Achieving Carbon Neutrality with Catalysts

To achieve carbon neutrality, it is effective not only to reduce carbon dioxide (CO_2) emissions, but also to recycle CO_2 as a raw material. The key to utilizing CO_2 as a raw material is the catalyst. We invited Dr. Jun-Chul Choi to talk with Hiroshi Igarashi, General Manager of our R&D Center. Dr. Choi is the principal research manager at the Interdisciplinary Research Center for Catalytic Chemistry, National Institute of Advanced Industrial Science and Technology. He has been engaged in the development of technologies for the effective utilization of CO_2 through catalysts.

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Potential of CO_2 as a raw material

Igarashi: Dr. Choi, you have been very helpful in our joint research. I understand that you first came to Japan in 1994 to enter the doctoral program at the Tokyo Institute of Technology the following year.
Choi: After completing my master's degree at a university in Korea, I decided to enter the Tokyo Institute of Technology to study with one of Japan's top professors in the field of complex and organometallic chemistry. After completing my Ph.D. program, I worked as a special researcher at the Japan Science and Technology Agency (JST) for one year. I was then hired by the National Institute of Advanced Industrial Science and Technology (AIST), where I was assigned to conduct research on the synthesis of basic chemicals using CO_2 as a raw material. Honestly, when I first heard about it, I was confused and thought it was unrealistic. This is because, as you know, CO_2 is a stable and very unreactive substance. After struggling with the problem, I turned my attention to supercritical CO_2. Since supercritical CO_2 has both gaseous and liquid properties, I thought that the reactivity of supercritical CO_2 would be different from gaseous CO_2. By reacting supercritical CO_2 with alcohol, I successfully developed a technology to synthesize carbonate ester, a raw material for engineering plastics, in a single step.
Igarashi: At that time, carbon neutrality was not a social topic. Yet you were among the first to focus on CO_2 utilization. You later studied in the U.S. and returned to Japan to become the head of the research team. Just around that time, you began working with us as well. Another example of your success in CO_2-based manufacturing is the development of urethane raw materials, an important basic chemical product, from silicon compounds and CO_2.
Choi: The silicon compound you are talking about is formed from silica, which is the main component of sand. Combining this with CO_2 to synthesize basic chemicals would also help reduce CO_2 emissions. This would kill two birds with one stone. As you can see, starting with carbonate esters, I have been consistently pursuing the development of technologies that use CO_2 to produce basic chemical products. It was not until 2019 that the government released the Roadmap for Carbon Recycling Technologies, setting a goal of using CO_2 to synthesize urethane and polycarbonate, but I have been working on developing such technologies since the early 2000s.
In 2003, I applied for a patent for the synthesis of urethane (carbamate ester) with CO_2 as "Method for producing carbamate ester."

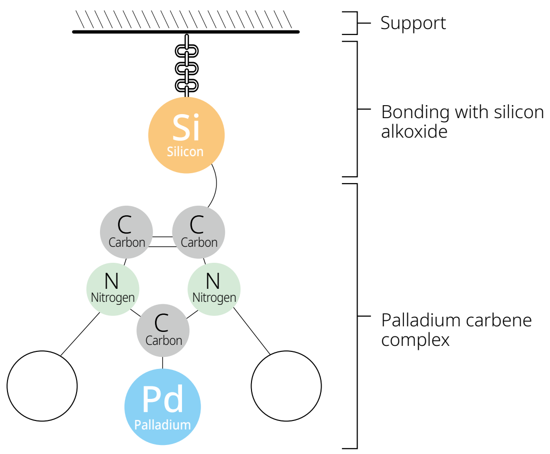
Creating useful materials with CO_2

Igarashi: I think it is wonderful that you came up with the idea of using CO_2 as a raw material more than 20 years ago, when CO_2 was considered waste. Beginning with the effective use of CO_2, you have delved into the creation of compounds using CO_2 as a material. Your world-leading research was truly innovative, judging from what happened thereafter. Although cars are usually considered the main source of CO_2 emissions, the emissions from factories and other industrial sources are also significant. As a large amount of CO_2 continues to be emitted, using it as a raw material in manufacturing is the right direction to go toward carbon neutrality. As a catalyst manufacturer, we recognize that this is an issue we must address. What kind of contribution do you expect from us, a company that deals mainly with precious metal catalysts?
Choi: As I mentioned earlier, CO_2 is extremely stable, so a catalyst is essential to increase its activity. The superiority of N.E. CHEMCAT's precious metal catalysts lies in their high activity. Moreover, your efforts to recover, refine and reuse catalysts after use make a significant contribution to resource conservation. I believe that in addition to the development of new catalysts, the development of recycling technology is an important issue.
Igarashi: Because precious metal catalysts are often expensive, we recognize that maximizing the activity of precious metals and reducing the amount of precious metals used in catalysts is top priority from a resource efficiency perspective. As a specialized manufacturer, we have accumulated a wealth of knowledge and expertise. One such example is our technology for dispersing and arranging precious metals so that each precious metal atom works well. In addition, placing precious metals on only one layer of the catalyst surface in contact with the feedstock can minimize the amount of precious metals used while maintaining high activity.
Choi: In my many years of catalyst research, I have also recognized that reducing the amount of precious metals is an important issue. As an example of my research achievements, I was able to develop a catalyst with very high activity by fixing monoatomic platinum with a ligand on a support such as silica.
Igarashi: When monoatoms can be allocated in a highly dispersed configuration, much higher performance can be achieved than with conventional solid catalysts. Moreover, because it is attached to a ligand, it becomes a "dream catalyst," combining the properties of a solid catalyst with those of a complex catalyst that selectively triggers only the necessary reaction. For realization of this catalyst, we started a joint research project with you.

Striving for carbon neutral with “Dream Catalysts”

Choi: When I started joint research with N.E. CHEMCAT, I was interested in palladium-based catalysts. So we worked on immobilizing palladium complex catalysts using a ligand called carbene, which stabilizes the palladium atom.

Jointly developed palladium complex immobilization catalyst



Igarashi: Palladium complex catalysts bonded to carbene ligands are high performance and have been nominated for the Nobel Prize. If they can be immobilized on a support material, they will be exactly the “dream catalyst” that we are pursuing.

You used silicon alkoxide as a bridging structure to bond the carbene ligand to the support member. The result was a complex catalyst with much higher performance than the original carbene ligand. That was very surprising.

Choi: Actual reaction tests of the complex catalyst prior to immobilization showed that the palladium was activated and the reaction temperature was lowered. So I tried different types of silicon alkoxides through a trial-and-error process. As a result, I achieved high catalytic activity for C-N cross-coupling reactions. It was N.E. CHEMCAT that found a support to immobilize this complex catalyst. When I actually fixed it on the support, I was able to create a unique catalyst that really has the characteristics of both a complex catalyst and a solid catalyst. When the experiment resulted in a faster reaction with improved performance at such a low temperature, I couldn’t believe it.

Igarashi: It was really unexpected. It is a very interesting catalyst. This research received the 2021 Japan Petroleum Institute Award for Encouragement of Research and Development (Industry Division). I believe this is a revolutionary technology that not only reduces the amount of precious metals in the catalyst, but also streamlines the process.

Choi: I totally agree. The catalyst we jointly developed has 2.5 times higher activity in the C-N cross-coupling reaction used in fine chemicals. Such higher catalytic activity also increases energy efficiency, leading to a reduction in environmental impact. This can help achieve carbon neutrality in chemical synthesis processes.

Carbon neutrality and catalysis in chemical synthesis processes

Igarashi: This is exactly the technology that society has been waiting for. We are very grateful that we were able to complete this technology in cooperation with your team.

Of course, there are technologies that directly reduce CO_2 emissions, such as clean energy. However, to reduce CO_2 emissions in factories, it is also important to save energy in the chemical synthesis process, for example, by shortening processes and time. In addition, if processes that require high temperatures and high pressures for reactions can be carried out under mild conditions, this will further reduce CO_2 emissions. We are also focused on developing catalysts that allow chemical reactions to occur at near room temperature.

Furthermore, since precious metals are a limited and valuable resource, we believe that the development of recycling technology is also necessary to realize a sustainable society. So we are focusing on the application of catalyst technology, such as scavengers.

We will continue to advance our initiatives to address social issues. We would like to hear your expectations and requests for us.

Choi: What should N.E. CHEMCAT aim for in the future? The most important thing is to identify the goal. The first thing to consider is the development of technologies that will help achieve Japan’s stated goal of carbon neutrality by 2050. It is also indispensable to develop value-added catalysts through dialogue with customers. Developing catalysts based on customers’ desires and concerns will certainly open up the future. My advice would be, “Make your customer relationships deeper and stronger.”

Igarashi: Thank you. That is true. We must keep our antennae up for really good development topics, and when we find one, we need a system that allows us to respond flexibly and quickly. We want to help achieve carbon neutrality through catalysts. This includes establishing production technologies that can contribute to high value-added, low-volume, multi-product manufacturing.

We have also learned from the joint research with you that we need to collaborate with external researchers and research institutions that have expertise. We will continue to engage in open innovation to create new value and develop catalysts that can contribute to society.

Thank you again for your continued support and guidance.

Jun-Chul Choi

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