hydrodesulfurization activities owing to an excellent hydrogenation ability originating from the initial number of active sites. The phosphate compound, derived from the TPP ligands, promoted the conversion of asphaltenes via demetallization of the intrinsic V species in the VR. These results demonstrated that Mo-TPP is an efficient precursor for achieving coke suppression that also improves product quality. This work will appear in the early 2020 issue of the Journal of Catalysis.



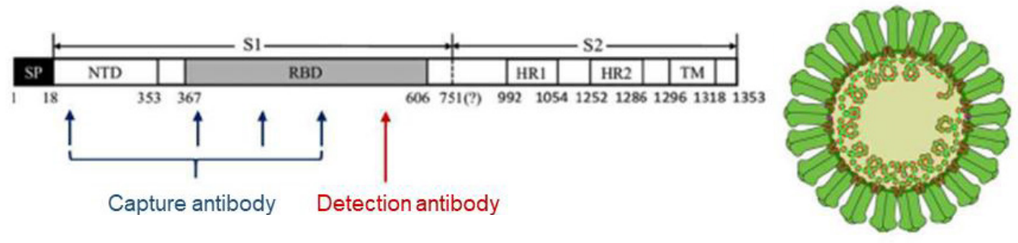
Center for Convergent Research of Emerging Virus Infection(CEVI)

Director / Kim Bum Tae / btkim@krict.re.kr

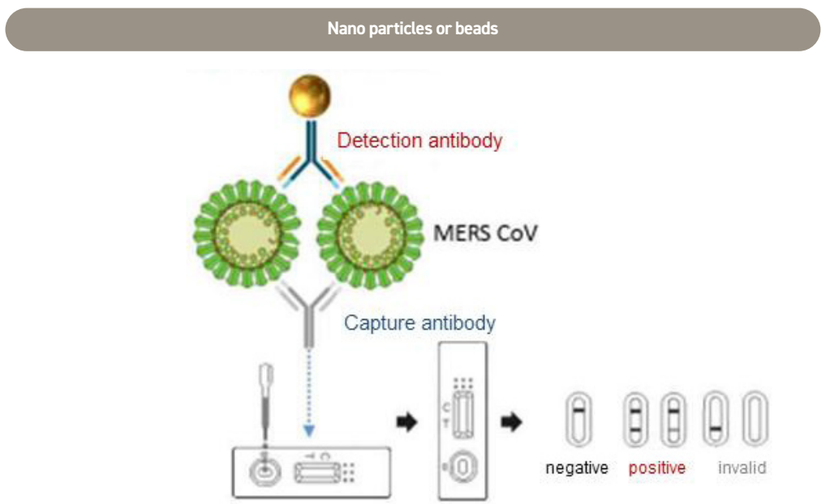
Virus Diagnosis Research	Anti-viral Research
· Development of high-sensitive screening technology for point-of-care testing (POCT) · Development of multi-technology based multi-sided diagnostic platform	· Discovery of wide-spectrum anti-corona virus drug candidates for the clinical use · Development of therapeutic agents for super-bacteria
Vaccine Research and Development	**Virus Spread Prevention**
· Vaccine development against emerging viruses · Establishment of a novel system for assessing vaccine safety and efficacy · Research on viral diseases (Viral pathogenesis)	· Development of Korean prediction model for preventing virus infection spread · Development of smart construction materials and tunnels for prevention of infectious diseases

Development and technology transfer of MERS antigen rapid diagnosis kit

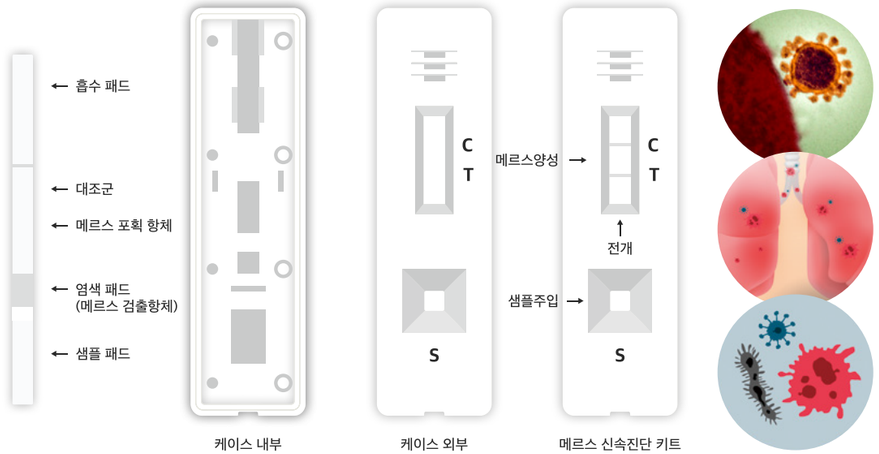
For analysis of MERS antigen, B-cell Linear epitope sequences were derived from NCBI Reference Sequence considering the hydrophilicity and surface accessibility of Spike 1 protein sequence analyzed by IEDB Analysis Resource. Antigen peptides were synthesized with 80% purity, and conjugation of the double-immune peptides C-term Cystein and KLH with S-S binding, and for ELISA peptides, C-term Cystein and BSA were conjugated with S-S binding. Monoclonal and polyclonal antigens were produced using these antigens. Gold nanoparticles were conjugated to monoclonal antibody (S-RBD3 # 8E5, Capture Ab.) and polyclonal antibody (S-RBD1 # 2, Detection Ab.) to produce Dipstick with Universal LFA kit and recombinant MERS CoV Spike 1 protein was detected. The monoclonal antibody (S-RBD3 # 8E5, Capture Ab) was dispensed with a pipette, and gold nanoparticles were conjugated to the polyclonal antibody (S-RBD1 # 2, Detection Ab) to prepare a dipstick manually. Using this, MERS CoV-infected Huh-7 cell lysate was detected. "MERS rapid diagnosis technology" utilizing the developed antibody was transferred to the Korean diagnostic company "WELLS BIO". (2019.2.28.)



Schematic diagram of MERS CoV S protein



MERS rapid diagnosis kit developed by the CEVI(KRICT)

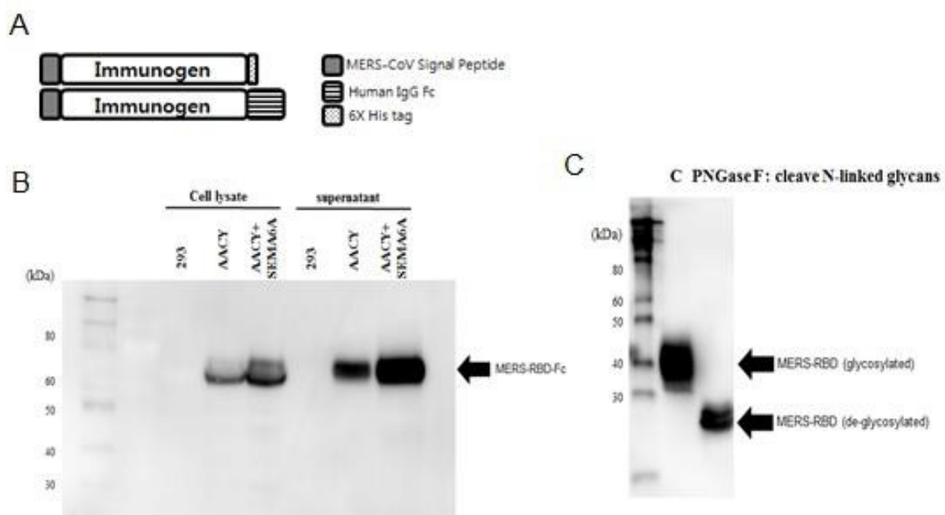


Development of novel MERS vaccine candidate

Viral structural proteins such as envelope, capsid and spike proteins are the most attractive targets for the development of preventive vaccine. It has been reported that various post-translational modifications of viral structural protein such as glycosylation affect binding affinity between virus and host receptor and subsequent immunogenicity during viral infection.

Thus, glycosylation of viral structural proteins is very important for increasing immunogenicity of recombinant vaccine candidate. To develop a novel MERS vaccine candidate, we have produced recombinant MERS spike receptor-binding domain (RBD) protein in mammalian cells supporting consistent protein glycosylation. To produce glycosylated recombinant RBD protein, we introduced multiple novel techniques including: (i) insertion of RBD gene in transcriptionally active sites of human chromosome using homology-directed repair (HDR) method based on CRISPR-Cas9 DNA editing technology, (ii) fusion of RBD protein and signal peptide facilitating secretion of glycosylated viral protein from the cell to culture media.

This technique simplifies the purification strategy of recombinant protein, (iii) preparation of RBD protein fused to novel cell-penetrating peptide (CPP) for effective delivery of viral protein into antigen presenting cells. This system supports enhanced immunogenicity of vaccine candidate during viral infection.



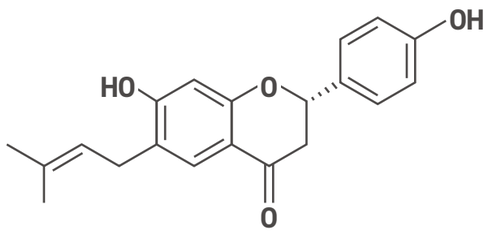
1

IC_{50} : 0.77 μM

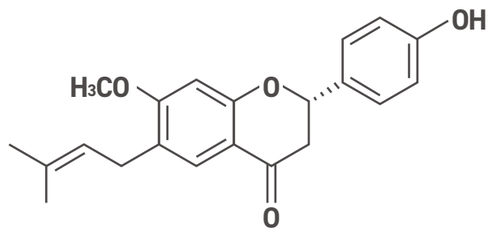
CC_{50} : > 25 μM

Synthesis and biological evaluation of 3-acyl-2-phenylamino-1,4-dihydroquinolin-4(1H)-one derivatives as potential MERS-CoV inhibitors

3-Acyl-2-phenylamino-1,4-dihydroquinolin-4(1H)-one derivatives were synthesized and evaluated to show high anti-MERS-CoV inhibitory activities. Among them, 6,8-difluoro-3-isobutyryl-2-((2,3,4-trifluorophenyl)amino) quinolin-4(1H)-one (6u) exhibits high inhibitory effect (IC50=86 nM) and low toxicity (CC50 > 25 μM). Moreover, it shows good metabolic stability, low hERG binding affinity, no cytotoxicity, and good in vivo PK properties.



Bavachin



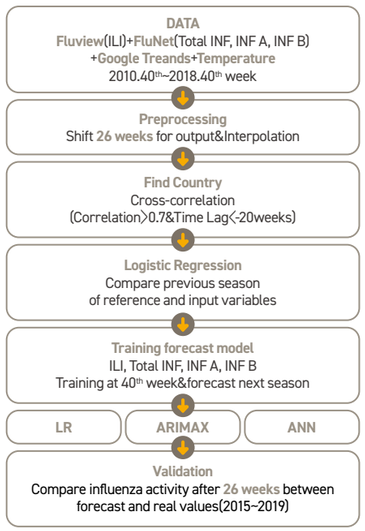
Bavachinin

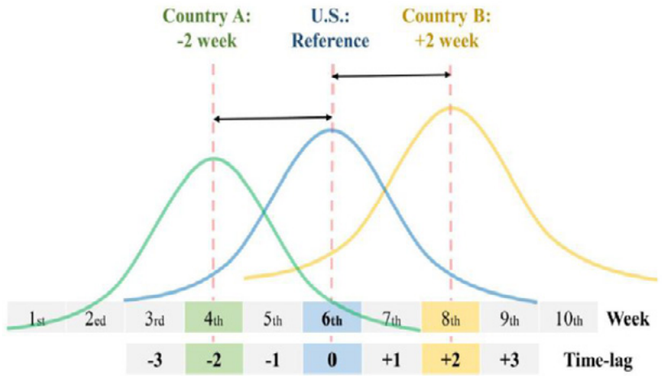
Study on the 2-phenylchroman-4-one derivatives and their anti-MERS-CoV activities

We screened a variety of natural products against MERS-CoV as an attempt of developing anti-MERS-CoV drugs, and many flavonoids showed anti-MERS activities. Among them, 2-phenylchroman-4-one derivatives e.g., bavachin and bavachnin separated from dry seed of Psoralea corylifolia L., Korean medicinal herb exhibited comparatively good activities. Bavachin and bavachinin showed good anti-MERS-CoV activities of 2.9 and 7.9 μM respectively by phenotypic cellular screening with vero cell. As the small structural difference between two compounds (-OH *vs.* -OMe) could change the anti-viral activity, we tried to synthesize the bavachin derivatives for structure–activity-relationship study (SAR study).

Forecasting type-specific seasonal influenza after 26 weeks in the United States using influenza activities in other countries

Our study forecasts the 2018–2019 seasonal influenza after 26 weeks in the U.S. using the 2018 seasonal influenza in Australia and Chile. The correlation between the seasonal influenza patterns in the U.S., Australia, and Chile could be used to forecast the next seasonal influenza pattern, which can help to determine influenza vaccine strategy approximately six months ahead in the U.S. Our prediction model allows to estimate peak timing, peak intensity, and type-specific influenza activities for next season at 40th week.





Appendix

Annual Report 2019
Korea Research Institute of Chemical Technology

Appendix

List of SCI Articles Published in 2019

Research Department	Research Center	Title	Authors	Journal Title	Vol.	Page
Department of Carbon Valorization	Green Carbon Research Center	Carbon Defect Characterization of Nitrogen-Doped Reduced Graphene Oxide Electrocatalysts for the Two-Electron Oxygen Reduction Reaction	Cho Young Hoon et al.	CHEMISTRY OF MATERIALS	31	3967
	Green Carbon Research Center	Effect of PEG-MEA and graphene oxide additives on the performance of Pebax®1657 mixed matrix membranes for CO2 separation	Cho Young Hoon et al.	J. of Membrane Science	572	300
	Green Carbon Research Center	Catalytic Reaction System for Rapid Selective Oxidation of Alkyl Sulfide	Han Yo-han et al.	J. of Hazardous Materials	379	120830
	Green Carbon Research Center	Mechanistic reaction model for oxidation of sulfur mustard simulant by a catalytic system of nitrate and tribromide	Han Yo-han et al.	J. of Hazardous Materials	365	511
	Green Carbon Research Center	Integrated production of polymer-grade lactide from aqueous lactic acid	Hwang In Taek et al.	Korean Journal of Chemical Engineering	36	203
	Green Carbon Research Center	Adsorptive removal of gaseous methyl iodide by triethylenediamine (TEDA) metal impregnated activated carbons under humid conditions	Hwang Young Kyu et al.	J. of Hazardous Materials	368	550
	Green Carbon Research Center	Highly Efficient Hydrotalcite/1-Butanol Catalytic System for the Production of the High-Yield Fructose Crystal from Glucose	Hwang Young Kyu et al.	ACS Catalysis	10	1388
	Green Carbon Research Center	Adsorption of hydrocarbons commonly found in gasoline residues 1 on household materials studied by inverse gas chromatography	Joungmo Cho et al.	J. of Chromatography A	1594	149
	Green Carbon Research Center	Enhanced boron rejection of a thin-film composite membrane by embedding additives including hydroxyl groups	Kim In-Chul et al.	Desalination and Water Treatment	162	112
	Green Carbon Research Center	Enhancement in permeability of piperazine-based thin-film composite membrane via surface roughening using a highly organic-soluble additive	Kim In-Chul et al.	J. of Applied Polymer Science	136	47913
	Green Carbon Research Center	In vitro activity of DNF-3 against drug-resistant Mycobacterium tuberculosis	Lee Kee In et al.	International Journal of Antimicrobial Agents	54	69
	Green Carbon Research Center	Pharmacokinetic Study of NADPH Oxidase Inhibitor Ewha-18278, a Pyrazole Derivative	Lee Kee In et al.	Pharmaceutics	11	482
	Green Carbon Research Center	Sequestration of CO2 into CaCO3 using Carbonic Anhydrase Immobilization on Functionalized Aluminum oxide	Lim He Kyoung et al.	Applied Biochemistry and Microbiology	55	375
	Green Carbon Research Center	High performance polyacrylonitrile-supported forward osmosis membranes prepared via aromatic solvent-based interfacial polymerization	Park Hosik et al.	Separation and Purification Technology	212	449
	Green Carbon Research Center	Maneuvering the ordered mesoporosity of electrospun silica nanofibers for water harvesting	Park Hosik et al.	Microporous and Mesoporous Materials	281	23
	Green Carbon Research Center	Degradation of full aromatic polyamide NF membrane by sulfuric acid and hydrogen halides: Change of the surface/permeability properties	Park You In et al.	Polymer Degradation and Stability	162	1
	Green Carbon Research Center	Facile integration of halloysite nanotubes with bioadhesive as highly permeable interlayer in forward osmosis membranes	Park You In et al.	J. Ind. Eng. Chem.	73	276
	Green Carbon Research Center	On the effects of water exposure of as-synthesized LTA membranes on their structural properties and dehydration performances	Park You In et al.	Separation and Purification Technology	238	116493
	Green Carbon Research Center	Stability and pervaporation characteristics of PVA and its blend with PVAm membranes in a ternary feed mixture containing highly reactive epichlorohydrin	Park You In et al.	RSC Advances	9	5908
	Green Carbon Research Center	Surface-modified halloysite nanotube-embedded polyvinyl alcohol/polyvinyl amine blended membranes for pervaporation dehydration of water/isopropanol mixtures	Park You In et al.	Applied Surface Science	493	193
	Green Carbon Research Center	Surface-modified polyvinyl alcohol (PVA) membrane for pervaporation dehydration of epichlorohydrin (ECH), isopropanol (IPA), and water ternary feed mixtures	Park You In et al.	J. Ind. Eng. Chem.	81	185
	Green Carbon Research Center	Tailoring the porous structure of hollow fiber membranes for osmotic powergeneration applications via thermally assisted nonsolvent induced phaseseparation	Park You In et al.	J. of Membrane Science	579	329
	Green Carbon Research Center	Thin-film composite membranes comprising ultrathin hydrophilic polydopamine interlayer with graphene oxide for forward osmosis	Park You In et al.	Desalination	449	41
	Environment & Sustainable Resources Research Center	Dry reforming of methane over Ni-substituted CaZrNiOx catalyst prepared by the homogeneous deposition method	Chang Tae Sun et al.	Catalysis Communications	120	1
	Environment & Sustainable Resources Research Center	Effect of Hydrocarbon on DeNOx Performance of Selective Catalytic Reduction by a Combined Reductant over Cu-Containing Zeolite Catalysts	Chang Tae Sun et al.	ACS Catalysis	9	9800
	Environment & Sustainable Resources Research Center	Nickel Oxide-Silica Core-Shell Catalyst for Acetylene Hydroxycarbonylation	Chang Tae Sun et al.	Catalysis Communications	123	86
	Environment & Sustainable Resources Research Center	Plasma-assisted selective catalytic reduction for 2 low-temperature removal of NOx and soot simulant	Iljeong Heo et al.	Catalysts	9	853
	Environment & Sustainable Resources Research Center	Removal of NOx by selective catalytic reduction coupled with plasma under temperature fluctuation condition	Iljeong Heo et al.	J. Ind. Eng. Chem.	72	400
	Environment & Sustainable Resources Research Center	Role of phosphate in ruthenium-complex-sensitized TiO2 system for hydrogen production: Mechanism and kinetics	Iljeong Heo et al.	Catalysis Today	335	236
	Environment & Sustainable Resources Research Center	Ultrafast Charge Transfer Coupled with Lattice Phonons in Two-dimensional Covalent Organic Frameworks	Jin-Ook Baeg et al.	Nature Communications	10	1873
	Environment & Sustainable Resources Research Center	Optimization of an Axial Catalyst Profile in Methane Dry Reformer:	Kim Beom Sik et al.	Ind. Eng. Chem. Res.	58	17433
	Environment & Sustainable Resources Research Center	Spatially patterned Catalytic reactor for steam-CO2 reforming of methane	Kim Beom Sik et al.	Ind. Eng. Chem. Res.	58	18731
	Environment & Sustainable Resources Research Center	System-level analysis and life cycle assessment of	Kim Beom Sik et al.	Green Chemistry	21	3442
	Environment & Sustainable Resources Research Center	Effect of fatty acid-based anionic surfactants on the emulsion properties of self-emulsifying poly(ethylene-co-acrylic acid) waxes	Kim Yeong Wun et al.	J. Ind. Eng. Chem.	71	393
	Environment & Sustainable Resources Research Center	Feasibility of Unsaturated Fatty Acid Feedstocks as Green Alternatives in Bio-Oil Refinery	Kim Yeong Wun et al.	Biofpr	13	690
	Environment & Sustainable Resources Research Center	Synthesis and antiwear properties of dicarboxylic acid derivatives containing dialkyl dithiophosphate groups	Kim Yeong Wun et al.	Lubrication Science	31	103
	Environment & Sustainable Resources Research Center	Synthesis of PIBSI Derivatives Using Highly Reactive Polybutene and Their Friction Reducing Effects	Kim Yeong Wun et al.	Polymer(Korea)	43	394
	Environment & Sustainable Resources Research Center	Toughened and hydrophobically modified polyamide 11 copolymers with dimer acids derived from waste evegetable oil	Kim Yeong Wun et al.	J. of Applied Polymer Science	136	47174

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	Environment & Sustainable Resources Research Center	Highly regioselective and sustainable solar click reaction: A new Post-synthetic modified triazole organic polymer as recyclable photocatalyst for regioselective azide-alkyne cycloaddition reaction	Park No Joong et al.	Green Chemistry	21	2677
	Environment & Sustainable Resources Research Center	3D printable non-isocyanate polyurethanes with tunable material properties	Park, Ji Hoon et al.	Polymer Chemistry	10	4665
	Environment & Sustainable Resources Research Center	Lipase-immobilized chitosan-crosslinked magnetic nanoparticle as a biocatalyst for ring opening esterification of itaconic anhydride	Park, Ji Hoon et al.	Biochemical Engineering Journal	143	141
	Environment & Sustainable Resources Research Center	A Crack Repair Patch Based on Acrylated Epoxidized Soybean Oil	SHIN, JIHOON et al.	Applied Surface Science	476	276
	Environment & Sustainable Resources Research Center	thermal conductivity enhancement in electrospun poly(vinyl alcohol) and poly(vinyl alcohol)/cellulose nanocrystal composite nanofibers	SHIN, JIHOON et al.	Scientific Reports	9	3026
	Environment & Sustainable Resources Research Center	Metal-organic framework-mediated strategy for enhanced methane production on copper nanoparticles in electrochemical CO2 reduction	Youngkook Kwon et al.	Electrochimical Acta	306	28
	C1 Gas & Carbon Convergent Research Center	Paraffin-enabled graphene transfer	Hong Jin Yong et al.	Nature Communications	10	867
	C1 Gas & Carbon Convergent Research Center	Activated carbon fibers for toxic gas removal based on electrical investigation: Mechanistic study of p-type/n-type junction structures	Im Ji Sun et al.	Scientific Reports	9	14458
	C1 Gas & Carbon Convergent Research Center	Correlation verification of process factors and harmful gas adsorption properties for optimization of physical activation parameters of PAN-based carbon fibers	Im Ji Sun et al.	J. Ind. Eng. Chem.	80	152
	C1 Gas & Carbon Convergent Research Center	Effects of pressure-controlled reaction and blending of PFO and FCC-DO for mesophase pitch	Im Ji Sun et al.	Carbon Letters	29	203
	C1 Gas & Carbon Convergent Research Center	High-performance all-solid-state hybrid supercapacitors based on surface-embedded bimetallic oxide nanograins loaded onto carbon nanofiber and activated carbon	Im Ji Sun et al.	Electrochimical Acta	332	135494
	C1 Gas & Carbon Convergent Research Center	Micropore-structured activated carbon prepared by waste PET/petroleum-based pitch	Im Ji Sun et al.	Carbon Letters	29	385
	C1 Gas & Carbon Convergent Research Center	Optimization of the preparation conditions for pitch based anode to enhance the electrochemical properties of LIBs	Im Ji Sun et al.	J. Ind. Eng. Chem.	73	241
	C1 Gas & Carbon Convergent Research Center	Preparation of petroleum-based binder pitch for manufacturing thermally conductive carbon molded body and comparison with commercial coal-based binder pitch	Im Ji Sun et al.	Carbon Letters	-	-
	C1 Gas & Carbon Convergent Research Center	Preparation of pitch-based activated carbon with surface-treated fly ash for SO2 gas removal	Im Ji Sun et al.	Carbon Letters	-	-
	C1 Gas & Carbon Convergent Research Center	Bench-Scale Steam Reforming of Methane for Hydrogen Production	Jun Ki Won et al.	Catalysts	9	615
	C1 Gas & Carbon Convergent Research Center	Direct conversion of carbon dioxide to liquid fuels and synthetic natural gas	Jun Ki Won et al.	J. of CO2 Utilization	34	293
	C1 Gas & Carbon Convergent Research Center	Higher alcohol synthesis from syngas over xerogel-derived Co-Cu-Al2O3 catalyst with an enhanced metal proximity	Jun Ki Won et al.	Molecular Catalysis	475	110481

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	C1 Gas & Carbon Convergent Research Center	Light hydrocarbons to BTEX aromatics over Zn-modified hierarchical ZSM-5 combined with enhanced catalytic activity and stability	Jun Ki Won et al.	Microporous and Mesoporous Materials	284	316
	C1 Gas & Carbon Convergent Research Center	Linear a-olefin production with Na-promoted Fe-Zn catalysts via Fischer-Tropsch synthesis	Jun Ki Won et al.	RSC Advances	9	14176
	C1 Gas & Carbon Convergent Research Center	Mechanistic insights into Cu and K promoted Fe-catalyzed production of liquid hydrocarbons via CO2 hydrogenation	Jun Ki Won et al.	J. of CO2 Utilization	34	522
	C1 Gas & Carbon Convergent Research Center	Non-oxidative dehydroaromatization of methane over Mo/H-ZSM-5 catalysts: A detailed analysis of the reaction-regeneration cycle	Jun Ki Won et al.	Applied Catalysis B: Environmental	241	305
	C1 Gas & Carbon Convergent Research Center	A Review on Recent Progress in the Aspect of Stability of Oxygen Reduction Electrocatalysts for Proton-Exchange Membrane Fuel Cell: Quantum Mechanics and Experimental Approaches	Kim Hyung Ju et al.	Energy Technology	7	1900312
	C1 Gas & Carbon Convergent Research Center	Improved Ion-Transfer Behavior and Capacitive Energy Storage Characteristics of SnO2 Nanospacer-Incorporated Reduced Graphene Oxide Electrodes	Kim Hyung Ju et al.	ChemElectroChem	6	2503
	C1 Gas & Carbon Convergent Research Center	Integrated strategy for concurrent production of furfuryl alcohol and glycerol oxygenates	Kim Hyung Ju et al.	J. Ind. Eng. Chem.	73	268
	C1 Gas & Carbon Convergent Research Center	Cost-effective and eco-friendly synthesis of MIL-101(Cr) from waste hexavalent chromium and its application for carbon monoxide separation	Kim Jeong Hoon et al.	J. Ind. Eng. Chem.	80	345
	C1 Gas & Carbon Convergent Research Center	Electrodialytic separation of volatile fatty acids from hydrogen fermented food wastes	Kim Jeong Hoon et al.	International Journal of Hydrogen Energy	44	3356
	C1 Gas & Carbon Convergent Research Center	Equilibrium and kinetics of nitrous oxide, oxygen and nitrogen adsorption on activated carbon and carbon molecular sieve	Kim Jeong Hoon et al.	Separation and Purification Technology	223	63
	C1 Gas & Carbon Convergent Research Center	Highly CO selective Cu(I)-doped MIL-100(Fe) adsorbent with high CO/CO2 selectivity due to π complexation: Effects of Cu(I) loading and activation temperature	Kim Jeong Hoon et al.	Microporous and Mesoporous Materials	274	17
	C1 Gas & Carbon Convergent Research Center	Hybrid membranes based on ionic-liquid-functionalized poly(vinyl benzene chloride) beads for CO2 capture	Kim Jeong Hoon et al.	J. of Membrane Science	572	365
	C1 Gas & Carbon Convergent Research Center	Low-temperature Cu(I) loading on a mesoporous Metal-Organic framework for adsorptive separation of C3H6/C3H8 mixtures	Kim Jeong Hoon et al.	Microporous and Mesoporous Materials	279	271
	C1 Gas & Carbon Convergent Research Center	Mixed matrix membranes incorporated with three-dimensionally ordered mesopore imprinted (3DOm-i) zeolite	Kim Jeong Hoon et al.	Separation and Purification Technology	210	29
	C1 Gas & Carbon Convergent Research Center	Palladium-copper membrane modules for hydrogen separation at elevated temperature and pressure	Kim Jeong Hoon et al.	Korean Journal of Chemical Engineering	36	563
	C1 Gas & Carbon Convergent Research Center	Solid-state facilitated transport of carbon monoxide through mixed matrix membranes	Kim Jeong Hoon et al.	J. of Membrane Science	592	117373
	C1 Gas & Carbon Convergent Research Center	Surface-attached brush-type CO2-philic poly(PEGMA)/PSf composite membranes by UV/Ozone-induced graft polymerization: fabrication, characterization and gas separation properties	Kim Jeong Hoon et al.	J. of Membrane Science	589	117214
	C1 Gas & Carbon Convergent Research Center	UV-crosslinked poly(PEGMA-co-MMA-co-BPMA) membranes: Synthesis, characterization, and CO2/N2 and CO2/CO separation	Kim Jeong Hoon et al.	J. of Membrane Science	587	117167
	C1 Gas & Carbon Convergent Research Center	One-pot di- and polysaccharides conversion to highly selective 2,5-dimethylfuran over Cu-Pd/Amino-functionalized Zr-based metal-organic framework (UiO-66(NH2))@SGO tandem catalyst	Kim Seok Ki et al.	Applied Catalysis B: Environmental	243	337

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	C1 Gas & Carbon Convergent Research Center	Nonoxidative direct conversion of methane on silica-based iron catalysts: effect of catalytic surface	Kim Yong Tae et al.	ACS Catalysis	9	7984
	C1 Gas & Carbon Convergent Research Center	Recent advances in hydrodeoxygenation of biomass-derived oxygenates over heterogeneous catalysts	Kim Yong Tae et al.	Green Chemistry	21	3715
	C1 Gas & Carbon Convergent Research Center	Control of Hierarchical Structure and Framework-Al Distribution of ZSM-5 via Adjusting Crystallization Temperature and Their Effects on Methanol Conversion	Kwak Geun Jae et al.	ACS Catalysis	9	2880
	C1 Gas & Carbon Convergent Research Center	Optimization-based assessment framework for carbon utilization strategies: Energy production from coke oven gas	Kwak Geun Jae et al.	Energy Conversion and Management	187	1
	C1 Gas & Carbon Convergent Research Center	Study on CH4 dry reforming process by high power inductively coupled plasma torch at atmospheric pressure	Kwak Geun Jae et al.	Current Applied Physics	20	196
	C1 Gas & Carbon Convergent Research Center	Techno-economic evaluation of the integrated polygeneration system of methanol, power and heat production from coke oven gas	Kwak Geun Jae et al.	Energy Conversion and Management	182	240
	C1 Gas & Carbon Convergent Research Center	A review on the Mo-precursors for catalytic hydroconversion of heavy oil	Lee Chul Wee et al.	J. Ind. Eng. Chem.	76	1
	C1 Gas & Carbon Convergent Research Center	Structure comparison of asphaltene aggregates from hydrothermal and catalytic hydrothermal cracking of C5-isolated asphaltene	Lee Chul Wee et al.	Fuel	235	677
	C1 Gas & Carbon Convergent Research Center	Synthesis of noble molybdenum and tungsten complexes for hydrocracking catalyst of heavy oil	Lee Chul Wee et al.	J. Ind. Eng. Chem.	72	408
	C1 Gas & Carbon Convergent Research Center	Exfoliated graphene nanosheets as high-power anodes for lithium-ion batteries	Lee Jea Uk et al.	Carbon Letters	29	81
	C1 Gas & Carbon Convergent Research Center	Highly stretchable fiber transistors with all-stretchable electronic components and graphene hybrid electrodes	Lee Jea Uk et al.	Organic Electronics	69	302
	C1 Gas & Carbon Convergent Research Center	Mass-Produced Electorchemically Exfoliated Grapene for Untrahigh Thermally Conductive Paper Using a Multimetal Electrode System	Lee Jea Uk et al.	ADVANCED MATERIALS INTEFACES	6	1900095
	C1 Gas & Carbon Convergent Research Center	Preparation of electrochemically exfoliated graphene sheets using DC switching voltages	Lee Jea Uk et al.	Carbon Letters	-	-
	C1 Gas & Carbon Convergent Research Center	CFD modeling of a compact reactor for methanol synthesis: Maximizing productivity with increased thermal controllability	Lee Yun Jo et al.	International J. of Heat and Mass Transfer	145	118776
	C1 Gas & Carbon Convergent Research Center	Design of highly efficient adsorbents for removal of gaseous methyl iodide	Lee Yun Jo et al.	Chemical Engineering J.	373	1003
	C1 Gas & Carbon Convergent Research Center	Chemically Mofified Chitosan as a Biopolymer Support in Copper-catalyzed ipso-Hydrxylation of Arylboronic Acids in Water	Park Soo Youl et al.	Bull. Korean Chem. Soc.	40	465
	C1 Gas & Carbon Convergent Research Center	Effect of the pretreated pyrolysis fuel oil: coal tar pitch ratio on the spinnability and oxidation properties of isotropic pitch precursors and the mechanical properties of derived carbon fibers	Young-Pyo Jeon et al.	Carbon Letters	29	193
	C1 Gas & Carbon Convergent Research Center	Improved understanding of the molecular structure of pyrolysis fuel oil: towards its utilization as a raw material for mesophase pitch synthesis	Young-Pyo Jeon et al.	Carbon Letters	29	307
	C1 Gas & Carbon Convergent Research Center	Preparation of petroleum impregnating pitches from pyrolysis fuel oil using two-step heat treatments	Young-Pyo Jeon et al.	Carbon Letters	29	369
	C1 Gas & Carbon Convergent Research Center	Shortening Stabilization Time Using Pressurized Air Flow in Manufacturing Mesophase Pitch-Based Carbon Fiber	Young-Pyo Jeon et al.	Polymers	11	1911
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	Process Design & Development Research Center	Effect of Metal Oxide-Support Interactions on Ethylene Oligomerization over Nickel Oxide/Silica-Alumina Catalysts	Chae Ho Jeong et al.	Catalysts	9	933
	Process Design & Development Research Center	Effect of Structure-Controlled Ruthenium Oxide by Nanocasting in Electrocatalytic Oxygen and Chlorine Evolution Reactions in Acidic Conditions	Chae Ho Jeong et al.	Catalysts	9	549
	Process Design & Development Research Center	Effect of Direct Reduction Treatment on Pt–Sn/Al2O3 Catalyst for Propane Dehydrogenation	Jeong-Rang Kim et al.	Catalysts	9	446
	Process Design & Development Research Center	Ligand Effect of Shape-Controlled β-Palladium Hydride Nanocrystals on Liquid-Fuel Oxidation Reactions	Jeong-Rang Kim et al.	CHEMISTRY OF MATERIALS	31	5663
	Process Design & Development Research Center	Formation of ordered macroporous ZnFe2O4 anode materials for highly reversible lithium storage	Kim Youngmin et al.	Chemical Engineering J.	372	363
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	Thin Film Materials Research Center	Lubricant-Added Conductive Composite for Direct Writing of a Stretchable Electrode	Choi Young Min et al.	ACS Appl. Mater. Interfaces	11	48459
	Thin Film Materials Research Center	Printable Thick Copper Conductors from Optically Modulated Multidimensional Particle Mixtures	Choi Young Min et al.	ACS Appl. Mater. Interfaces	11	20134
	Thin Film Materials Research Center	Three-dimensionally printed pressure sensor arrays from hysteresis-less stretchable piezoresistive composites	Choi Young Min et al.	RCS Advances	9	39993
	Thin Film Materials Research Center	Three-Dimensionally Printed Stretchable Conductors from Surfactant-Mediated Composite Pastes	Choi Young Min et al.	ACS Appl. Mater. Interfaces	11	12622
	Thin Film Materials Research Center	High-Performance Thin-Film Transistors of Quaternary Indium-Tin Oxide Films Grown by Atomic Layer Deposition	CHUNG, TAEK-MO et al.	ACS Appl. Mater. Interfaces	11	14892
	Thin Film Materials Research Center	Phase-controlled SnO2 and SnO growth by atomic layer deposition using Bis(N-ethoxy-2,2-dimethyl propanamido)tin precursor	CHUNG, TAEK-MO et al.	Ceramics International	45	5124
	Thin Film Materials Research Center	SnO-decorated TiO2 nanoparticle with enhanced photocatalytic performance for methylene blue degradation	CHUNG, TAEK-MO et al.	Applied Surface Science	480	1089
	Thin Film Materials Research Center	Atomic Layer Deposition of Nanocrystalline-As-Deposited (GeTe)x(Sb2Te3)1–x Films for Endurable Phase Change Memory	Eom Taeyong et al.	CHEMISTRY OF MATERIALS	31	8752
	Thin Film Materials Research Center	Effect of Electrode Material on the Crystallization of GeTe Grown by Atomic Layer Deposition for Phase Change Random Access Memory	Eom Taeyong et al.	Micromachines	10	281
	Thin Film Materials Research Center	A synergistic combination of zinc oxide nanowires array with dual-functional zeolitic imidazolate framework-8 for hybrid nanomaterials-based gas sensors	Jung Ha Kyun et al.	Composites Part B: Engineering	180	107552
	Thin Film Materials Research Center	Amplifying gas sensor performance by embedding a cellulose-based buffer layer in organic transistors	Jung Ha Kyun et al.	J. of Materials Chemistry C	7	14504

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	Thin Film Materials Research Center	Foldable and water-resist electrodes based on carbon nanotubes/methyl cellulose hybrid conducting papers	Jung Ha Kyun et al.	Composites Part B: Engineering	160	512
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	Thin Film Materials Research Center	Piezoresistive Behaviour of Additively Manufactured Multi-Walled Carbon Nanotube/ Thermoplastic Polyurethane Nanocomposites	Jung Sung Mook et al.	Materials	12	2613
	Thin Film Materials Research Center	A facile synthetic route to tungsten diselenide using a new precursor containing a long alkyl chain cation for multifunctional electronic and optoelectronic applications	Kim Chang Gyoun et al.	RCS Advances	9	6169
	Thin Film Materials Research Center	New red-emitting phosphor RbxK3-xSiF7: Mn4+(x= 0,1,2,3): DFT predictions and synthesis	Kim Chang Hae et al.	RCS Advances	9	39589
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	Energy Materials Research Center	Macroporous carbon nanofiber decorated with platinum nanorods as free-standing cathodes for high-performance Li-O2 batteries	Kang Yongku et al.	Carbon	154	448
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-	Eco-Friendly New Materials Research Center	ARS2 plays divers roles in DNA damage response, fungal development, and pathogenesis in the plant pathogenic fungus Fusarium graminearum	Choi Gyung Ja et al.	Front. Microbiol.	10	2326
	Eco-Friendly New Materials Research Center	Control of root-knot nematodes using Waltheria indica producing 4-quinolone alkaloids	Choi Gyung Ja et al.	Pest Management Science	75	2264
	Eco-Friendly New Materials Research Center	Discovery of new triterpenoid saponins isolated from Maesa japonica with antifungal activity against rice blast fungus Magnaporthe oryzae	Choi Gyung Ja et al.	J. Agric. Food Chem.	67	7706
	Eco-Friendly New Materials Research Center	Physical localization of root-knot nematode (Meloidogyne incognita) resistance locus Me7 in pepper (Capsicum annuum)	Choi Gyung Ja et al.	Front. Plant Sci.	10	886
	Eco-Friendly New Materials Research Center	Isolation, identification and characterization of Streptomyces metabolites as a potential bioherbicide	Choi Jung Sub et al.	PLOS ONE	14	e0222933
	Eco-Friendly New Materials Research Center	Anti-cancer activity of the novel 2-hydroxydiarylamide derivatives IMD-0354 and KRT1853 through suppression of cancer cell invasion, proliferation, and survival mediated by TMPRSS4	Lee Ill Young et al.	Scientific Reports	9	10003
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	Center for Advanced Specialty Chemicals	A ball milling-based one-step transformation of chitin biomass to organo-dispersible strong nanofibers passing highly time and energy consuming processes	Park Jong Mok et al.	Int. J. Biol. Macromol.	125	660
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	Center for Bio-based Chemistry	Recent Advances in the Metabolic Engineering of Klebsiella pneumoniae: A Potential Platform Microorganism for Biorefineries	Kim Hee Taek et al.	Biotechnol. Bioprocess Eng.	24	48
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	Chemical Analysis Center	Chemically Denatured Structures of Porcine Pepsin using Small-Angle X-ray Scattering	Rho Ye Cheol et al.	Polymers	11	2104
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	CCP	Adsorptive removal of nerve-agent simulant with zirconium-based metalorganic	Chang Jong-San et al.	Microporous and Mesoporous Materials	285	61
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	CCP	Modeling of reaction and deactivation kinetics in methanol-to-olefins (MTO) reaction on SAPO-34	Kim Chul Ung et al.	Ind. Eng. Chem. Res.	58	13227
	CCP	Preparation of SSZ-13 zeolites from beta zeolite and their application in the conversion of ethylene to propylene	Kim Chul Ung et al.	Chemical Engineering J.	377	119546
	CCP	Propane to Light Olefins by One-Pot Cascade and Series Reactions	Kim Chul Ung et al.	Chemical Engineering J.	377	120114
	CCP	Synthesis of SSZ-13 zeolite in the presence of dimethylethylcyclohexyl ammonium ion and direct conversion of ethylene to propylene with the SSZ-13	Kim Chul Ung et al.	Chemical Engineering J.	377	120116
	CCP	Boosting the electrocatalytic glycerol oxidation performance with highly-dispersed Pt nanoclusters loaded on 3D graphene-like microporous carbon	Kim Tae Wan et al.	Applied Catalysis B: Environmental	245	555
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	CCP	Effect of a Li2SiO3 phase in lithium silicate-based sorbents for CO2 capture at high temperatures	Park Yong Ki et al.	Separation and Purification Technology	214	104
	CCP	Novel regenerable solid sorbents based on lithium orthosilicate for carbon dioxide capture at high temperatures	Park Yong Ki et al.	Separation and Purification Technology	214	120
	CCP	Regenerable sodium-based lithium silicate sorbents with a new mechanism for CO2 capture at high temperature	Park Yong Ki et al.	Renewable Energy	144	180
	CCP	The swing adsorption reactor cluster (SARC) for post combustion CO2 capture: Experimental proof-of-principle	Park Yong Ki et al.	Chemical Engineering J.	377	120145
	CEVI	A novel green solvent alternative for polymeric membrane preparation via nonsolvent-induced phase separation (NIPS)	Kim Jung et al.	J. of Membrane Science	574	44
	CEVI	Bio-inspired robust membranes nanoengineered from interpenetrating polymer networks of polybenzimidazole/polydopamine	Kim Jung et al.	ACS Nano	13	125
	CEVI	Densification-induced Hollow Fiber Membranes using Crosslinked Thermally Rearranged (XTR) Polymer for CO2 Capture	Kim Jung et al.	J. of Membrane Science	573	393
	CEVI	Cell Type-Specific Interferon-χ-mediated Antagonism of KSHV Lytic Replication	Kim Seong Jun et al.	Scientific Reports	9	2372
	CEVI	Zika Virus Proteins NS2A and NS4A Are Major Antagonists that Reduce IFN-β Promoter Activity Induced by the MDA5/RIG-I Signaling Pathway	Kim Seong Jun et al.	J. Microbiol. Biotechnol.	29	1665
	CEVI	Ganglioside GQ1b ameliorates cognitive impairments in an Alzheimer's disease mouse model, and causes reduction of amyloid precursor protein.	Kim, Hong Gi et al.	Scientific Reports	9	8512
	CEVI	Toosendanin From Melia Fructus Suppresses Influenza A Virus Infection by Altering Nuclear Localization of Viral Polymerase PA Protein.	Kwon SUN OH et al.	Front. Pharmacol.	10	1025
	CEVI	Osthenol, a prenylated coumarin, as a monoamine oxidase A inhibitor with high selectivity	Park Chul Min et al.	Bioorg. Med. Chem. Lett.	29	839
	CEVI	Discovery of (E)-5,5-difluoro-1-[2-[5-(3-fluorophenyl)pyridin-2-yl]vinyl] octahydrospiro(indene-2,5'-oxazolidin)-2'-one as a PAR-1 antagonist	Song Jong Hwan et al.	Bull. Korean Chem. Soc.	40	658
	CEVI	Natural Bis-Benzylisoquinoline Alkaloids-Tetrandrine, Fangchinoline, and Cepharanthine, Inhibit Human Coronavirus OC43 Infection of MRC-5 Human Lung Cells	Song Jong Hwan et al.	Biomolecules	9	696
	CEVI	Study on the 2-phenylchroman-4-one derivatives and their anti-MERS-CoV activities	Song Jong Hwan et al.	Bull. Korean Chem. Soc.	40	906
	CEVI	Synthesis and biological evaluation of 3-acyl-2-phenylamino-1,4-dihydroquinolin-4(1H)-one derivatives as potential MERS-CoV Inhibitors	Song Jong Hwan et al.	Bioorg. Med. Chem. Lett.	29	126727
	CEVI	Adsorption characteristics of benzene on resin-based activated carbon under humid conditions	Suh Jeong Kwon et al.	J. Ind. Eng. Chem.	71	242
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PCT	AN, Ki-Seok	Manufacturing method of graphene oxides	2019-04-05	PCT/KR2019/004056
PCT	Chae Ho Jeong	A chlorination process using a crystalline carbon material as a catalyst	2019-04-23	PCT/KR2019/004877
PCT	Chae Ho Jeong	Method of methylchloride production by multi-reaction process	2019-09-17	PCT/KR2019/011970
PCT	Chang Jong-San	Energy saving type air dryer and preparing method of dry air using the same	2019-10-25	PCT/KR2019/014171
PCT	Chang Jong-San	Novel metal-organic framework having porous structure comprising Zirconium cluster secondary building units and multitopic organic linker molecules	2019-05-31	PCT/KR2019/006620
USA	Chang Jong-San	Organic-inorganic porous hybrid material containing intramolecular anhydride groups, adsorbent composition comprising the same and usage thereof for the separation of gaseous hydrocarbon mixtures	2019-04-17	16/342937
USA	Chang Tae Sun	Thermally Stable Monolith Catalysts for MethaneReforming and Preparing Method of the Same	2019-11-13	16/613,119
PCT	CHO SONG YUN	Carbon nanotube foam and thermoelectric comprising carbon nanotube foam	2019-12-31	PCT/KR2019/018825
CHN	Cho Sung Yun	Pyrimidine derivative compound, optical isomer thereof, or pharmaceutically acceptable salt thereof, and composition for preventing or treating tyro 3 related disease comprising same as active ingredient	2019-12-31	2.0188E+11
EPO	Cho Sung Yun	Pyrimidine derivative compound, optical isomer thereof, or pharmaceutically acceptable salt thereof, and composition for preventing or treating tyro 4 related disease comprising same as active ingredient	2019-11-04	18794872.4
JPN	Cho Sung Yun	Pyrimidine derivative compound, optical isomer thereof, or pharmaceutically acceptable salt thereof, and composition for preventing or treating tyro 5 related disease comprising same as active ingredient	2019-11-01	2019-560304
USA	Cho Sung Yun	Pyrimidine derivative compound, optical isomer thereof, or pharmaceutically acceptable salt thereof, and composition for preventing or treating tyro 6 related disease comprising same as active ingredient	2019-11-01	16/610327
CHN	Choi, Won Choon	A method for producing olefin by using circulating fluidization process	2019-12-02	2.0188E+11
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KSA	Choi, Won Choon	A method for producing olefin by using circulating fluidization process	2019-10-30	519410416
USA	Choi, Won Choon	A method for producing olefin by using circulating fluidization process	2019-06-17	16/471383
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JPN	Choi, Won Choon	A method for producing olefin comprising reduction pretreatment	2019-12-02	567242/2019
KSA	Choi, Won Choon	A method for producing olefin comprising reduction pretreatment	2019-10-29	519410414
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USA	Choi, Won Choon	Catalyst for manufacturing olefin and continuousreaction regeneration method for manufacturing olefinusing the same	2019-05-14	16/349843
CHN	Choi, Won Choon	Catalyst having enhanced stability, conversion ratio and selectivity for manufacturing olefin, and A method thereof	2019-12-02	2.0188E+11
JPN	Choi, Won Choon	Catalyst having enhanced stability, conversion ratio and selectivity for manufacturing olefin, and A method thereof	2019-12-02	567355/2019
KSA	Choi, Won Choon	Catalyst having enhanced stability, conversion ratio and selectivity for manufacturing olefin, and A method thereof	2019-10-30	519410415
USA	Choi, Won Choon	Catalyst having enhanced stability, conversion ratio and selectivity for manufacturing olefin, and A method thereof	2019-06-11	16/468556
PCT	CHUNG, TAEK-MO	Group IV transition metal compounds, preparation method thereof and process for the formation of thin films using the same	2019-10-18	PCT/KR2019/013698
CHN	Ha Jae Du	Novel piperidine-2,6-dione derivatives and use thereof	2019-11-12	2.0188E+11
EPO	Ha Jae Du	Novel piperidine-2,6-dione derivatives and use thereof	2019-10-28	18798940.5
JPN	Ha Jae Du	Novel piperidine-2,6-dione derivatives and use thereof	2019-11-06	561172/2019
PCT	Ha Jae Du	Novel piperidine-2,6-dione derivatives and use thereof	2019-11-07	PCT/KR2019/015061
USA	Ha Jae Du	Novel piperidine-2,6-dione derivatives and use thereof	2019-10-31	16/609805
PCT	Heeyeong Cho	Novel tricyclic compound as IRAK4 inhibitors	2019-11-20	PCT/KR2019/015948
EPO	Hwang Sung Yeon	Method for preparing poly(arylene ether) copolymers containing isohexide unit and poly(arylene ether) copolymers prepared therefrom	2019-12-04	18831710.1
USA	Hwang Sung Yeon	PBS composite material and method for producing same	2019-12-20	16/625,260
JPN	Hwang Sung Yeon	Self-healable thermoplastic polyurethane copolymer containing aromatic disulfide bonds, and method for preparation thereof	2019-10-09	PCT/KR2018/007866
USA	Hwang Sung Yeon	Self-healable thermoplastic polyurethane copolymer containing aromatic disulfide bonds, and method for preparation thereof	2019-12-02	16/618582
PCT	Hwang Young Kyu	The Catalyst for preparing 1,2-pentanediol and Method for preparing 1,2-pentanediol using the same	2019-07-04	PCT/KR2019/008195
PCT	Iljeong Heo	Automatically pressure-controlled gas generator	2019-03-26	PCT/KR2019/003468
PCT	Iljeong Heo	CDR reactor for preventing catalyst inactivation having multi-layered catalyst	2019-11-22	PCT/KR2019/016143
PCT	Iljeong Heo	deNOx catalyst with improved NOx reduction performance, method of manufacturing the same and NOx abatement method	2019-06-28	PCT/KR2019/007916
USA	Iljeong Heo	Electrochemical system for producing ammonia from nitrogen oxides and preparation method thereof	2019-06-21	16/448692
USA	Iljeong Heo	Exhaust gas post processing apparatus	2019-11-25	16/694508

Country	Inventor	Title	Application Date	Application Number
USA	Jeon Jong Yeol	Catalyst for olefin metathesis and method for preparing thereof	2019-02-28	16/329469
PCT	Jeyoung Park	Method for producing aramid nano fiber dispersion	2019-03-19	PCT/KR2019/003169
JPN	Joo Jeong Chan	Recombinant corynebacterium glutamicum strain for producing glutaric acid and method of producing glutaric acid by using same	2019-08-22	2019-151894
USA	Joo Jeong Chan	Recombinant corynebacterium glutamicum strain for producing glutaric acid and method of producing glutaric acid by using same	2019-08-22	16/548093
PCT	Jun Ki Won	Energy-Efficient System and Method for Direct Hydrogenation of Carbon Dioxide	2019-05-29	PCT/KR2019/006437
PCT	Jun Ki Won	System for producing syngas from carbon dioxide through a redox process and the method thereof	2019-03-28	PCT/KR2019/003671
PCT	Jun Kun	Carbazole multi β-oxime ester derivative compounds and, photopolymerization initiator and photoresist composition containing the same	2019-12-27	PCT/KR2019/018657
USA	Ka Jae Won	Updatable holographic writing method with high sensitivity and fast dynamics proprties utilizing photo-responsable polymer material	2019-11-08	16/678963
PCT	Kang Na Young	Catalyst for manufacturing light olefin, method for manufacturing the same, and method for manufacturing light olifn using the same	2019-05-02	PCT/KR2019/005245
PCT	Kang Na Young	Method for manufacturing ZSM-5 type zeolite	2019-05-02	PCT/KR2019/005992
USA	Kim Byoung Gak	A compound having bis phenylene group substituted with alkylamide, Composition for controlling polyphenylene polymer flowability comprising thereof and method of polyphenylene polymer flowability cont	2019-01-15	16/248556
PCT	Kim Hyoung Rae	Novel quinolinone derivatives, preparation method thereof, and an antiviral composition containing the same as an active ingredient	2019-09-11	PCT/KR2019/011856
USA	Kim Jeong Hoon	BCDA-based semi-alicyclic polyimide membrane materials for gas separation and the preparation methods	2019-11-20	16/689651
CHN	Kim Jeong Hoon	Purification technology for the recovery of high purity N2O from emission gases in adipic acid production process	2019-01-18	2.0178E+11
PCT	Kim Mee hyein	Novel nucleoside or nucleotide derivatives, and use thereof	2019-01-24	PCT/KR2019/001036
PCT	Kim Seong Jun	Cell penetrating peptide derived from human CLK2 and cargo delivery system using the same	2019-12-16	PCT/KR2019/017828
PCT	Kim Seong Jun	Cell penetrating peptide derived from human GPATCH4 and cargo delivery system using the same	2019-12-16	PCT/KR2019/017830
PCT	Kim Seong Jun	Cell penetrating peptide derived from human LRRC24 and cargo delivery system using the same	2019-12-16	PCT/KR2019/017829
PCT	Kim Seong Jun	Vectors for expressing recombinant antigens using CRISPR and method for simultaneously multiplexing thereof	2019-09-11	PCT/KR2019/011830
PCT	Kim Yong Tae	Fishcer-Tropsch Catalysts for Preparing Long Chain Olefin and Method for Preparing Long Chain Olefin Using the Same	2019-02-13	PCT/KR2019/001269
PCT	Kim Yong Tae	Method for preparing catalysts for oxygen-free direct conversion of methane	2019-09-24	PCT/KR2019/012390
USA	Kim Yong Tae	Reactor for Oxygen-free Direct Conversion of Methane and Method for Preparing Aromatic Hydrocarbon and Ethylene Using the Same	2019-10-30	16/667,936

Country	Inventor	Title	Application Date	Application Number
AUS	Ko Young Kwan	Pyridine derivatives possessing isoxazoline ring and their use as herbicides	2019-01-23	2017287716
EPO	Ko Young Kwan	Pyridine derivatives possessing isoxazoline ring and their use as herbicides	2019-01-10	17820499.6
INA	Ko Young Kwan	Pyridine derivatives possessing isoxazoline ring and their use as herbicides	2019-01-16	PID201900387
IND	Ko Young Kwan	Pyridine derivatives possessing isoxazoline ring and their use as herbicides	2019-01-10	2.01917E+11
VIE	Ko Young Kwan	Pyridine derivatives possessing isoxazoline ring and their use as herbicides	2019-01-23	1-2019-00410
PCT	Kwak Geun Jae	Catalytic Structure for Fischer—Tropsch Synthesis	2019-05-31	PCT/KR2019/006595
PCT	Kwak Geun Jae	Direct Method for Preparing Monocyclic Aromatics by Using Syngas	2019-10-30	PCT/KR2019/014465
PCT	Kwak Geun Jae	Stabilizing electric power system using plasma reforming module	2019-07-17	PCT/KR2019/008829
CHN	Kwan-Young Jeong	Composition for reinforcement of pancreas function	2019-03-29	2.0178E+11
EPO	Kwan-Young Jeong	Composition for reinforcement of pancreas function	2019-02-27	17839857.4
JPN	Kwan-Young Jeong	Composition for reinforcement of pancreas function	2019-02-12	507773/2019
USA	Kwan-Young Jeong	Composition for reinforcement of pancreas function	2019-02-12	16/325073
JPN	Lee Chang Jin	Oxime ester based photoinitiator and photosensitive compositions including the same	2019-01-08	500541/2019
PCT	Lee Chang Jin	Pigment particles with improved in insulation, dispersibility and resistance	2019-05-23	PCT/KR2019/006180
PCT	Lee Chul Wee	Catalyst precursor for hydrocracking and method for hydrocracking of heavy oil using thereof	2019-06-27	PCT/KR2019/007776
EPO	Lee Hyeon-Kyu	Pharmaceutical Composition Containing DUSP1 Inhibitor	2019-10-22	18783771.1
USA	Lee Hyeon-Kyu	Pharmaceutical Composition Containing DUSP1 Inhibitor	2019-10-09	16/603993
PCT	Lee Hyuk	Compounds for inhibiting TNIK and medical uses thereof	2019-01-31	PCT/KR2019/001403
PCT	Lee Hyuk	Hetero ring-fused phenyl compounds for inhibiting TNIK and medical uses thereof	2019-01-31	PCT/KR2019/001404
PCT	Lee Jaemin	Composition for organic electroluminescent device and novel organic electroluminescent and organic electroluminescent device comprising the same	2019-07-04	PCT/KR2019/008179
PCT	Lee Jong Cheol	Hybrid self-chargeable battery structure	2019-08-02	PCT/KR2019/009664
PCT	Lee Joo Youn	Human NADP-dependent steroid dehydrogenase-like (NSDHL) enzyme inhibitors and pharmaceutical composition for use in preventing or treating cancer or hypercholesterolemia containing the same as an active ingredient	2019-08-29	PCT/KR2019/011094

Country	Inventor	Title	Application Date	Application Number
CHN	Lee Joo Youn	Pharmaceutical composition for prevention and treatment of DYRK1A related diseases comprising pyridine compounds	2019-08-14	2.0178E+11
EPO	Lee Joo Youn	Pharmaceutical composition for prevention and treatment of DYRK1A related diseases comprising pyridine compounds	2019-06-19	17881667.4
JPN	Lee Joo Youn	Pharmaceutical composition for prevention and treatment of DYRK1A related diseases comprising pyridine compounds	2019-06-14	532126/2019
USA	Lee Joo Youn	Pharmaceutical composition for prevention and treatment of DYRK1A related diseases comprising pyridine compounds	2019-06-14	16/470014
PCT	Lee Kwangho	Isoindolin-1-one derivatives, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer containing the same as an active ingredient	2019-08-12	PCT/KR2019/010202
USA	Lee Kwangho	Novel [1,2,4]Triazolo[4,3-a]quinoxaline derivatives, preparation method therof, and pharmaceutical composition for use in preventing or treating BET protein related diseases containing the same as an active ingredient	2019-07-25	16/480908
BRA	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-05-08	BR 1120190094326
CAN	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-05-08	3043295
CHN	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-06-26	2.0178E+11
EPO	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-06-06	17868973.3
HKG	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-10-16	19131037.4
JPN	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-05-08	2019-535276
USA	Lee Kwangho	Novel pyrimidine compounds, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer and inflammation disease containing the same as an active ingredient	2019-05-03	16/347480
PCT	Lee Sang Goo	Method of preparing heptafluoroisopropyl trifluorovinyl ether	2019-08-28	PCT/KR2019/011008
PCT	Lee, Jeong O	Graphene complex for electron microscope observation and method for producing sample substrate	2019-12-06	PCT/KR2019/017192
PCT	Lee, Jeong O	Preparing method of sensor device and sensor device made thereby	2019-07-02	PCT/KR2019/008023
AUS	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-02-07	2017304434
BRA	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-01-29	BR112019001805-0
CAN	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-01-28	3032270
CHN	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-01-29	2.0178E+11
EPO	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-02-04	17834751.4

Country	Inventor	Title	Application Date	Application Number
INA	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-02-26	P-00201901661
IND	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-01-14	2.01917E+11
MEX	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-01-28	MX/A/2019/001202
RUS	Lim Hwan Jung	Compound inhibiting formation of C-MYC/MAX/DNA complex	2019-02-27	2019105499
PCT	Lim Hwan Jung	Compound inhibiting YAP-TEAD interaction and Pharmaceutical Composition for Treating or Preventing Cancer comprising the same as an active ingredient	2019-11-08	PCT/KR2019/015172
PCT	Lim Hwan Jung	Pharmaceutical Composition for Treating or Preventing Cancer comprising compound inhibiting interactions between YAP and TEAD	2019-09-04	PCT/KR2019/011422
AUS	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-02-07	2017304546
BRA	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-01-29	BR 11 2019 001808-5
CAN	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-01-28	3032293
CHN	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-01-29	2.0178E+11
EPO	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-02-08	17834790.2
INA	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-02-26	P-00201901662
IND	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-02-18	2.01917E+11
JPN	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-01-25	503984/2019
MEX	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-01-28	MX/A/2019/001210
RUS	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-02-27	2019105506
USA	Lim Hwan Jung	Pharmaceutical compounds having anti-cancer effect	2019-01-29	16/321631
PCT	Lim Hwan Jung	Pyrazole carboxamide compounds containing organosulfur group and insecticide composition comprising same	2019-01-31	PCT/KR2019/001339
USA	Noh, Jun Hong	Highly Stable Inorganic—Organic Hybrid Solar Cells	2019-01-29	16/260647
PCT	Oh Kwang-Seok	Compound for inhibiting PDE9A and medical uses thereof	2019-12-05	PCT/KR2019/017127
PCT	Oh Kwang-Seok	Compound for inhibiting PDE9A and medical uses thereof	2019-12-05	PCT/KR2019/017128
PCT	Park Dae Sung	A catalyst for manufacturing olefin, including oxygencarrier material and dehydrogenation catalyst	2019-05-14	PCT/KR2019/005548
PCT	Park Dae Sung	A method for producing olefin by using circulating fluidization process	2019-12-04	PCT/KR2019/016985
PCT	Park Dae Sung	Catalyst having enhanced conversion ratio and selectivity for manufacturing olefin, and a manufacturing method thereof	2019-04-15	PCT/KR2019/004511

Country	Inventor	Title	Application Date	Application Number
PCT	Park In Joon	The advanced preparation method and apparatus for trifluoroamine oxide	2019-05-31	PCT/KR2019/006580
TPE	Park In Joon	The advanced preparation method and apparatus for trifluoroamine oxide	2019-08-01	108127424
USA	Park In Joon	The advanced preparation method and apparatus for trifluoroamine oxide	2019-12-19	16/624,735
PCT	Park In Joon	The preparation method for trifluoroamine oxide	2019-05-31	PCT/KR2019/006582
TPE	Park In Joon	The preparation method for trifluoroamine oxide	2019-08-01	108127423
USA	Park In Joon	The preparation method for trifluoroamine oxide	2019-12-19	16/624,752
EPO	Park, Ji Hoon	System for storage and release of hydrogen using pyridine-based hydrogen storage materials	2019-02-19	17848943.1
PCT	Park Jong Mok	Composition comprising phase change material and method for producing thereof	2019-12-20	PCT/KR2019/018165
CHN	Park Jong Mok	Photonic crystal structure and colorimetric film for preventing forgery including the same	2019-07-04	2.0188E+11
EPO	Park Jong Mok	Photonic crystal structure and colorimetric film for preventing forgery including the same	2019-07-19	18735952.6
IND	Park Jong Mok	Photonic crystal structure and colorimetric film for preventing forgery including the same	2019-08-02	2.01937E+11
JPN	Park Jong Mok	Photonic crystal structure and colorimetric film for preventing forgery including the same	2019-07-04	536832/2019
PCT	Park Yong Ki	Catalyst regenerator	2019-05-10	PCT/KR2019/005644
USA	Park Yong Ki	Catalyst regenerator, fluid catalystic crackingreaction system, and catalyst regeneration method	2019-03-22	16/336040
USA	Pilho Kim	Pyrazolopyrimidine derivatives, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer, autoimmune disease and brain disease containing the same as an active ingredient	2019-11-11	16/612592
PCT	Ryu Beyong Hwan	Bead for removing inorganic acid and manufacturing method thereof	2019-10-21	PCT/KR2019/013819
PCT	Ryu jae Wook	Thiophene Carboxamide Derivatives and Plant Disease Control Agents Containing the Same	2019-10-07	PCT/KR2019/013131
PCT	Seong Hwan KIM	Compositions for preventing or treating oral disease or bone disease	2019-09-20	PCT/KR2019/012220
PCT	Sohn, Eun-Ho	The fluorinated polymers with blood compatible property and thin film containing them	2019-12-10	PCT/KR2019/017415
PCT	Suh Jeong Kwon	Activated carbon catalyst for hydrogen peroxide decomposition, preparation method thereof and hydrogen peroxide decomposition method using the same	2019-10-31	PCT/KR2019/014597
USA	Young-Pyo Jeon	A method of preparing impregnating pitch from petroleum material and impregnating pitch prepared using the same	2019-06-25	16/473336
INA	Yu Ju Hyun	Recovery method for sugar solution prepared by enzymatic hydrolysis of biomass and an apparatus therefor	2019-02-15	P-00201901433
USA	Yu Ju Hyun	Recovery method for sugar solution prepared by enzymatic hydrolysis of biomass and an apparatus therefor	2019-01-18	16/319167

List of International Patents Registered in 2019

Country	Title	Inventor	Application Number	Registration Date	Registration Number
IND	Catalyst for converting sugar to sugar alcohols by catalytic hydrogenation, Preparing method of the same and Converting sugar to sugar alcohols using the same	Chang Jong-San	1931/MUMNP/2013	2019-01-03	305326
USA	Rh/WxC Heterogeneous catalyst for acetic acid synthesis by carbonylation reaction	Chang Tae Sun	15/540857	2019-02-05	10196339
USA	Rh-C3N4 Heterogeneous catalyst for acetic acid synthesis by carbonylation reaction	Chang Tae Sun	15/540497	2019-05-21	10293335
CHN	Synthetic method of metal nano-particle by continuous-reaction method and method of forming conductive metal thin film via solution-processed	Choi Young Min	2.0158E+11	2019-05-03	ZL 201580029015.3
USA	Metal nanoparticles, and preparation method therefor	Choi Young Min	15/314759	2019-07-30	10,363,602
USA	Method for modifying surface of metal siliside, method for producing trichlorosilane using surface modified metal siliside and apparatus for producing the same	Choi, Won Choon	15/110229	2019-03-12	226757
EPO	Microspherical silicoaluminophosphate-34 catalyst with high performance & mechanical strength, Preparing method of the same and Preparing method of light olefins using that	Jeong Soon Yong	10825126.5	2019-01-09	2492010
FRN	Microspherical silicoaluminophosphate-34 catalyst with high performance & mechanical strength, Preparing method of the same and Preparing method of light olefins using that	Jeong Soon Yong	10825126.5	2019-01-09	2492010
GBR	Microspherical silicoaluminophosphate-34 catalyst with high performance & mechanical strength, Preparing method of the same and Preparing method of light olefins using that	Jeong Soon Yong	10825126.5	2019-01-09	2492010
GER	Microspherical silicoaluminophosphate-34 catalyst with high performance & mechanical strength, Preparing method of the same and Preparing method of light olefins using that	Jeong Soon Yong	10825126.5	2019-01-09	2492010
USA	Beta zeolite catalyst for preparation of mixture of BTEX(Benzene, Toluene, Ethylbenzene, Xylene) from poly aromatic hydrocarbons and preparation method thereof	Jeong Soon Yong	15/272687	2019-06-04	10307742
USA	Metal-loaded zeolite catalyst for dehydrogenation of light alkane and preparation method thereof	Jeong-Rang Kim	15/951152	2019-11-26	10487024
USA	A direct method for preparing monocyclic aromatics and longer-chain olefin by using CO2-rich syngas	Jun Ki Won	15/542264	2019-02-19	10208256
USA	Highly efficient methanol production method with low carbon dioxide emission	Jun Ki Won	15/502134	2019-02-26	10214469
CHN	Novel oxime ester compounds, photopolymerization initiator and photoresist composition containing the same	Jun Kun	2.0168E+11	2019-08-20	ZL 201680008616.0
CHN	Novel fluorenyl β-oxime ester compounds, photopolymerization initiator and photoresist composition containing the same	Jun Kun	2.0158E+12	2019-09-24	ZL201580004793.7
EPO	Novel fluorene oxime ester compounds, photopolymerization initiator and photoresist composition containing the same	Jun Kun	13785166.3	2019-07-03	2 845 845
JPN	Metal fluoride-based red phosphors and light emitting device containing the same	Kim Chang Hae	515570/2018	2019-09-27	6591054
JPN	pyrimidine-2,4-diamine derivatives and pharmaceutical composition for anti cancer containing the same as an active ingredient	Kim Hyoung Rae	2016-573780	2019-11-22	6622726
USA	4-(2-amino-tetrahydronaphthaleneyl)pyrimidine derivatives, preparation method thereof, and pharmaceutical composition for use in preventing or treating cancer containing the same as an active ingredie	Kim Hyoung Rae	15/567224	2019-08-06	10369149
USA	Transition metal supported sulfonated polymer-aminated polymer complex membranes and olefin/paraffin separation process using the same	Kim Jeong Hoon	15/920962	2019-10-08	10434463
USA	Novel organic semiconductor compound, its production method and organic electronic device using them	Lee Jong Cheol	15/964451	2019-07-09	10344028
EPO	The fusion-type CO2 change-over system connecting the oxyfuel combustor and catalyst conversion process	Lee Kew Ho	13850853.6	2019-11-06	2915779

Country	Title	Inventor	Application Number	Registration Date	Registration Number
GBR	The fusion-type CO3 change-over system connecting the oxyfuel combustor and catalyst conversion process	Lee Kew Ho	13850853.6	2019-11-06	2915779
GER	The fusion-type CO4 change-over system connecting the oxyfuel combustor and catalyst conversion process	Lee Kew Ho	13850853.6	2019-11-06	6.02013E+11
USA	The fusion-type CO5 change-over system connecting the oxyfuel combustor and catalyst conversion process	Lee Kew Ho	14/439414	2019-01-15	10180253
USA	Double crosslinked sodium alginate/polyvinyl alcohol composite nanofiltration membrane and preparation method thereof	Lee Kew Ho	15/064317	2019-10-01	10427104
AUS	Pyrrolidine carboxamido derivatives or pharmaceutically acceptable salts thereof, preparation method thereof and pharmaceutical composition for use in preventing or treating Bowel inflammation disease	Lee Kwangho	2016290963	2019-10-10	2016290963
COL	Pyrrolidine carboxamido derivatives or pharmaceutically acceptable salts thereof, preparation method thereof and pharmaceutical composition for use in preventing or treating Bowel inflammation disease	Lee Kwangho	NC2017/0010530	2019-03-18	34907
EAPO	Pyrrolidine carboxamido derivatives or pharmaceutically acceptable salts thereof, preparation method thereof and pharmaceutical composition for use in preventing or treating Bowel inflammation disease	Lee Kwangho	201791945	2019-09-30	33342
SIN	Pyrrolidine carboxamido derivatives or pharmaceutically acceptable salts thereof, preparation method thereof and pharmaceutical composition for use in preventing or treating Bowel inflammation disease	Lee Kwangho	11201707145Q	2019-10-11	11201707145Q
USA	Compounds for inhibiting C-MYC/MAX/DNA complex formation	Lim Hwan Jung	15/909088	2019-03-12	10227306
CHN	Precursor layer for inorganic/organic hybrid perovskite compound	Noh, Jun Hong	2.0158E+11	2019-03-15	ZL 201580041999.7
EPO	Fabrication Method of Nanostructured Inorganic-Organic Heterojunction Solar Cells	Noh, Jun Hong	11744919.9	2019-06-12	2560212
JPN	Solar Cell with Pillar-Structured Photo Sensitizer	Noh, Jun Hong	2017-201595	2019-08-02	6564001
EPO	Process for catalytic cracking reaction of naphtha and methanol mixture	Park Yong Ki	15826774	2019-04-03	3176242
FRN	Process for catalytic cracking reaction of naphtha and methanol mixture	Park Yong Ki	15826774	2019-04-03	3176242
GER	Process for catalytic cracking reaction of naphtha and methanol mixture	Park Yong Ki	15826774	2019-04-03	6.02015E+11
NED	Process for catalytic cracking reaction of naphtha and methanol mixture	Park Yong Ki	15826774	2019-04-03	3176242
USA	Precursors for highly efficient inorganic/organic hybrid solar cells and method for its materials	Sang Il Seok	15/102403	2019-03-26	10243141
CHN	Back sheet for solar cell and solar cell comprising thereof	Soo Bok Lee	2.0148E+11	2019-02-19	ZL201480068757.2
EPO	Back sheet for solar cell and solar cell comprising thereof	Soo Bok Lee	14 872 669.8	2019-06-26	3085747
CHN	A substrate for surface-enhanced Raman scattering spectroscopy and a preparing method thereof	Suh, Yung Doug	2.0148E+11	2019-05-07	ZL201480051274.1
IND	Intra-nanogapped core-shell nanoparticle and preparation method thereof	Suh, Yung Doug	1813/KOLNP/2013	2019-06-24	314512
INA	Concentrated feedstuff using palm oil byproducts and method for preparing the same	Yu Ju Hyun	P-00201304511	2019-03-28	IDP0057567
MAS	Hydrolysis method of biomass with enzymes for reducing unfavorable metabolite by the contaminated microorganisms and apparatus therefor	Yu Ju Hyun	PI2017703715	2019-10-08	MY-171303-A
USA	Method for producing microbial inhibitor-free fermentable sugar solutions from lignocellulosic biomass	Yu Ju Hyun	14/991209	2019-06-25	10329589

List of Technology Transferred in 2019

Name of Technology	Date of Signing
Improvement of properties of high-strength bead activated carbon for COV treatment and recovery	2019/01/11
Development of non-halogenated sulfonate metal salt flame retardant for polycarbonates	2019/01/11
Development of protein and cell separation kit using agarose-coated magnetic beads	2019/01/11
Technology for manufacturing of palladium catalytic ink	2019/01/30
New polymer membrane with crosslinked poly(vinyl alcohol) and manufacturing method thereof	2019/01/30
Method of manufacturing thallium nanowires and bismuth telluride using solvothermal method	2019/01/30
Evaluation of SAMIRNA drug for dengue fever using dengue animal infection model	2019/01/31
Method of manufacturing highly ionized calcium using sonochemical synthesis	2019/01/31
Knowhow on development of long-term reliability evaluation for outdoor plastic materials and surface treatment	2019/02/11
Development of rare disease treatment using composite prediction system	2019/02/15
Technology for manufacturing of composite for crop protection	2019/02/21
MERS antigen diagnostic technology	2019/02/28
Anionic multi-chain surfactant and manufacturing method thereof	2019/02/28
Technical information and knowhow on metal thin film fabrication	2019/02/28
Culture plate for 3D cell culture and 3D cell coculture method thereof	2019/03/04
PVDF manufacturing process technology	2019/03/12
Technical knowhow on MLK3 inhibitor	2019/03/18
Corrosive material extracting device and method thereof	2019/03/18
Plasma-based CO2 lipo and system development for composite gas manufacturing	2019/03/18
Method of manufacturing functional well plate	2019/03/20
Candidate drug for treatment of influenza virus	2019/04/11
Technology for development of cancer immunotherapy with CD39-CD73 inhibition using low molecular weight compounds	2019/04/19
Anticancer drug to inhibit binding of YAP-TEAD	2019/04/19
Technology for manufacturing of next-generation immunotherapy	2019/04/24
Technology for manufacturing of durable, organic fluorescent material to prevent forgery	2019/04/30
Selective hydrogenation catalyst and selective hydrogenation method thereof	2019/04/30

Name of Technology	Date of Signing
Development of candidate material for liver cirrhosis treatment through autophagy control	2019/04/30
Method of manufacturing cellulose nanofiber	2019/04/30
Production of L-lactic acid from lactobacillus paracasei LA104	2019/04/30
Technology for manufacturing of catalytic reaction system to retrieve carbon monoxide from formic acid	2019/05/23
Method of manufacturing cosmetic nanoparticle composition for whitening effect	2019/05/23
Knowhow on "polymer composite cured at low temperature for LCD polishing and patent analysis of catalysts cured at low temperature"	2019/05/24
Porous carbon structure comprised of porous polymers and manufacturing method thereof	2019/05/27
Carbazole ion exchange binder and fuel cell containing thereof	2019/05/31
Development of liver disease treatment using protein breakdown inducer platform technology	2019/06/01
Automatic expansion device containing highly functional bobbin	2019/06/03
Technology for novel, candidate material used in selective PDE9A inhibition	2019/06/10
Desiccant technology for households using hybrid nanoporous water adsorbent	2019/06/17
Development of technology for high-purity N2O recovery and refinement from highly concentrated exhaust gas	2019/06/20
Development of bemotrizinol UV adsorber for superabsorbent (at least UV 340nm, E 820) cosmetics	2019/07/02
Development of manufacturing technology for internal sheets of lignin-based eco-friendly vehicles	2019/07/02
Development of manufacturing technology for bio-derived epoxy resin below EEW 170	2019/07/02
Development of eco-friendly nano-cellulose film with superior gas barrier effect	2019/07/02
Development of insulation material and process technology for safety googles at high voltage of 22.9 kV	2019/07/02
Development of anaerobic digestion methane generator to operate household fuel cells	2019/07/02
Advanced CAR T cell treatment targeting immune checkpoint antigens	2019/07/12
Research on development of hepatitis B treatment using capsid inhibitor	2019/07/26
Knowhow on high-purity refinement of dipropylene glycol	2019/08/05
Nano/semi-nano long fibers and manufacturing method thereof	2019/08/13
Device for continuous manufacturing of carbon nanofibers with enhanced mechanical strength due to electrospinning and manufacturing method thereof	2019/08/13
Technology for manufacturing of dimers from Raman active molecules and nanoparticles	2019/08/30
Sepsis diagnostic kit and diagnostic method thereof	2019/08/30

Name of Technology	Date of Signing
Manufacturing of eco-friendly non-crystalline superengineering plastic resin	2019/09/16
Catalyst for manufacturing of antimony-based acrylonitrile (AN)	2019/09/16
Technology for manufacturing of new metal catalyst for diol manufacturing	2019/10/10
BTK protein breakdown inducer technology	2019/10/15
Microspherical sustained release preparation and manufacturing method thereof	2019/10/15
Method of manufacturing lactonic sophorolipid	2019/10/30
Technology for manufacturing of vehicle exterior material polyDCPD	2019/10/30
Development of composite to harden soft tissue	2019/11/05
Method of controlling dispersion of polymer coagulant for water treatment (Industry-University-Research Institute Cooperative Technology Development Program)	2019/11/25
Method of mass producing non-oxidative exfoliated graphite through electrochemical treatment and device thereof	2019/11/27
Development of manufacturing process for exfoliated graphite-metal hybrid composite	2019/11/27
Knowhow on calcium phosphate catalytic technology for lactate-dehydrogenated acrylic acid	2019/11/29
Development, evaluation and mechanism study of 11β-HSD1 inhibitor (KR-67607) for glaucoma treatment	2019/11/30
Analysis and development of adhesive materials for automobile component molding	2019/12/06
Technology for manufacturing of biodegradable plastic based on PBAT	2019/12/09
Acquisition of experimental reactive technology for ethylene tetramerization	2019/12/12
Technical support to acquire dying technology for paper used in records restoration	2019/12/12
Technical support for manufacturing of silver nano solution to manufacture antimicrobial weaved gloves	2019/12/12
Development of technology to manufacture high-purity urea solution and composites for use in by-product-free vehicles	2019/12/12
Support for acquisition of basic technology for waterborne polyurethane synthesis	2019/12/12
Development of anaerobic digestion methane generator to operate household fuel cells	2019/12/13
Technical support for cleaning during electropolishing of SUS surface to minimize impurities	2019/12/13
Technology for manufacturing of surfactant with enhanced adhesion for asphalt anti-stripping and warm asphalt mixture products	2019/12/13
Technology for development of EGFR inhibitor/decomposer	2019/12/17
Technology for candidate material used in selective inhibition of PI3K	2019/12/17
Manufacturing of hydrated chitosan and support for functional nanosheet manufacturing	2019/12/23

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