New Energy and Industrial Technology Development Organization

Moonshot Research and Development Program [Goal 4]

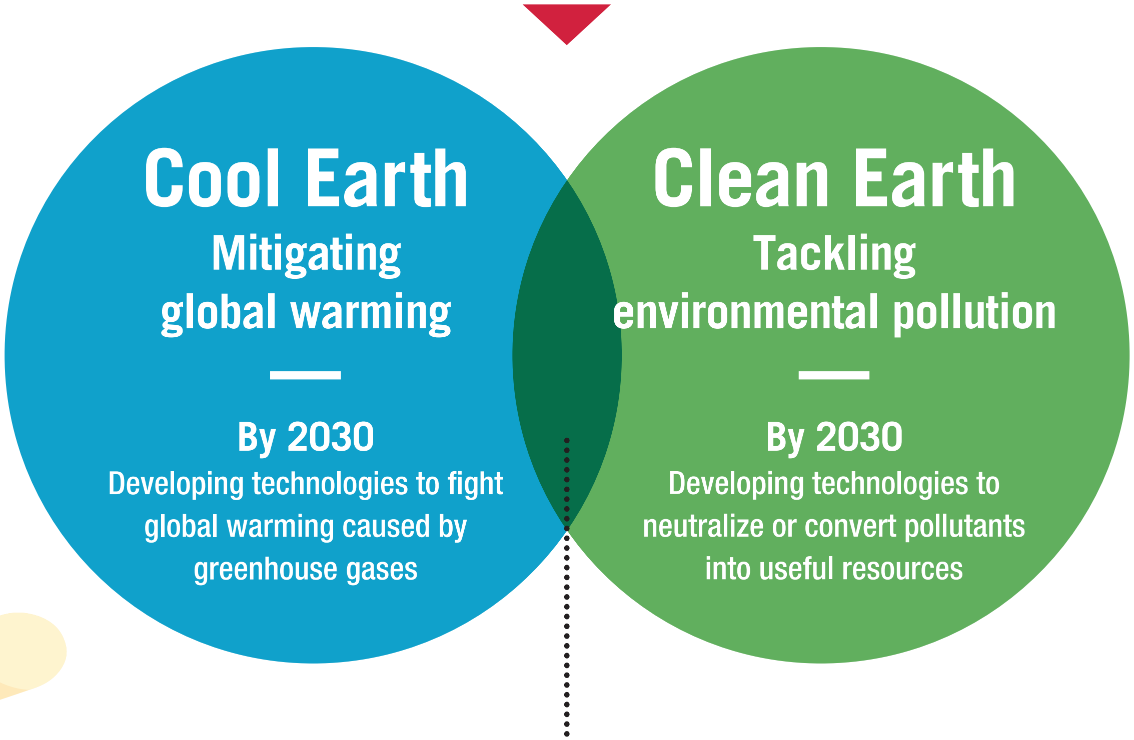
# MOONSHOT GOAL-4

## Achieving sustainable resource recycling to restore Earth's environment by 2050


MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

# MOONSHOT GOAL-4

To restore the global environment by 2050,
Moonshot Goal 4 will address two problems.




## Planetary Boundaries

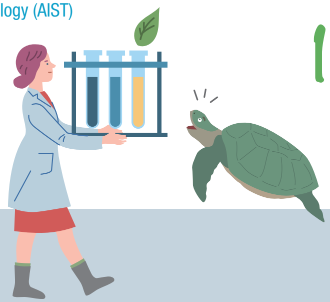
Earth is approaching the tipping point for environmental pollution, especially nitrogen compounds.

## Achieving sustainable resource recycling to restore Earth's environment by 2050

The Cabinet Office is promoting 10 goals in the Moonshot Research and Development Program to encourage disruptive innovation based on bold ideas.
NEDO is responsible for Goal 4, overseeing a wide range of research projects focused on restoring our warming and polluted global environment and achieving real-world social implementation of the technologies that can help realize a sustainable, resource-recycling society by 2050.

## Cool Earth Projects







## Clean Earth Projects

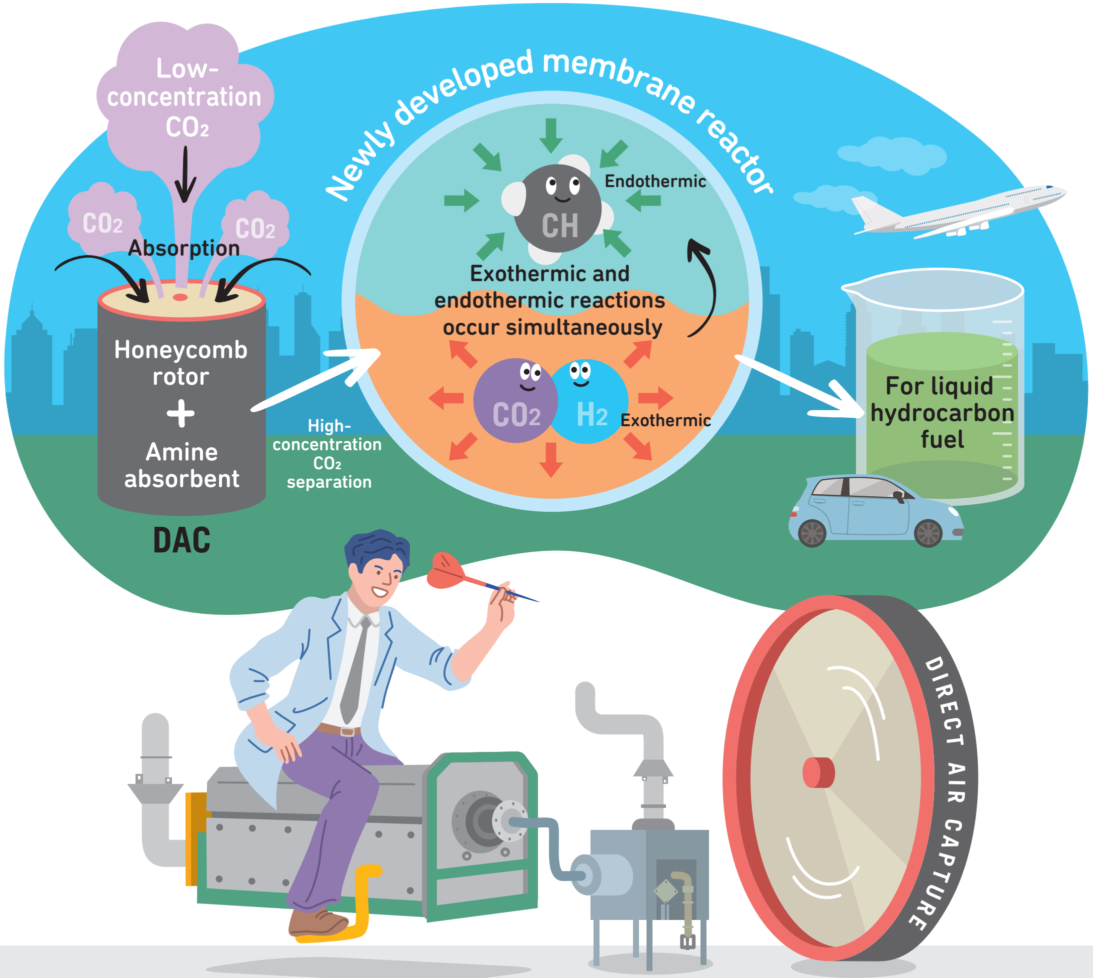


# 01 PROJECT

# Effective Capture of Low-Concentration $CO_2$: Absorbents and Thermal Control Are Key

## Development of Highly Efficient Direct Air Capture (DAC) and Carbon Recycling Technologies

Trends indicate that $CO_2$ emissions from industrial activities account for the greatest increase in greenhouse gases (GHGs) over the past thirty years. Direct Air Capture, or DAC, is viewed as a possible way to deal with this problem. These systems recover $CO_2$ directly from the atmosphere, but performance depends on the $CO_2$ absorbent used, and the process of separating and concentrating the captured $CO_2$ requires large amounts of thermal energy. We are working to maximize DAC capacity and develop the technologies that will power this innovative solution to the global warming crisis.

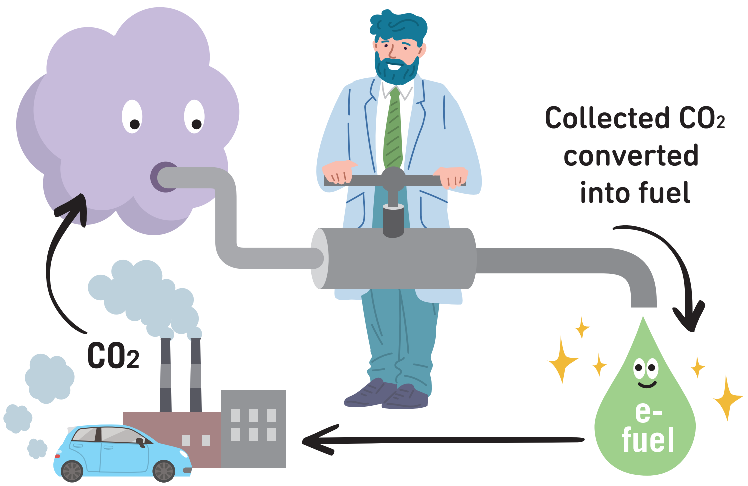



## Partnering With the Earth to Create an Ideal Future With New Technologies

Dr. KODAMA Akio
Professor, Institute for Frontier Science Initiative, Kanazawa University

Separating garbage from recyclables is now an established practice for many of us. Development of technologies for more efficient fuel and energy use has also made progress. However, I find the idea of promoting all these efforts and technologies as particularly "environmentally friendly" rather odd. After all, the Earth—on its own—is self-repairing and protects the ecosystem from the burdens we place on it. What we should aim to do is rethink our dependence on the Earth's generosity and the human activities that continue to burden the Earth, using new technologies in harmony with nature.

## Effective Capture of Low-Concentration $CO_2$: Absorbents and Thermal Control Are Key




### » Newly Developed Amine + Honeycomb Structure Boosts DAC

The heart of this DAC system is an amine-coated $CO_2$ absorbent. The *amines* used currently have high absorption capacity, but they also have disadvantages. For one, they require large amounts of thermal energy to separate and concentrate $CO_2$. Secondly, absorption nearly stops after oxidative degradation. But our extensive research has led to the development of an amine that overcomes these two challenges. It was also discovered that if a highly breathable porous honeycomb shape is used, the energy required for moving the air is reduced, and that increasing the application area of the amine improves the absorption rate to allow for more rapid $CO_2$ capture.

### » Aiming for Zero Emissions With Synthetic Fuels

The high-concentration $CO_2$ that we capture is utilized by partnering organizations. One application is converting the $CO_2$ to liquid hydrocarbon fuel through hydrogen reactions. Also called synthetic fuel or e-fuel, this alternative to petroleum-based fuels can be used in internal combustion engine vehicles. This next-generation fuel boasts high energy density, can be handled by conventional facilities like gas stations, and can be produced even in resource-poor countries. It can also be converted to e-methane, a synthetic natural gas alternative. Since the $CO_2$ emissions released while using e-fuel and e-methane represent $CO_2$ captured from the atmosphere, the net global warming potential is zero.

KEYWORD

**Amine**

This alkaline chemical substance is composed of carbon and nitrogen. It absorbs $CO_2$ well, but it can also release $CO_2$ due to heating or pressure loss. The molecular structure is easy to design, which makes it possible to create amines for various applications.

# FUTURE VISION

**2025**

### Exhibit DAC at Expo 2025 Osaka, Kansai, Japan

A full-scale DAC system will be exhibited at Expo 2025 in Osaka. In addition to conducting demonstration experiments to identify operational problems, we will analyze the energy costs of $CO_2$ separation and recovery.

**2027**

### Repeated Inspection and Verification of DAC System

After analyzing the data collected from the exhibition at Expo 2025, we will scale up the system and conduct repeated demonstration experiments to verify the scale and performance in terms of real-world social implementation.

**2029**

### Establish and Evaluate DAC Technology

After the technology is established, our goal will be to build a DAC system while taking into account the energy costs for $CO_2$ separation and capture. We will also collaborate with other project teams and enterprises to evaluate the effectiveness, practicality, applicability, and economic impact of the system.

**Implementation** Kanazawa University, Research Institute of Innovative Technology for the Earth (RITE)

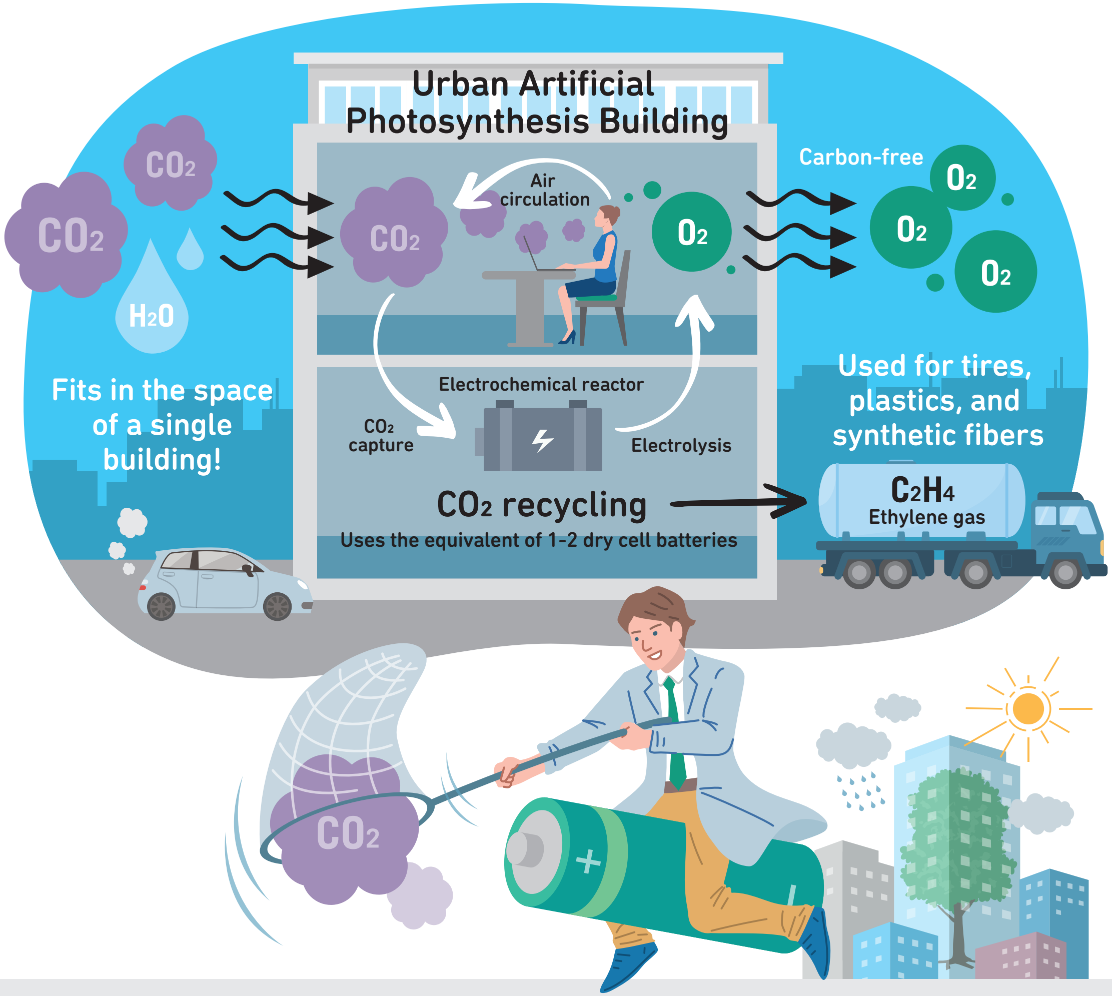
**Project Introduction Video** https://www.youtube.com/watch?v=hblRUkJjlx8&&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

# 02 PROJECT

# Forests of High-Rises in the City Absorb and Reuse $CO_2$: The Future Is Urban Artificial Photosynthesis

## Integrated Electrochemical Systems for Large-Scale $CO_2$ Recycling

Global warming is a result of humanity's continual pursuit of convenience while ignoring global sustainability. As one step toward solving this problem, we are working on the development of a system that captures $CO_2$ and converts it into a resource. At its heart is a filter that captures $CO_2$ using minimal electricity with a compact reactor that converts the $CO_2$ into *ethylene* and other useful resources. We are contributing to carbon neutrality through the creation of cities using this system based on our core electrochemical technologies.




## Taking on the Issue at Multiple Scales, From Conducting Studies to Changing the Structure of Society

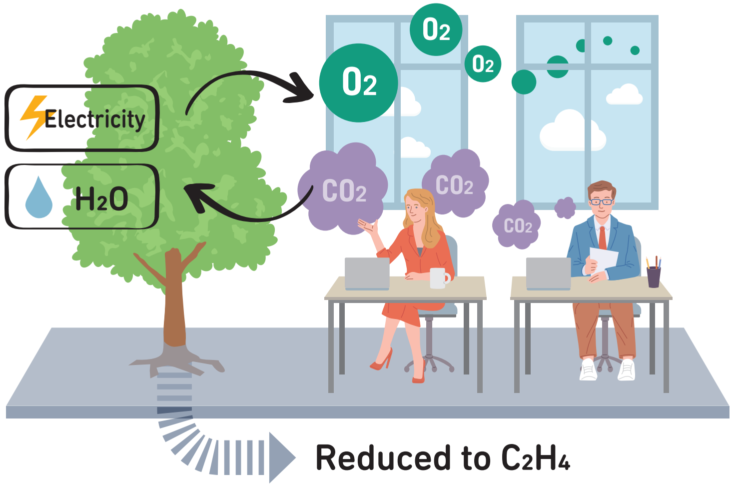
Dr. SUGIYAMA Masakazu
Professor, Research Center for Advanced Science and Technology, The University of Tokyo

Everyone emits $CO_2$ when they breathe. $CO_2$ can return as oxygen and be converted into useful resources and used as a material for chemical products. It's not magic.
This is an example of the carbon cycle that will soon be incorporated into our own living environments. Daily personal carbon cycles will prompt behavioral change, which will in turn change habits and lead to better conservation of the environment. I feel that working toward such a society is one of science's missions.

# Forests of High-Rises in the City Absorb and Reuse $CO_2$: The Future Is Urban Artificial Photosynthesis

## » Buildings...Performing Photosynthesis?

The advantage of our system lies in its ability to continuously capture $CO_2$ using the air flow created by HVAC systems. $CO_2$ reacts with water and is converted into ethylene and other materials for chemical products used in daily life. Oxygen is derived as a by-product. The building's HVAC system circulates this oxygen throughout the building for us to breathe. A complete system works just like photosynthesis, with the building itself functioning as a living tree does. It covers all processes from $CO_2$ capture to resource conversion and use of the oxygen by-product within the building.




## » Daily Life Becomes Ecofriendly

Our system uses a building's existing HVAC system to reduce the concentration of $CO_2$ while maintaining the concentration of oxygen. In contrast with conventional systems, there is no need for intake of outside air, significantly reducing the electricity required to regulate air temperature. These advantages essentially allow the building to perform photosynthesis, covering all processes from $CO_2$ capture to recycling, without wasting energy or materials. The offices we commute to every day, the department stores where we shop, even hotels in resort areas can all become bases for cutting-edge carbon circulation systems that can support urban artificial photosynthesis in the future.

### KEYWORD

**Ethylene**

Ethylene is a raw material for many familiar chemical products, such as plastics and synthetic fibers. Our system produces ethylene through the direct reaction of $CO_2$ with water and does not require hydrogen produced by water electrolysis.

# FUTURE VISION

**2025**

### Create a Carbon Circulation System

We will construct a compact device that applies electrochemistry to achieve highly efficient conversion of $CO_2$ to ethylene, laying the foundation for personal carbon circulation.

**2027**

### Blueprint to Real-World Social Implementation

We will collaborate with businesses to integrate building HVAC systems with units that capture $CO_2$ and convert it into ethylene.

**2029**

### Debut the Personal Carbon Cycle

We will complete a demonstration space and allow the general public to experience converting the $CO_2$ that they exhale into ethylene.

**Implementation** The University of Tokyo, Osaka University, Institute of Physical and Chemical Research (RIKEN), UBE Corporation, Shimizu Corporation, Chiyoda Corporation, Furukawa Electric Co., Ltd.

**Project Introduction Video** https://www.youtube.com/watch?v=EGunSE1MOMc&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3&

# 03 PROJECT

# Can "White Carbon" Save the Earth? Concrete of the Future Created Through Recycling

## C4S* Research and Development Project

*C4S: Calcium Carbonate Circulation System for Construction

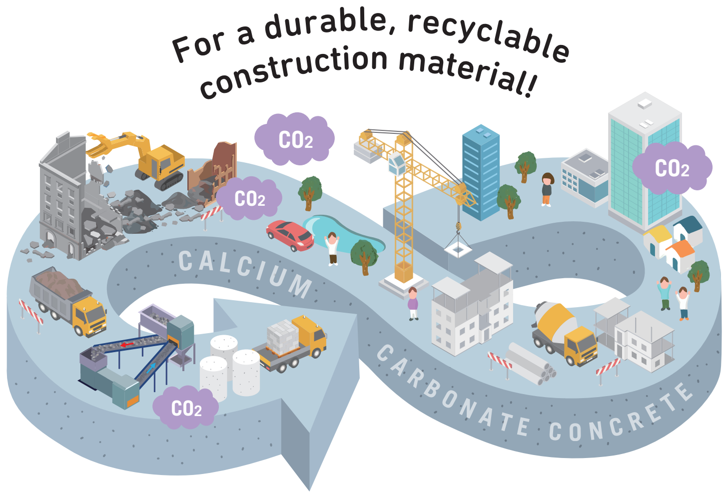
While the burning of fossil fuels is one major source of $CO_2$ emissions, another is the production of concrete. The raw material for cement used in making concrete is limestone. $CO_2$ is released during cement manufacturing when thermal energy is added to the calcium carbonate ($CaCO_3$) contained in limestone. Considering the amount of concrete in cities, it's easy to grasp the impact of these emissions. Our effort to help restore the global environment is based on the concept of resource circulation, where the $CO_2$ emitted by concrete is also recovered by concrete.


## The Himalayas and the Alps: The Challenge for Concrete Is to Model Great Mountain Ranges

Dr. NOGUCHI Takafumi
Professor, Graduate School of Engineering,
The University of Tokyo

During Earth's Cenozoic era, the uplift and weathering of the Himalayas and Alps fixed large amounts of $CO_2$ when calcium contained in the rock trapped carbon dioxide in the atmosphere as carbonate. What if we could reproduce the same process with concrete, a material containing that very same calcium? With this concept in mind, we worked on developing a new technology to produce concrete by combining $CO_2$ with used waste concrete. Our code name for it is "*CCC*!"

## Can "White Carbon" Save the Earth?
## Concrete of the Future Created Through Recycling




### >> CCC to the Rescue

Continuing to make concrete using limestone, the raw material in cement, poses a number of problems, including $CO_2$ emissions and depletion of resources. The solution requires a new material that doesn't use limestone or emit $CO_2$. Our answer is CCC, calcium carbonate concrete, which is made by combining crushed waste concrete and rock with calcium carbonate that has trapped atmospheric $CO_2$.

### >> Add White Carbon to the Mix

CCC is made from waste concrete, $CO_2$, rock, and other resources that are abundant throughout the world. It's a recyclable material that reduces emissions as it is produced. Using CCC in 50 percent of future construction has the potential to fix approximately one billion tons of atmospheric $CO_2$ annually. As with green carbon fixed in terrestrial ecosystems and blue carbon fixed in marine ecosystems, this version is symbolized by color; in this case, white. It will likely make a major contribution toward environmental renewal.

**KEYWORD**

**CCC**
**(Calcium Carbonate Concrete)**

Calcium carbonate concrete is formed by fixing $CO_2$ in waste concrete. This sustainable new material fixes more $CO_2$ with less energy than conventional methods and simplifies recycling and use.

# FUTURE VISION

**2025**

### Set Expo 2025 as a Target

We will develop CCC that's as strong as standard concrete and construct a model building at Expo 2025 in Osaka, Kansai, Japan. With this exhibition, we will confirm that the amount of captured $CO_2$ exceeds the amount of $CO_2$ emitted.

»

**2027**

### Collect Data on Small Mock-up Buildings

We will construct small (one- or two-story) mock-up buildings and collect data to prepare for real-world social implementation. Based on the data, we will confirm that the materials used for supporting columns and walls meet the requirements of Japan's Building Standards Act and can guarantee a specified service life.

»

**2029**

### Complete Construction of First CCC Building

After construction of one CCC building and using collected data to show it conforms to Japan's Building Standards Act, we will obtain approval for the use of CCC in this project. The ultimate objective is to have the material approved for use anywhere and at any time and achieve real-world social implementation by 2050.

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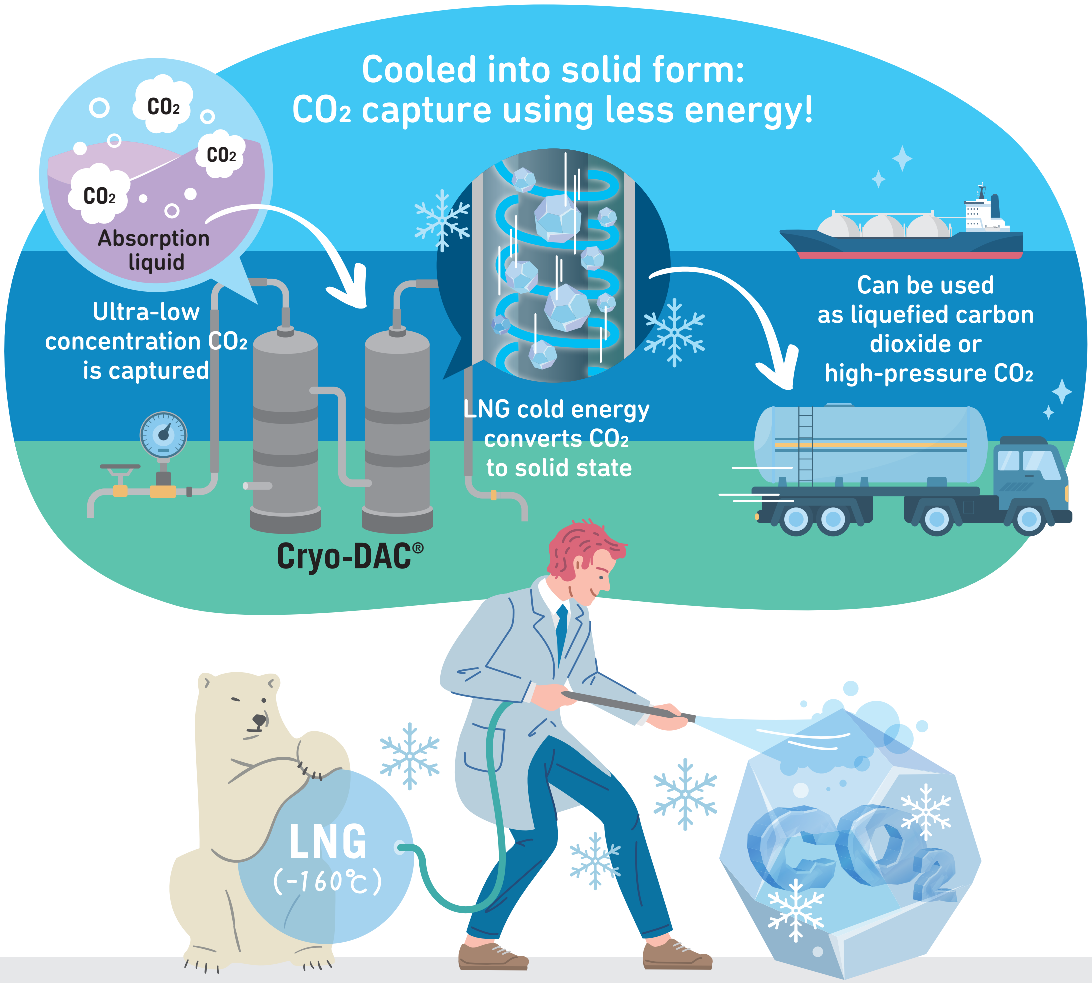
| **Implementation** | The University of Tokyo, Hokkaido University | **Project Introduction Video** | https://www.youtube.com/watch?v=M6vyIFMQ5xE&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3 |

# 04 PROJECT

# Using the "Power of Cold" to Convert Atmospheric $CO_2$ Into Dry Ice

## Research and Development on Direct Air Capture With Available Cold Energy

$CO_2$ accounts for 75 percent of greenhouse gas emissions that cause global warming. However, the concentration of 400 parts per million means that only four out of every 10,000 molecules in the atmosphere are $CO_2$. One mechanism for efficiently capturing this low-concentration $CO_2$ is Direct Air Capture (DAC), but this requires a large amount of heat energy. To solve this problem, we are developing technologies that take the opposite approach: capturing $CO_2$ using ***cold energy***.




## Daily Discoveries Drive Research

Dr. NORINAGA Koyo
Professor, Graduate School of Engineering, Nagoya University

Removing $CO_2$ in the atmosphere caused by the mass consumption of fossil fuels since the Industrial Revolution is a pressing issue for humanity. The solution to this problem requires equipment and plants designed on a scale that matches society's infrastructure, and we believe that our engineering-centered research and development plays an important role in achieving that. When we deal with technical hurdles and unexpected challenges, when we employ unique technologies, when we feel the joy of working at the forefront of our field, and when we envision a future where these technologies are used every day—this is what motivates us as researchers.

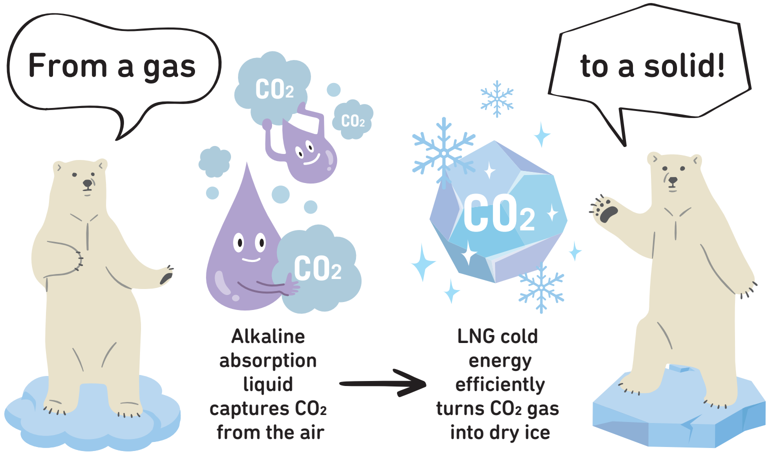
# Using the "Power of Cold" to Convert Atmospheric $CO_2$ Into Dry Ice

## » The Challenge of Creating a New Process

Cold...energy? These would usually be contradictory terms, as coldness is simply an absence of heat energy. The cold energy demonstrated here refers to the way liquefied natural gas (LNG) can draw heat from the surrounding space as it cools during evaporation. LNG chilled to -160°C is transported to a receiving terminal, and it generates this cold energy as it returns to a gaseous state. However, much of this cold is not used as energy but disposed of in seawater and elsewhere. We came up with the idea of carbon recycling centered on Cryo-DAC®, or low temperature direct air capture, as a means of both effectively utilizing this wasted energy and solving problems with DAC systems.

## » Transformation From Solid to Liquid (Fluid)

With Cryo-DAC®, $CO_2$ is first absorbed and concentrated in an alkaline liquid. By reducing the pressure, the $CO_2$ is then recovered into a sublimation tank, where cold energy turns it into solid dry ice that can be collected. In addition, while $CO_2$ ordinarily is liquified through intense compression, Cryo-DAC® saves energy by eliminating the need for this. Simply bringing the dry ice back up to ambient temperature in a sealed environment enables the production of liquefied $CO_2$ suitable for transport and underground storage. And since LNG is shipped around the world in large quantities, using previously discarded cold as a new energy source can have a major impact. It is expected to contribute to about 30 percent of the international DAC $CO_2$ capture index.




### KEYWORD

**Cold Energy**

This form of energy utilizes temperatures lower than the ambient temperature to absorb surrounding heat.

# FUTURE VISION

**2025**

### Demonstrate System at Expo 2025 in Osaka, Kansai, Japan

We will exhibit at the World Expo and conduct a six-month demonstration test to show that Cryo-DAC® can reliably capture $CO_2$ from the atmosphere. We also aim to bench test the system at the university to confirm successful operation and to widely share the results of this research.

**2027**

### Produce Further Proof of Concept

In collaboration with business partners, we will proceed with testing for real-world social implementation. We will also confirm whether this technology can be competitive against others.

**2029**

### Proceed to Commercialization Phase

We will complete the conceptual design of the commercial system and the plan for real-world social implementation. We will recruit companies domestically and internationally to implement DAC, and foster the development of the business environment.

| Implementation | Nagoya University, Toho Gas Co., Ltd., Tokyo University of Science | Project Introduction Video | https://www.youtube.com/watch?v=qV1py3OZwIM&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3 |
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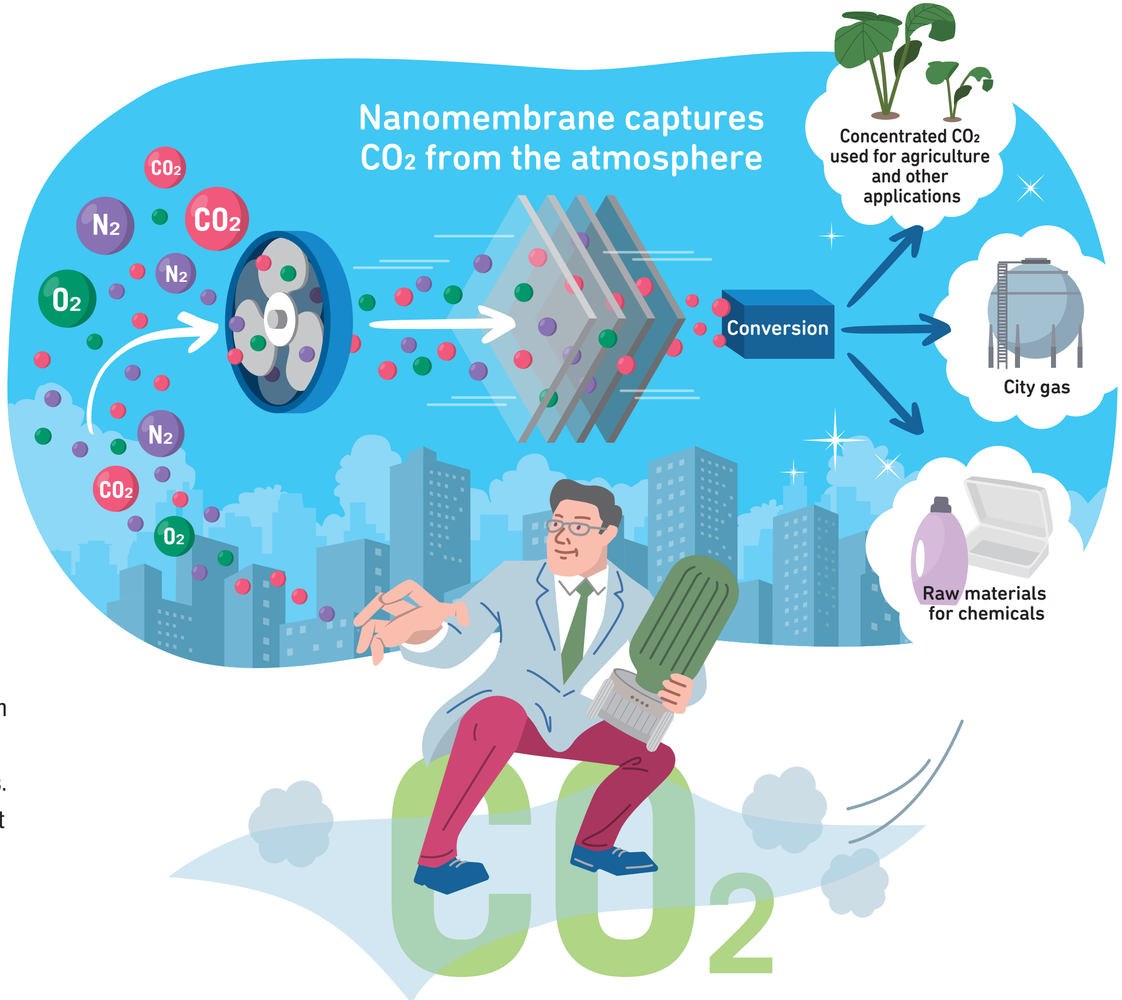
# 05 PROJECT

# $CO_2$ Capture Anywhere Using Ultrathin Membranes

## Development of a $CO_2$ Recycling System for a Beyond-Zero Society

How can plants absorb $CO_2$ and perform photosynthesis anywhere simply by spreading their leaves? Our research began with this simple question. Extensive trials led to success in developing an ultra-thin nanomembrane, one like a cell membrane. Widespread use of this compact and size-scalable system for $CO_2$ capture and utilization at homes and business will enable $CO_2$ capture and use in our daily lives. We aim to contribute to the revitalization of the global environment by building social infrastructure that can directly capture and utilize $CO_2$ in the atmosphere, anywhere and anytime.




## Friend or Foe? Getting to the Heart of $CO_2$ and Beyond

Dr. FUJIKAWA Shigenori
Distinguished Professor, International Institute for Carbon-Neutral Energy Research, Kyushu University

$CO_2$ is often called the main cause of global warming. But is that right? If we can control the circulation of $CO_2$ as a resource, we can then create value from it, turning it into an asset. The value of agricultural products and water depends on where they come from. You probably care about where your food and water are sourced, but have you ever considered the source of the carbon dioxide in the carbonated drinks you drink or the carbon dioxide used in photosynthesis in the crops you eat? The essence of our research addresses the development of social infrastructure and a system that gives new value to $CO_2$. Our goal is to go “Beyond-Zero!”

# $CO_2$ Capture Anywhere Using Ultrathin Membranes

## » Efficient $CO_2$ Separation With an Ultrathin Membrane

This system features a separation membrane that captures $CO_2$ directly from the atmosphere and converts the captured $CO_2$ into a resource. We will combine these units as a single system called DAC-U® (Direct Air Capture Utilization system). Conventional membrane separator systems have been impractical, since only minuscule amounts of $CO_2$ are separated. However, as a result of extensive research focused on developing thinner membranes, we succeeded in fabricating an ultrathin membrane 1/300th the thickness of household plastic wrap, which is close to the thickness of plant cell membranes. This ultrathin membrane exhibits extraordinarily high $CO_2$ permeability (20 times or greater), compared to conventional membrane performance. This high $CO_2$ permeability enables economically efficient direct $CO_2$ capture with membranes.

## » Toward a Society That Fully Recycles $CO_2$

The DAC-U® system offers a range of potential applications for captured $CO_2$, including its use in agriculture. Additionally, it can be chemically converted for use as a raw material for city gas or industrial chemical products. Furthermore, concentrated $CO_2$ can be used directly in general households to make carbonated water. The DAC-U® system has the benefit of sharing a common feature with photovoltaic systems, namely the ability to accommodate flexible unit combinations. Its design allows for a range of combinations and scales, offering the versatility to meet the specific needs of each installation site, so it can capture and recycle $CO_2$ anywhere, from homes to public facilities, parks, and office buildings. This system contributes to the creation of a ***carbon recycling society*** for local production and consumption of atmospheric carbon sources.

KEYWORD

**Carbon Recycling Society**

We believe that the direct use and conversion of captured $CO_2$ can create a carbon resource recycling process. If we make it possible not only to capture $CO_2$ but also reuse it, we will be taking a step towards achieving a carbon-neutral society.

# FUTURE VISION

**2025**

### Debut DAC-U® System

We will develop a first prototype of the DAC-U® system.

**2027**

### Test the Prototype

There are numerous applications for DAC-U® systems. We will produce and test prototypes for use in a variety of applications.

**2029**

### Develop Systems for Everyday Needs

The objective is to gradually improve performance and enable more efficient capture of $CO_2$, specifically capturing about 2 kg per day, or enough to cover the daily energy needs of a family of four.

| | |
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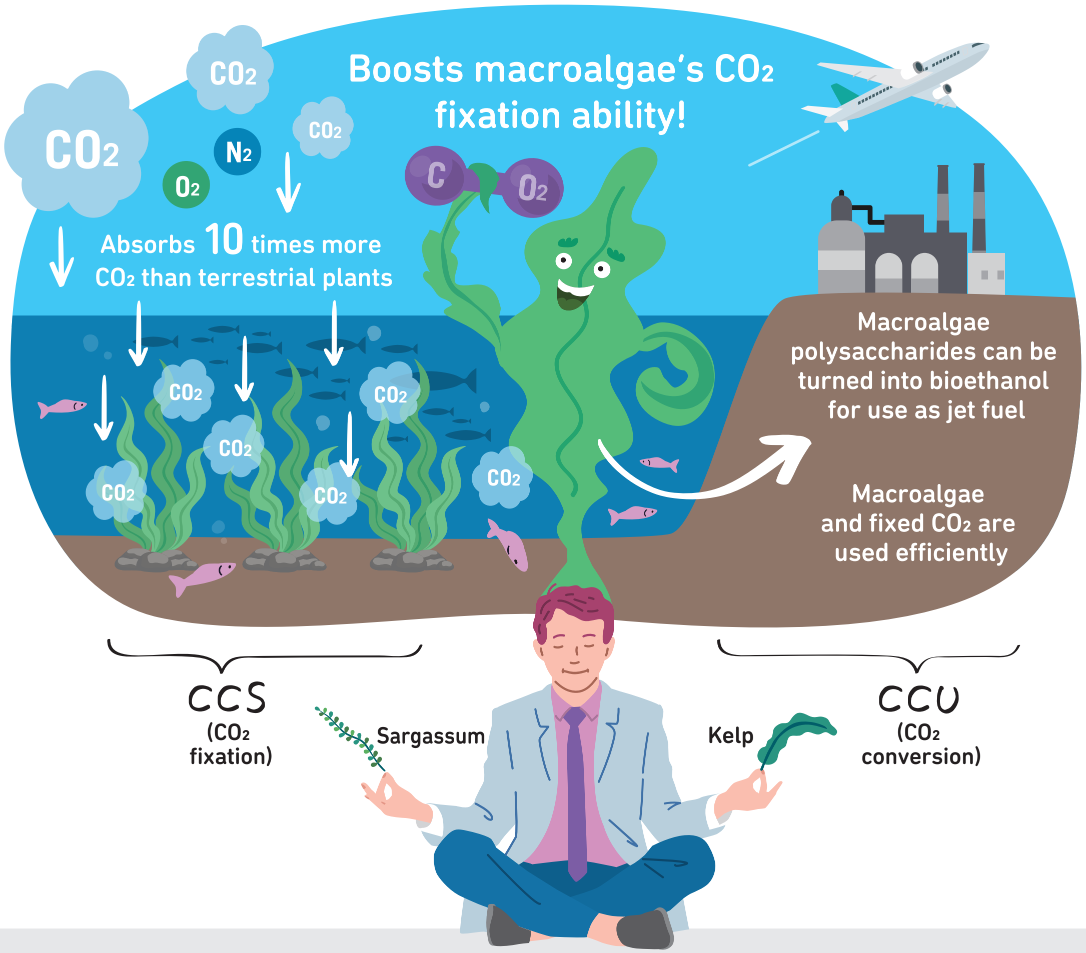
| Implementation | Kyushu University, Kumamoto University, Hokkaido University |
| Project Introduction Video | https://www.youtube.com/watch?v=iNjqtC22C-g&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3 |

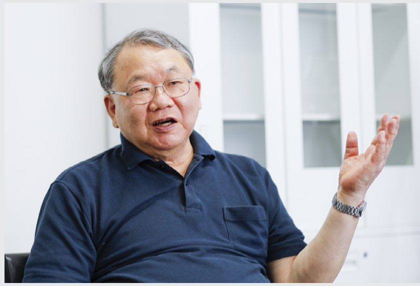
# 06 PROJECT

# From Fixing $CO_2$ to Producing Energy, Marine Brown Macroalgae Play a Major Role

## Redesign of Macroalgae for Highly Efficient $CO_2$ Fixation by Functional Modifications and Their Product Generation

What do you associate with “Blue Gold?” This term means that there are precious resources (Gold) in the ocean (Blue). The goal of our research is to realize the ultimate resource circulation system; one that utilizes the resources of the ocean to rehabilitate the global environment and produce materials. We aim to improve the $CO_2$ fixation rate of macroalgae and treat them as unused resources, converting them to bioethanol for fuel and for other uses. Since macroalgae farms are also places for fish to spawn and grow, this system is expected to have a positive impact on the ocean industry, too. This initiative is unique to Japan, a country surrounded by the ocean.



## Becoming a Leading Maritime Nation by Expanding Macroalgae Farming and With $CO_2$ Resource Conversion Technology

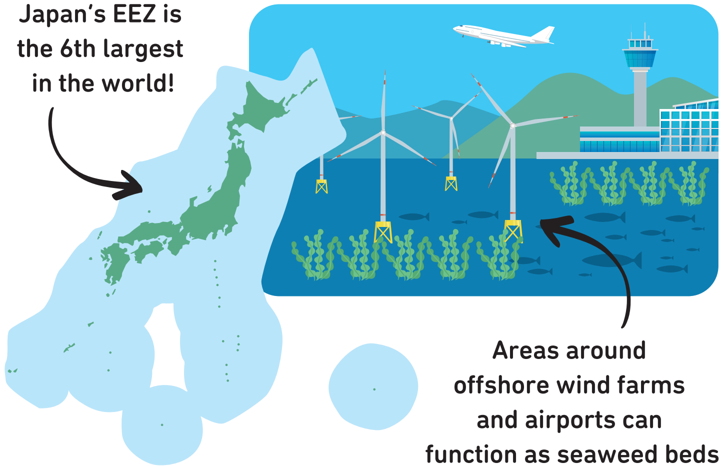
Dr. UEDA Mitsuyoshi
Specially Appointed Professor, IAC: Institutional Advancement and Communications, Kyoto University

This macroalgae cultivation technology wasn’t possible anywhere in the world until now. Our technology to produce bioethanol from macroalgae is also a world first. If we can combine these two technologies to allow for widespread use of bioethanol that can replace fossil fuels, it will benefit the environment tremendously. Japan is an island nation that is well-suited for social implementation of these two technologies. Although Japan is dependent on other countries for much of its energy supply, we hope these technologies will help Japan contribute to the world going forward.

# From Fixing $CO_2$ to Producing Energy, Marine Brown Macroalgae Play a Major Role

## » The Outstanding Hidden Abilities of Macroalgae

As a result of extensive genetic research focused on selective breeding to enable macroalgae to fix $CO_2$ more efficiently, it is now possible to cultivate all species of macroalgae. Presently, we are planning to expand the cultivation areas within Japan's exclusive economic zone but beyond the immediate vicinity of offshore airports and wind farms, while simultaneously conducting tests at various ports in Japan. Plants fix $CO_2$ through photosynthesis, but compared to terrestrial plants, large macroalgae have an overwhelmingly superior ability to fix $CO_2$. They can also contribute to energy production and the ocean industry. For these reasons, macroalgae are praised as "Blue Gold" capable of restoring and conserving the global environment. By using the inedible parts of macroalgae like sargassum that are rarely consumed by humans, we can avoid competition with food production.




## » Will Airplanes Fly Using Macroalgae-Based Fuel?

The polysaccharides that macroalgae produce through photosynthesis can be converted into ethanol and used for airplane jet fuel and other forms of energy. A key role here is being played by newly invented ***arming yeasts*** that increase the efficiency of sugar breakdown.

### KEYWORD

**Arming Yeasts**

These yeasts have enzymes resembling arms that are arming on the yeast surface. Using these yeasts to catalyze chemical changes helps the breakdown of sugars and other unused resources that do not readily decompose, making ethanol easier to produce.

# FUTURE VISION

**2025**

**Start a System Combining Newly Developed Technologies**

We will operate a new system that combines our proprietary macroalgae cultivation and ethanol-producing yeast technology.

**2027**

**Aim to Become a Leading Exporting Nation**

In addition to conserving and restoring the environment, resource-poor Japan may be able to reduce its dependence on imported fossil fuels for energy.

**2029**

**Welcome the Age of Aviation Energy Self-Sufficiency**

We aim to increase macroalgae production to 210 tons per hectare per year, increase $CO_2$ fixation to 8 to 10 kg-$CO_2$ per $m^2$, and increase the $CO_2$ fixation rate to 200 times that of terrestrial plants. Our objective is to contribute to aviation energy self-sufficiency by 2030 with macroalgae-derived products.

**Implementation**: Kyoto University, Kyoto Institute of Technology, Mie University, Green Earth Institute Co., Ltd., Kansai Chemical Engineering Co., Ltd.

**Project Introduction Video**: https://www.youtube.com/watch?v=F95Kte8ZIno&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

# 07 PROJECT

# Combination of Three Technologies Makes Plants Do More Than Just Absorb $CO_2$

## Integrating Gene Optimization, Distant Hybridization, and Microbial Symbiosis Technologies Leads to Development of Next-Generation $CO_2$-Fixing Plants

Merely stopping the progression of global warming is not enough; we need to return the environment to how it was 30 or 40 years ago. The key lies in low-cost, sustainable plant biotechnologies. We are focusing on three of them: ***gene optimization, super-distant hybridized plants, and microbial symbiosis***. By combining technologies based on different principles, we aim to achieve results that cannot be reached with any single one.


## Using Plants' Power in Creating a Content, Comfortable Society

Dr. MITSUDA Nobutaka
National Institute of Advanced Industrial Science and Technology (AIST)

We wish to create an Earth where everyone can live comfortably throughout their lifetime. A powerful determination to do that continues to drive our research. It will require achieving not just zero emissions, but negative emissions. In other words, we need to increase the amount of carbon that is fixed in the environment. Trees that have been fine-tuned through gene optimization technology and exhibit superior $CO_2$ fixation can produce dense, sturdy, and flame-resistant building materials. Imagine a city of high-rises built with wood from these trees. The city would act as a forest, and as long as those buildings remain there, $CO_2$ stays there. It would be a city that truly symbolizes environmentalism.

## Combination of Three Technologies Makes Plants Do More Than Just Absorb $CO_2$

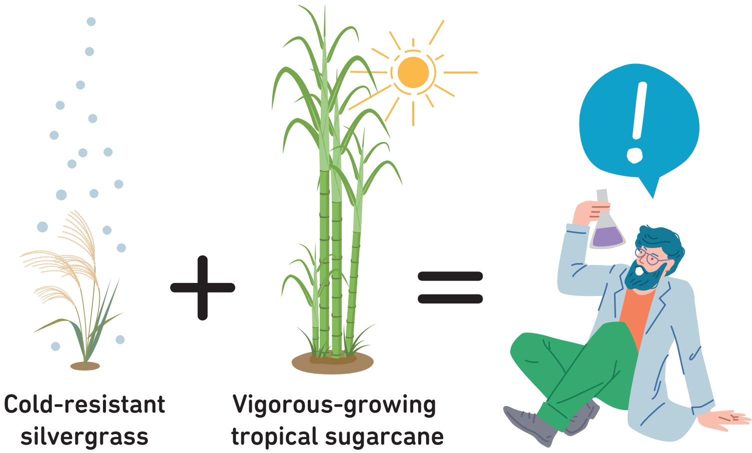
### » Using Biotechnology to Create New Plants

**1. Gene Optimization**

This technology enhances plants' ability to capture $CO_2$ by forcing small changes to their genes that mimic naturally-occurring ones. Increasing the ***lignocellulose*** in tree cells in turn increases woody biomass, a reusable biological resource, and the amount of $CO_2$ fixed by the plants, thus helping prevent global warming. Furthermore, it results in sturdy trees with high density and strength, expanding applications as a building material.

**2. Using Super-Distant Hybrids to Create New Plants**

Using *in vitro* fertilization and other breeding methods, we attempt to create new species that cannot be crossbred in nature. For example, by crossing plants with different characteristics, such as one that is cold-resistant and another that grows well in tropical regions, it may be possible to create a plant that grows vigorously regardless of the location. We hope to use fast-growing grasses developed with this technology to generate biomass power and produce jet fuel to reduce petroleum consumption.




**3. Microbial Symbiosis**

This technology promotes plant growth via microbial activity. While we have thus far succeeded in increasing biomass 20 to 30 percent in the laboratory, it is actually not that easy to achieve this in the field. For example, the diversity of soil environments in which crops grow poses challenges to researchers. Issues to overcome include whether the technology is effective in every type of soil, how it should be applied, and how often soil should be treated with the microorganisms.

KEYWORD

**Lignocellulose**

Made of lignin and cellulose, this component of wood accounts for the majority of plant biomass. Biologically, it is the secondary cell wall of plants. Reinforcing the lignocellulose can increase the amount of $CO_2$ fixed by plants. An additional anticipated benefit in trees is wood that is denser, more durable, and more fire-resistant.

## FUTURE VISION

**2025**

### Test Each of the Three Technologies

We will conduct tests using larch trees to verify the effectiveness of the gene optimization strategy, attempt to establish a new hybrid plant based on wheat with enhanced biomass, and continue with field tests to confirm the effectiveness of symbiotic microorganisms.

»

**2027**

### Apply the Technology More Broadly

Following the experiments with larch trees, we will apply the gene optimization strategy to Japanese cedars. We will develop a new hybrid of *Erianthus* grass that can be cultivated in various environments. For symbiotic microorganisms, we will establish methods for utilization.

»

**2029**

### Check and Prove the Synergistic Effects

We will verify the combined effect of the three technologies of microbial symbiosis, new hybrid plants, and gene optimization is greater than the sum of its parts.

**Implementation** | National Institute of Advanced Industrial Science and Technology (AIST), Tokyo Metropolitan University, Sumitomo Forestry Co., Ltd.

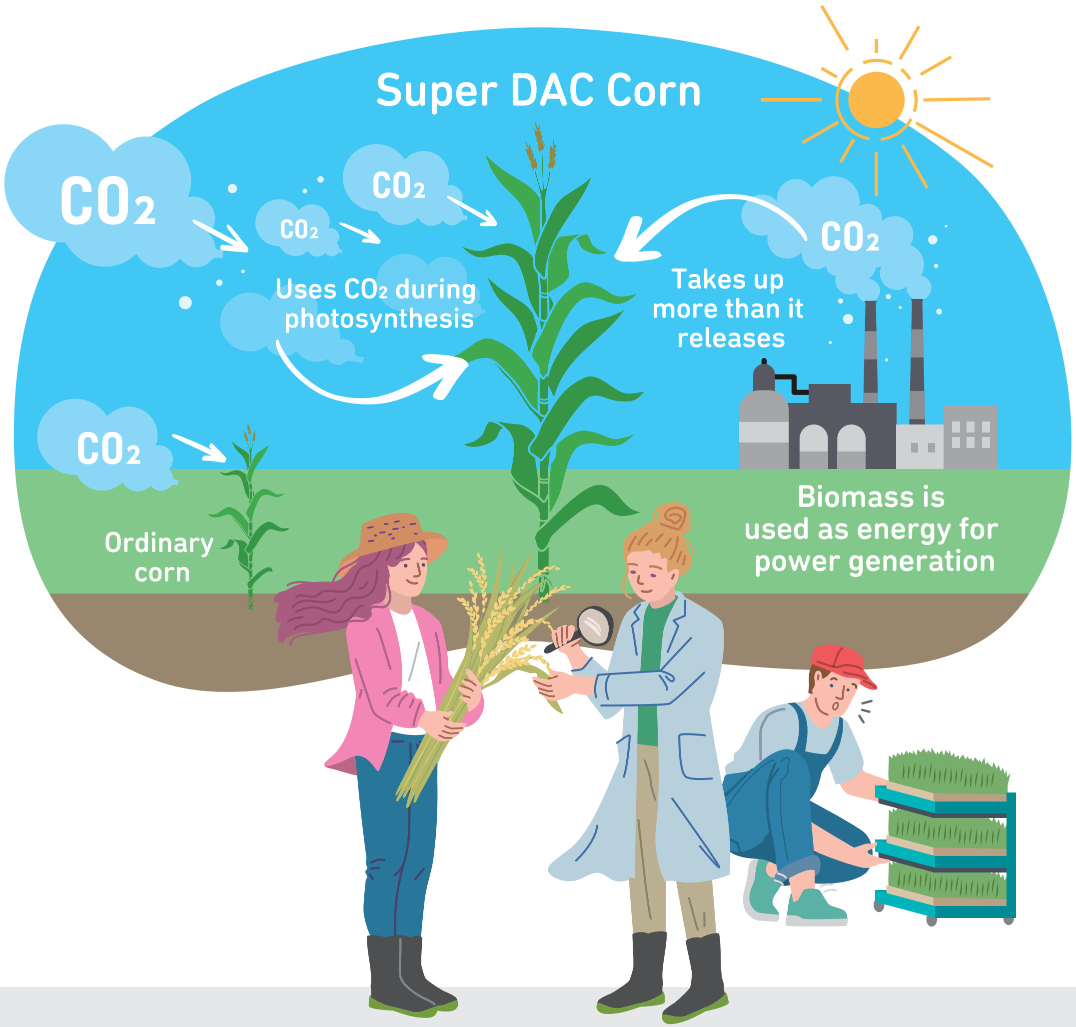
**Project Introduction Video** | https://www.youtube.com/watch?v=ho0_vySYuLU&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

# 08 PROJECT

# Super Crops Absorb Large Amounts of $CO_2$ and Convert It to Energy

## DAC Agriculture Propels Us Towards a Carbon-Circulating Society

Direct Air Capture (DAC) is a well-known technology used to collect the greenhouse gas $CO_2$ from the atmosphere. In a way, agriculture can also be considered DAC, since we harvest crops that fix carbon through photosynthetic growth. However, when the crops are consumed as food, the fixed carbon returns to the atmosphere as $CO_2$, breaking the link from agriculture to decarbonization. We are working towards a new form of agriculture that contributes to carbon resource circulation without returning fixed $CO_2$ to the atmosphere.




## Awaken Dormant Farmlands! The Future of Japanese Industry, Envisioned with Super Crops

Dr. YANO Masahiro
Senior Executive Researcher, Research Center for Agricultural Information Technology (NARO)

Japan's industrial technology is more than capable of producing energy. Yet Japan is not energy self-sufficient, since we depend on importing the raw materials needed to make use of those technologies. This challenge could be overcome by increasing production of recyclable biological resources, or biomass, through improved crops. Using fallow land for this purpose would increase energy resource self-sufficiency without posing any competition to food production. Providing industries with biomass materials from agriculture would not only contribute to sustainable environmental conservation, but would also enable agriculture to play a role in the future co-creation of a variety of industries.

## Super Crops Absorb Large Amounts of $CO_2$ and Convert It to Energy

### » Doubling Biomass Productivity With Improved Species

Biomass yields cannot be easily increased just by altering a single gene. With rice crops, we hope to increase yields in one try by changing multiple genes simultaneously. Selected genes are related to photosynthesis, nutrient uptake capacity, and grain count and size. We use genome editing technology targeting these genes in an effort to create rice with increased biomass production capacity. With corn, we are working to dramatically increase the amount of biomass by taking advantage of a characteristic called heterosis, or hybrid vigor, instead of genome editing technology.

### » A New Form of Agriculture to Realize a Carbon-Circulating Society

This new type of agriculture can be referred to as "***DAC agriculture***." Crops with dramatically increased biomass production capacity capture and fix more $CO_2$, contributing to carbon resource circulation. In DAC agriculture, $CO_2$ Life Cycle Assessments (LCAs) for the resulting biomass are continuously carried out, making it possible to visualize the contribution to curbing global warming. This new form of agriculture meets a variety of needs, from the creation of sustainable industries to new businesses.


### KEYWORD

**DAC Agriculture**

By developing crops with improved $CO_2$ absorption and fixation capacity and efficiently converting their biomass into energy and useful substances, this new form of agriculture contributes to the realization of a carbon-neutral society.

## FUTURE VISION

**2025**

### On the Brink of Super Crops

We will modify super DAC rice genes to increase biomass and make it more readily usable. We will develop seed collection technologies for super DAC corn.

**2027**

### Super Crops Arrive

We will complete development of DAC crops that incorporate modified genes to maximize biomass production. Cultivation methods that reduce emissions of methane ($CH_4$), dinitrogen monoxide ($N_2O$), and other greenhouse gases will be designed.

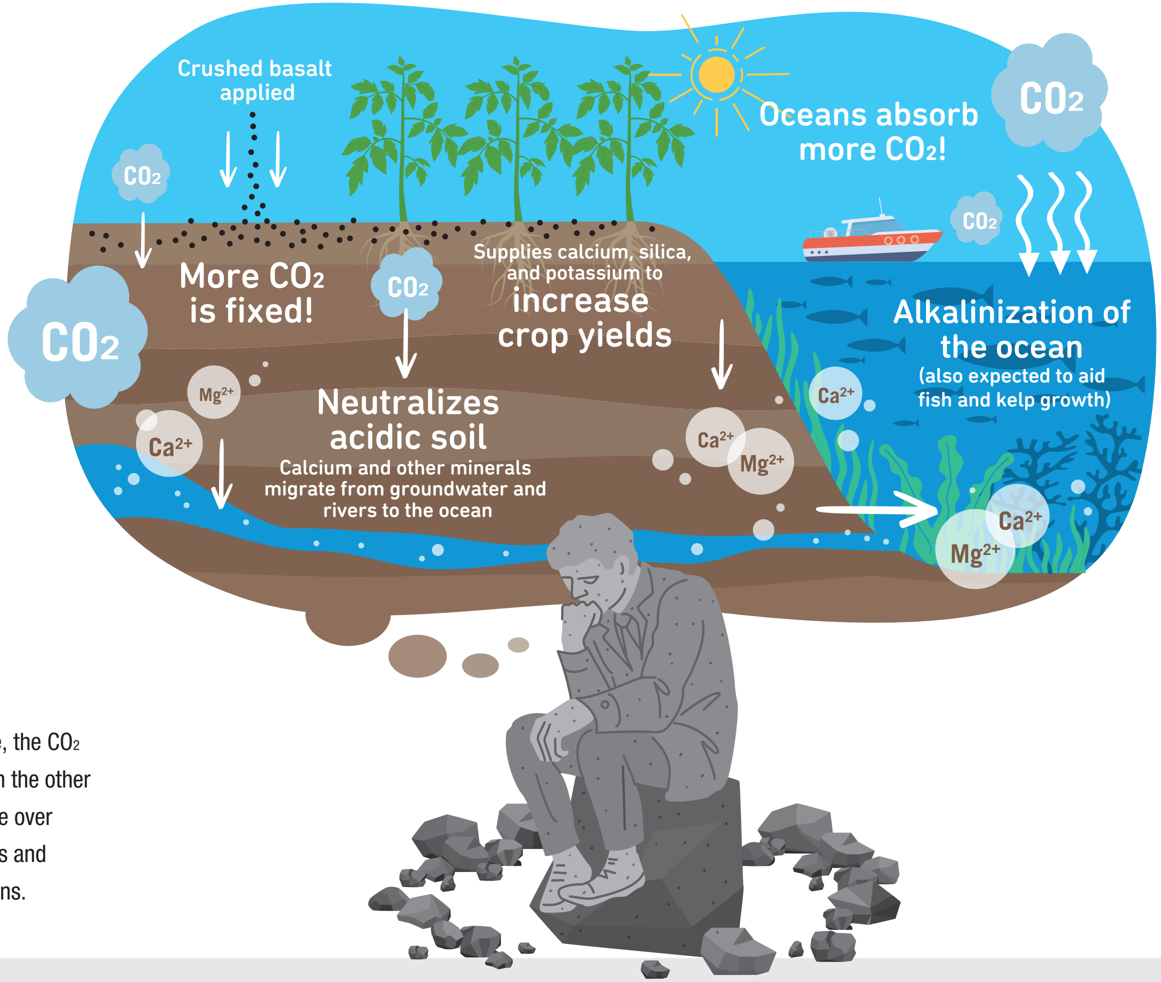
**2029**

### Plant-Based Fuel for Aviation

Through rigorous testing of ethanol and sustainable aviation fuel (SAF) made from DAC crop biomass raw materials, we will conduct precise cost evaluations and LCA to determine their feasibility.

| | |
|---|---|
| **Implementation** | National Agriculture and Food Research Organization (NARO), Tokyo University of Agriculture and Technology, Nagoya University |
| **Project Introduction Video** | https://www.youtube.com/watch?v=Dn6QHc3f9J8&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3 |

# 09 PROJECT




## Advanced Enhanced Rock Weathering Technology Provides Rapid $CO_2$ Fixation and Accurate Carbon Accounting

### A-ERW Combines Technology and Site Characteristics

Did you know that most of the carbon on Earth exists as carbonates in rocks and sediment? To put it another way, this is more $CO_2$ than the amount fixed by plants. Additionally, when plants die, the $CO_2$ they'd fixed is decomposed by microorganisms in the soil and released back into the atmosphere. On the other hand, the sequestering of $CO_2$ in rock is more permanent, as weathering is a process that takes place over long periods of time. Advanced Enhanced Rock Weathering (A-ERW) artificially speeds up the process and efficiently captures and sequesters $CO_2$, meaning this technology could bring about negative emissions.

### Using Japan's Unique A-ERW Technology in Creating New Value Through Local Production and Consumption to Fix $CO_2$

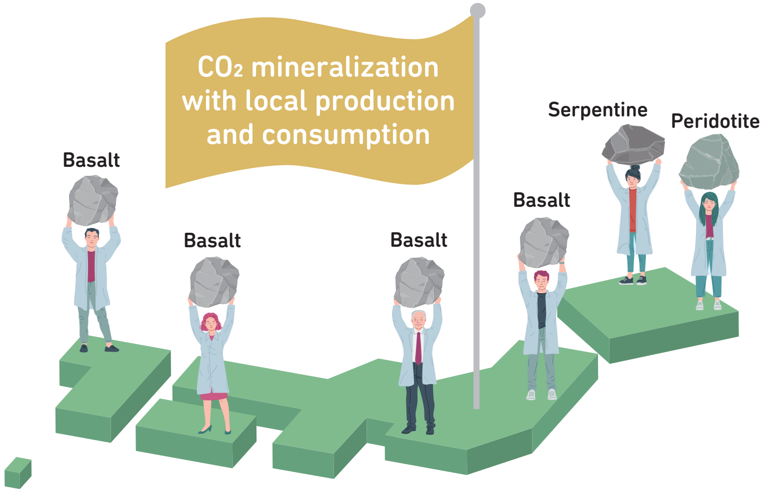
Dr. NAKAGAKI Takao
Professor, Faculty of Science and Engineering, Waseda University

Known as a land of earthquakes and volcanoes, Japan's location on a plate subduction zone gives it easy access to rock exposed to the Earth's surface and suitable for absorbing $CO_2$. This is an advantage for developing site-specific A-ERW and gathering data to problem-solve effective soil use. For example, A-ERW may reduce dependence on agricultural lime in mitigating acidity, which is a source of $CO_2$ emissions. For these reasons, Japan wishes to be a leader in this technology and encourage its use in other Asian island countries with similar volcanic geology.

# Advanced Enhanced Rock Weathering Technology Provides Rapid $CO_2$ Fixation and Accurate Carbon Accounting

## » Amplifying the Power of Nature

$CO_2$ in the atmosphere is absorbed by rain, and when these carbonic acid raindrops fall on rock, they react with the rock's calcium (Ca) and magnesium (Mg) to form semi-permanently fixed carbonates. A-ERW is a weathering enhancement technology that artificially accelerates this process by crushing rocks to expand their surface area and matching them to the characteristics of the site where the crushed rock is applied. The amount of $CO_2$ already being removed from the atmosphere by natural weathering is an estimated 300 million tons per year, so the decarbonization impact potential from A-ERW is great.




## » Vast Amounts of Data and Advanced Calculations Are Needed

In parallel with a demonstration project using a gas-solid contacting house, we are also testing A-ERW by applying crushed rock in diverse regions. After the rock is applied to cultivated soil, we track crop growth conditions, yield, effect on soil improvement, and carbon storage. We also measure the remaining amount of calcium, which acts as a natural fertilizer. After application to abandoned mines, we check for effectiveness in neutralizing highly acidic acid mine drainage, alkalinization of nearby seawater, $CO_2$ fixation, and impact on marine life. We plan to achieve a real-world social implementation model for A-ERW by demonstrating accurate ***carbon accounting*** based on measured data.

### KEYWORD

**Carbon Accounting**

The process of quantifying the carbon balance; that is, the increase or decrease in greenhouse gas emissions produced by businesses. Transparency in measuring, reporting, and verifying is essential for carbon crediting.*

* A system in which reductions in greenhouse gas emissions are deemed credits that can be bought and sold between companies. Greenhouse gases that cannot be completely eliminated by a company may be offset by acquiring credits.

# FUTURE VISION

**2025**

### Collection of Accurate Data

We will conduct trial applications at each site (gas-solid contacting house, farmland, forested slopes, and abandoned mines) to collect carbon accounting data and develop rules for measurement and verification.

**2027**

### Expected Benefits Besides $CO_2$ Fixing

In addition to improving accuracy in carbon accounting, we will also verify collateral effects such as positive impacts on crop cultivation and neutralization of acid mine drainage.

**2029**

### Steady Progress Towards Commercialization

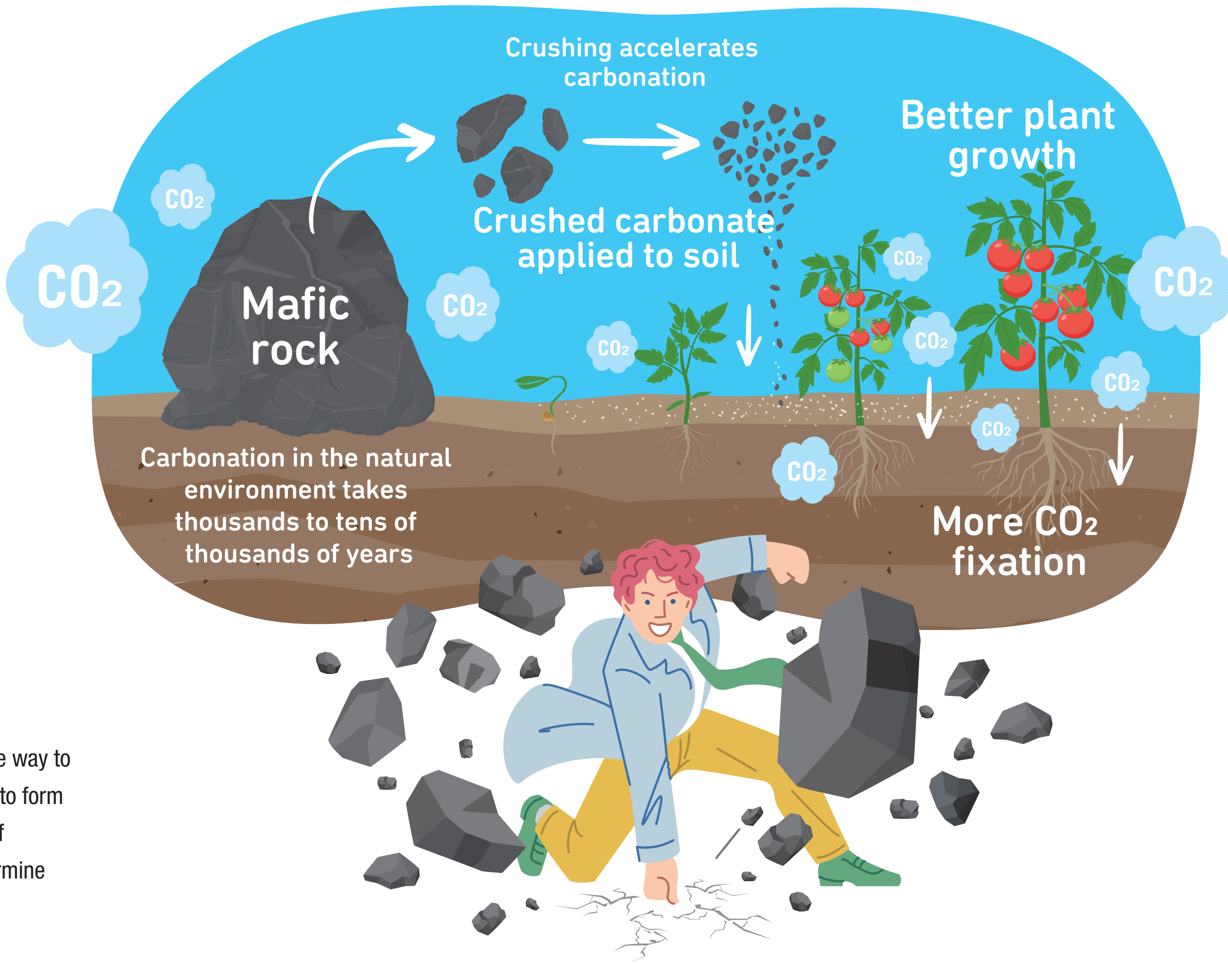
We will begin full-scale CDR crediting via $CO_2$ fixation in gas-solid contacting houses. We will also establish an accurate carbon accounting system to demonstrate the effectiveness of applying crushed rock to farmland.

**Implementation** | Waseda University, Hokkaido University, Kyoto Prefectural University, Mitsubishi Heavy Industries, Ltd.

**Project Introduction Video** | https://www.youtube.com/watch?v=68dylv1Ajj0&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

# 10 PROJECT

# Tackling Current Problems with Solutions Transcending Time and Space: The Appeal of Enhanced Rock Weathering




## Establishing a Platform for Evaluating LCA/TEA in Research and Development of Enhanced Weathering Systems

Some types of rock on Earth are capable of fixing $CO_2$, making rock weathering an effective way to sequester atmospheric $CO_2$. As dissolution occurs, elements of the rock combine with $CO_2$ to form carbonates, but this process normally takes place over eons. We are building a database of information on conditions that enable artificial acceleration of weathering, and aim to determine the optimal system for introducing enhanced mineralization on a global scale.

## Developing an Analytical Tool for Use Worldwide

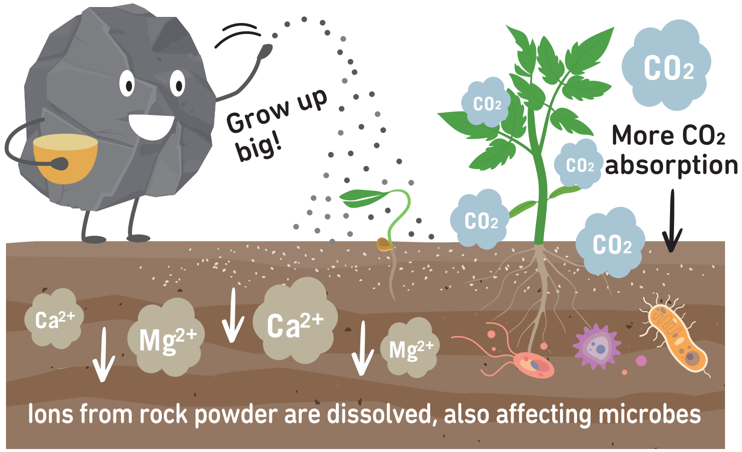
Dr. MORIMOTO Shinichirou
National Institute of Advanced Industrial Science and Technology (AIST)

To achieve the social implementation of enhanced weathering technology, we are developing a tool to analyze the optimal conditions for fixing atmospheric $CO_2$ using the natural process of rock weathering. Rocks that undergo enhanced weathering not only help counter global warming by fixing $CO_2$; they enhance the growth of agricultural crops. Enhanced weathering is expected to create jobs and provide other related economic benefits as well. The “optimal condition” is a beacon for a prosperous society woven from enhanced weathering and human activity. Researchers with various specialties are collaborating and working together to achieve this.

# Tackling Current Problems with Solutions Transcending Time and Space: The Appeal of Enhanced Rock Weathering

## >> The Challenge of Dealing with Nature

In order to artificially accelerate weathering, rocks are crushed and applied to soil, where they react with $CO_2$ to form carbonates. However, there is a major pitfall here; the energy required to crush the rocks also emits $CO_2$ into the atmosphere. Therefore, enhanced weathering needs to take this $CO_2$ into account. Furthermore, accelerating the adoption of enhanced weathering requires that the process be accompanied by other benefits to society besides $CO_2$ fixation. Therefore, calculating carbon balances and assessing effectiveness requires an evaluation tool that simultaneously calculates economic effects.




## >> Japanese Technology Leads the World

Using the evaluation tool being developed in this project, we will analyze and quantitatively evaluate a wide range of factors, including $CO_2$ emissions and fixation, rock characteristics, and location characteristics, including the distance from quarry to application site. Furthermore, by analyzing the results in conjunction with a business profitability evaluation based on Techno-Economic Analysis (TEA), we will identify the optimal conditions for the social implementation of enhanced weathering in each area. The development of a systematized ***LCA/TEA evaluation tool*** based on a vast database will contribute to suggesting optimal conditions for the world's first enhanced weathering projects.

### KEYWORD

**LCA/TEA**
(Life Cycle Assessment/ Techno-Economic Analysis)
**Evaluation Tool**

This tool analyzes various characteristics of the land, taking into account future economic effects and risk assessments, and compares it against a vast amount of research data from a wide range of fields to identify the optimal conditions for enhanced weathering.

# FUTURE VISION

**2025**

### Solidify the Foundation for Gathering Data

We will develop measurement technology to build a precision database regarding $CO_2$ fixation.

**2027**

### Data Collection

Through a wide variety of experiments conducted both indoors and outdoors, we will continue to accumulate large amounts of data on $CO_2$ fixation. We aim to deepen our collaborations with overseas partners and garner international recognition for these data measurement methods.

**2029**

### Anticipate Social Implementation

We will collect empirical data to promote the commercialization of enhanced weathering and complete the business design. With internationally recognized data, we aim to create conditions for market establishment and overseas expansion.

**Implementation** National Institute of Advanced Industrial Science and Technology (AIST), RIKEN

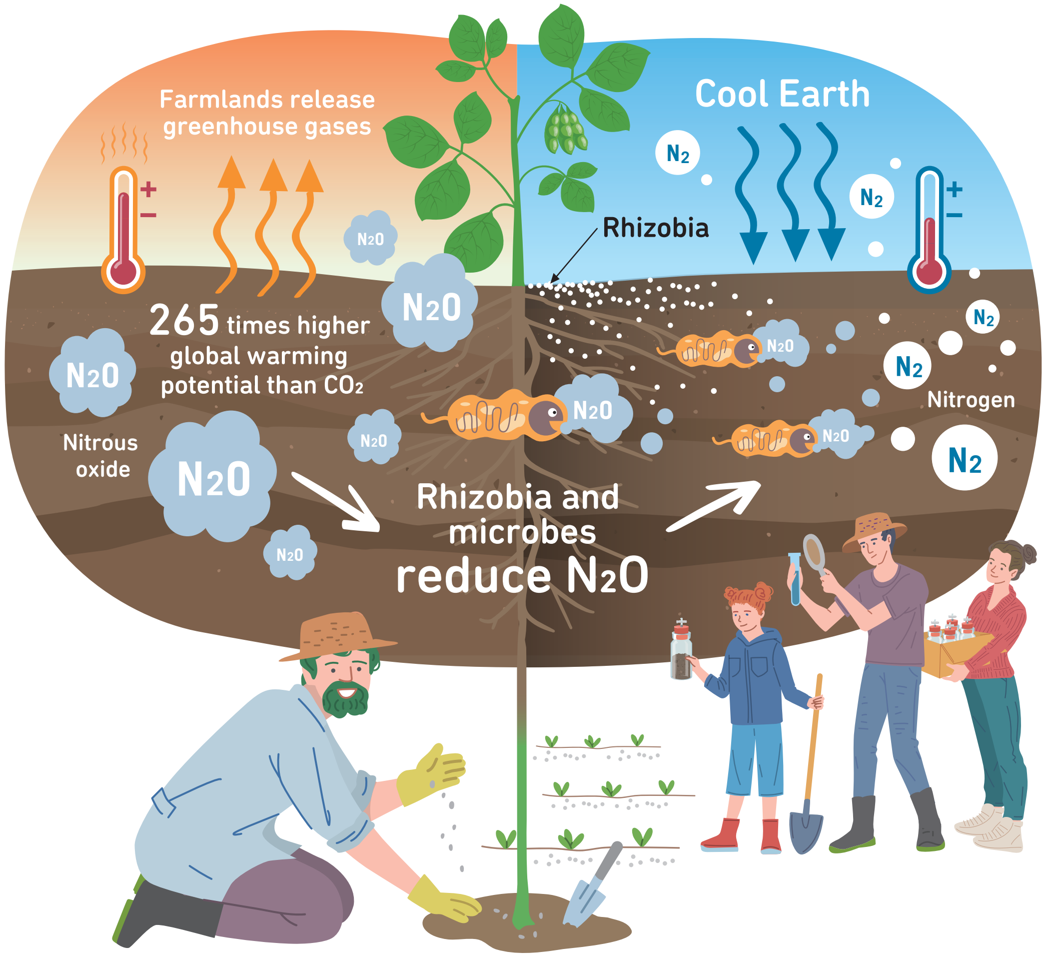
**Project Introduction Video** https://www.youtube.com/watch?v=GhKDGpC3NgE&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

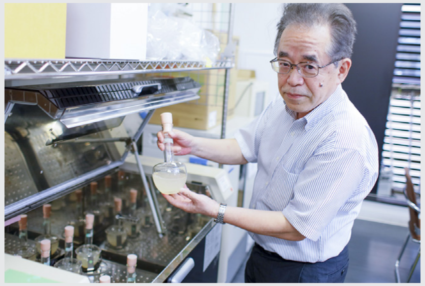
11 PROJECT

# Microbes Hiding in the Soil Help Curb Greenhouse Gases

## Mitigation of Greenhouse Gas Emission from Agricultural Lands by Optimizing Nitrogen and Carbon Cycles

You probably know that $CO_2$ is a greenhouse gas, but have you heard of $N_2O$?
Nitrous oxide exists in the atmosphere in lower concentrations than carbon dioxide, but its greenhouse effect is 265 times higher! The largest source of human-caused $N_2O$ emissions is agriculture, and approximately 60 percent of that comes from cultivated soil. As Earth's population continues to grow, more food is needed. If the use of chemical fertilizers increases proportionately, we will generate greater amounts of $N_2O$ as well. Ways to reduce agricultural $N_2O$ emissions without affecting food production are urgently needed to protect the global environment.



## Soil Samples Collected by the Citizens Lead to New Possibilities

Dr. MINAMISAWA Kiwamu
Specially Appointed Professor, Graduate School of Life Sciences, Tohoku University

Our citizen science subproject was launched to raise awareness among the general public about $N_2O$ and its connection to global warming. We asked people to collect soil and air samples that we used in our search for microbes that decompose $N_2O$. Inspired by the microorganisms we discovered and the soil aggregate structure in which these microorganisms live, we have developed ***artificial soil aggregates***. We have also partially succeeded in reducing $N_2O$ from nitrogen fertilizers. Our goal is to contribute to a Cool Earth by reducing $N_2O$ emissions from agriculture.

# Microbes Hiding in the Soil Help Curb Greenhouse Gases

## Beans and Bacteria Make the Strongest Tag Team

Fertilizers used to improve crop growth contain nitrogen compounds. These are broken down by microbes and fungi in the soil and released into the atmosphere as $N_2O$. Rhizobia, which live on the roots of legumes, are one such type of microbe. We were the first in the world to identify a specific strain that has a high capacity for decomposing $N_2O$. When this strain of rhizobia was used on actual farmland, the result was a 30 percent reduction in $N_2O$ emissions. We call these $N_2O$-reducing microbes "Global Cooling Microbes."


## Exploring Global Cooling Microbes

Rhizobia are amazing, but they can only reduce $N_2O$ on the roots of leguminous plants. Reducing all types of agricultural $N_2O$ means finding microbes that are not dependent on legumes.

This is why we launched our citizen science project. We have found several Global Cooling Microbe candidates from the soil samples submitted thus far, and we feel that our research is making progress. We hope to reduce agricultural $N_2O$ through the application of these Global Cooling Microbes in agriculture.

### KEYWORD

**Artificial Aggregates**

These ball-shaped clods of synthetic soil are designed to be a favorable habitat for $N_2O$-reducing microbes. Applying these aggregates like fertilizer can help create soil that does not release $N_2O$.

# FUTURE VISION

**2025**

**Collection of Data for Real-World Use**

We aim to obtain data that will serve as the foundation for the development of rhizobial technology in Japan and internationally. We will continue research on rhizobia, artificial aggregates, and artificial carriers with the aim of deploying them in agriculture.

**2027**

**Rapid Adoption of Rhizobia and Artificial Aggregates**

Our objective is to commercialize the rhizobia, starting with domestic and then international application.

**2029**

**The Dream Is a Society With Half the Nitrogen**

With full-scale rhizobia deployment domestically and internationally, and the use of artificial aggregates and carriers underway, we aim to reduce $N_2O$ emissions by about 50 percent. We will achieve results in our core research, clarifying the functions of soil microbes, and demonstrate both technological and academic progress.

| | | | |
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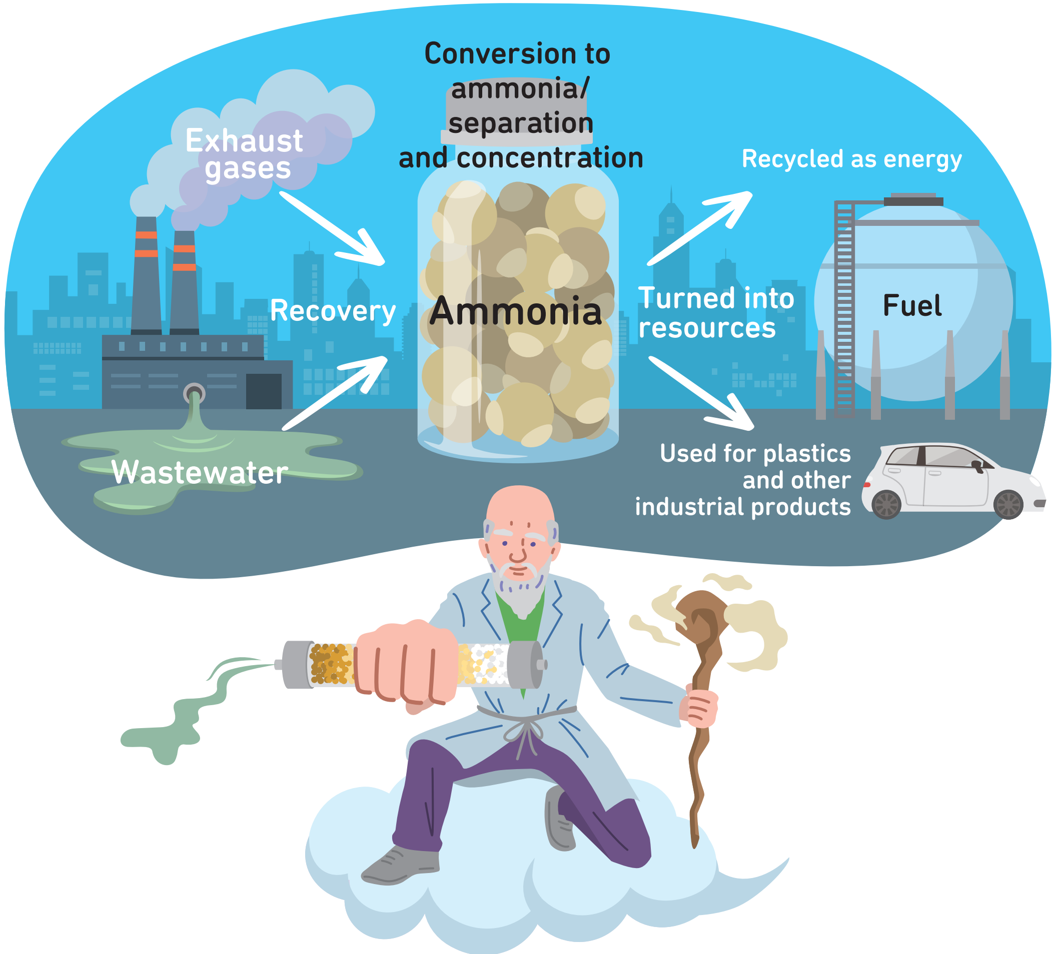
| Implementation | Tohoku University, National Agriculture and Food Research Organization (NARO) | Project Introduction Video | https://www.youtube.com/watch?v=1Rqh-tcPerl&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3 |

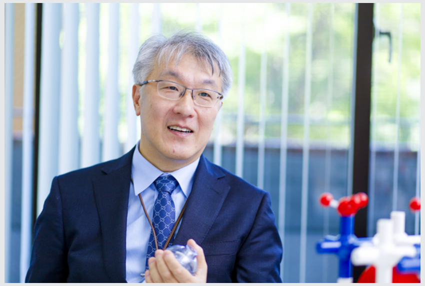
# 12 PROJECT

# Turning Problems Into Resources With Technology That Recycles Nitrogen

## Nitrogen Recycling Technology Can Keep Us Within Our Planetary Boundary

Global environmental degradation is the price humans have been paying in exchange for prosperity, and pollution from nitrogen waste in particular may be reaching the limit of what the Earth can handle, known as the planetary boundary. Ammonia is a nitrogen compound that we need in daily life for things like chemical fertilizers, but when released in exhaust or wastewater, it causes environmental problems. Processing this waste requires tremendous amounts of energy. If we want to restore the environment with no impact on industrial activity, we need *nitrogen management* systems that convert this waste into ammonia resources through nitrogen recycling technology.



## Hokusai's Favorite, Prussian Blue, Is the Key to Ammonia Adsorption

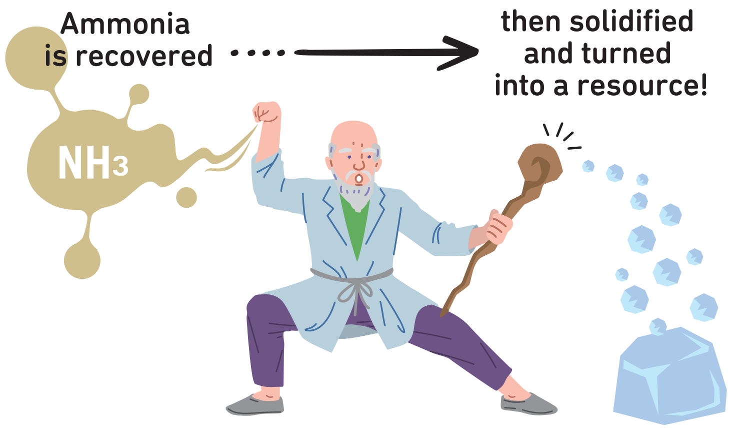
Dr. KAWAMOTO Tohru
Principal Researcher, Nanomaterials Research Institute, Department of Materials and Chemistry, National Institute of Advanced Industrial Science and Technology (AIST)

Katsushika Hokusai's "Thirty-Six Views of Mount Fuji" are prints known worldwide as classic examples of ukiyo-e culture. The Prussian blue pigment he used is still widely used today. We discovered that this pigment is an optimal substance for adsorption of ammonia. Tests confirmed there is no decrease in the pigment's adsorptive capacity even with frequent use, and that the adsorbed ammonia can even be extracted and recycled as a resource. Based on these promising results, we have produced a plan for practical application, and expectations are high for a future colored with Prussian blue.

# Turning Problems Into Resources
# With Technology That Recycles Nitrogen

## » The Road to Nitrogen Resource Recycling

Altering the composition of Prussian blue at the atomic level creates separate adsorbents for exhaust gases and wastewater, allowing selective recovery of ammonia. But recovery is not the final step. Technology is required to convert the nitrogen waste products into a form that can be tapped for ammonia resources. We have been working to develop NTA (NOx to Ammonia) technology which uses a catalyst in exhaust gas to detoxify nitrogen waste such as NOx and convert it into ammonia, along with technology that uses biological reactions in wastewater to convert ammonium ions into ammonia.




## » Technology Brings Hope

The ammonia converted from nitrogen waste is separated and concentrated using membranes and adsorbents. This concentrated ammonia can then be used as a raw material for plastics and fuels. Fuel made from ammonia is carbon-free and does not emit $CO_2$, so is an energy resource that addresses a major social need. We believe that by combining the conversion, separation, and concentration processes in factory production systems we will succeed in creating a society that recycles nitrogen waste into a resource and helps protect the earth from environmental pollution.

### KEYWORD

**Nitrogen Management**

As global environmental pollution from nitrogen waste worsens, the 2022 United Nations Environment Assembly confirmed the need for sustainable nitrogen management to investigate and review the state of air, water, and soil pollution.

# FUTURE VISION

### 2025 — Market Already-Completed Products

We will initially focus on technological development in the laboratory. We will continue to conduct trial-and-error experiments with the aim of finding practical applications, and begin selling some ammonium adsorbent to factories for reuse of wastewater.

### 2027 — One Step From Practical Application

We will start pilot tests in collaboration with businesses. Focused on achieving a nitrogen recycling society, we will try to overcome hurdles as they arise and develop systems for wastewater reuse at large factories and sewage treatment plants.

### 2029 — Achieving a Nitrogen Recycling Society

Using a pilot plant, we will demonstrate that the series of processes from nitrogen waste recovery to recycling it as a resource can work together in a system. Real-world social implementation will be on the horizon.

**Implementation**: National Institute of Advanced Industrial Science and Technology (AIST), The University of Tokyo, Waseda University, Tokyo University of Agriculture and Technology, Kobe University, Osaka University, Yamaguchi University, Kirin Holdings Co., Ltd., Astom Corporation, Toyobo MC Corporation, Fuso Corporation

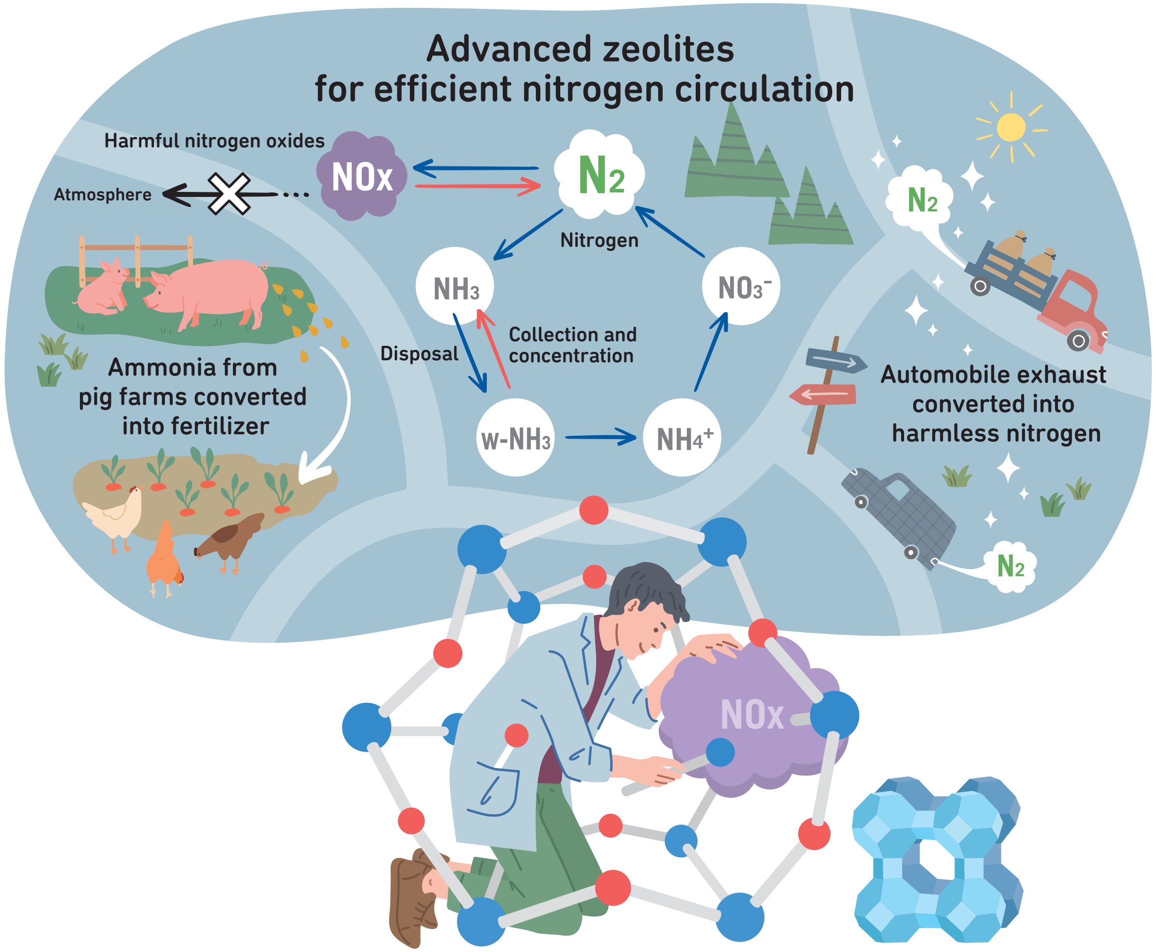
**Project Introduction Video**: https://www.youtube.com/watch?v=do3o39UaZFA&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

# 13 PROJECT

# Working in Nanoscale Space to Perfect Zeolite for a Nitrogen-Recycling Society

## Developing Technologies for Recovery and Removal of Dilute Reactive Nitrogen

Nitrogen gas ($N_2$) circulates naturally in the atmosphere, in land, and in the oceans in various forms. However, human activities such as the use of chemical fertilizers in agriculture and the burning of fossil fuels have disrupted the nitrogen cycle's balance by increasing the amount of harmful nitrogen oxides in the atmosphere. This has led to air pollution and climate change and impacts the global environment. We are researching nitrogen circulation systems using *zeolite* and other materials that do not place such burdens on the environment.




## Ending the Era of Reactive Nitrogen's Harm on Earth

Dr. WAKIHARA Toru
Professor, Graduate School of Engineering,
The University of Tokyo

What is reactive nitrogen? This is a general term for forms of nitrogen that are easy to utilize by organisms. Since most cannot make use of atmospheric nitrogen directly, they use it in the form of reactive nitrogen. For example, the proteins in food contain reactive nitrogen. On the other hand, ammonia ($NH_3$) in chemical fertilizers and nitrogen oxides emitted by burning fossil fuels also contain reactive nitrogen. Reactive nitrogen is deeply involved in our lives, but it is the unnatural, excessive, human-produced reactive nitrogen that causes environmental problems.

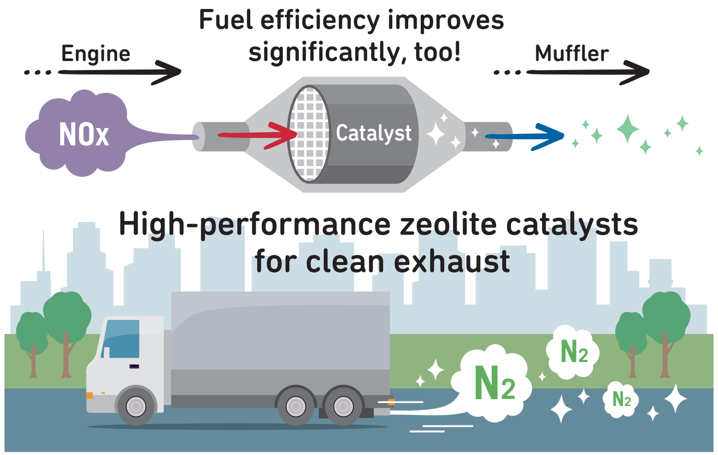
# Working in Nanoscale Space to Perfect Zeolite for a Nitrogen-Recycling Society

## >> Zeolite Works in Multiple Ways

Many people may have never heard of zeolite before, but it is actually used in common products such as detergents and deodorizers. A number of zeolites have pores identical in size to molecules like nitric oxide, nitrous oxide, and ammonia, and can trap these molecules or react with them to convert them into other molecules. Another feature of zeolites is that they are easy to synthesize and their structure can be modified for specific applications. We plan to make full use of zeolite to take on the challenge of reducing human-caused excess reactive nitrogen.

## >> Working Toward a Society That Doesn't Emit Reactive Nitrogen

Zeolites are conventionally used as catalysts in automobiles. However, they suffer from temperature range limitations and durability issues and emit nitrous oxide when they age and deteriorate. This can be solved by creating zeolites that are precisely tuned at the atomic level. Another application is their use in agriculture. Incorporating zeolite-like substances in ammonia recycling systems allows ammonia generated at pig farms to be converted into fertilizer. Yet another use for zeolite is in sewage treatment plants, where it can process harmful nitrogen oxides and turn them into harmless nitrogen. Adopting technologies to create zeolites can enable the development of a nitrogen circulating society where reactive nitrogen is reused as a resource, contributing to environmental restoration.




### KEYWORD

**Zeolite**

This is a general term for porous crystalline aluminosilicates. Zeolites are used in many fields as catalysts and adsorbents. They feature tiny pores smaller than 1 nanometer (1 billionth of meter), and it is thought that zeolites with even smaller pores will be useful in achieving a nitrogen circulating society.

# FUTURE VISION

**2025**

### Develop Advanced Zeolites

We will complete the development of zeolite that does not deteriorate even under harsh conditions, a long-standing challenge.

**2027**

### Complete the System's Constituent Components

We will complete the development of the ultimate denitrification catalyst and materials for the recovery of nitrous oxide and ammonium ions, and begin to promote the system. Social implementation of the technology is almost achieved. We will also complete the development of zeolites for various applications.

**2029**

### Zeolites Become Integral to Society

Finally, we will conduct user evaluations needed for social implementation of the process.

**Implementation** The University of Tokyo, National Institute of Advanced Industrial Science and Technology (AIST), Japan Fine Ceramics Center, Mitsubishi Chemical Corporation

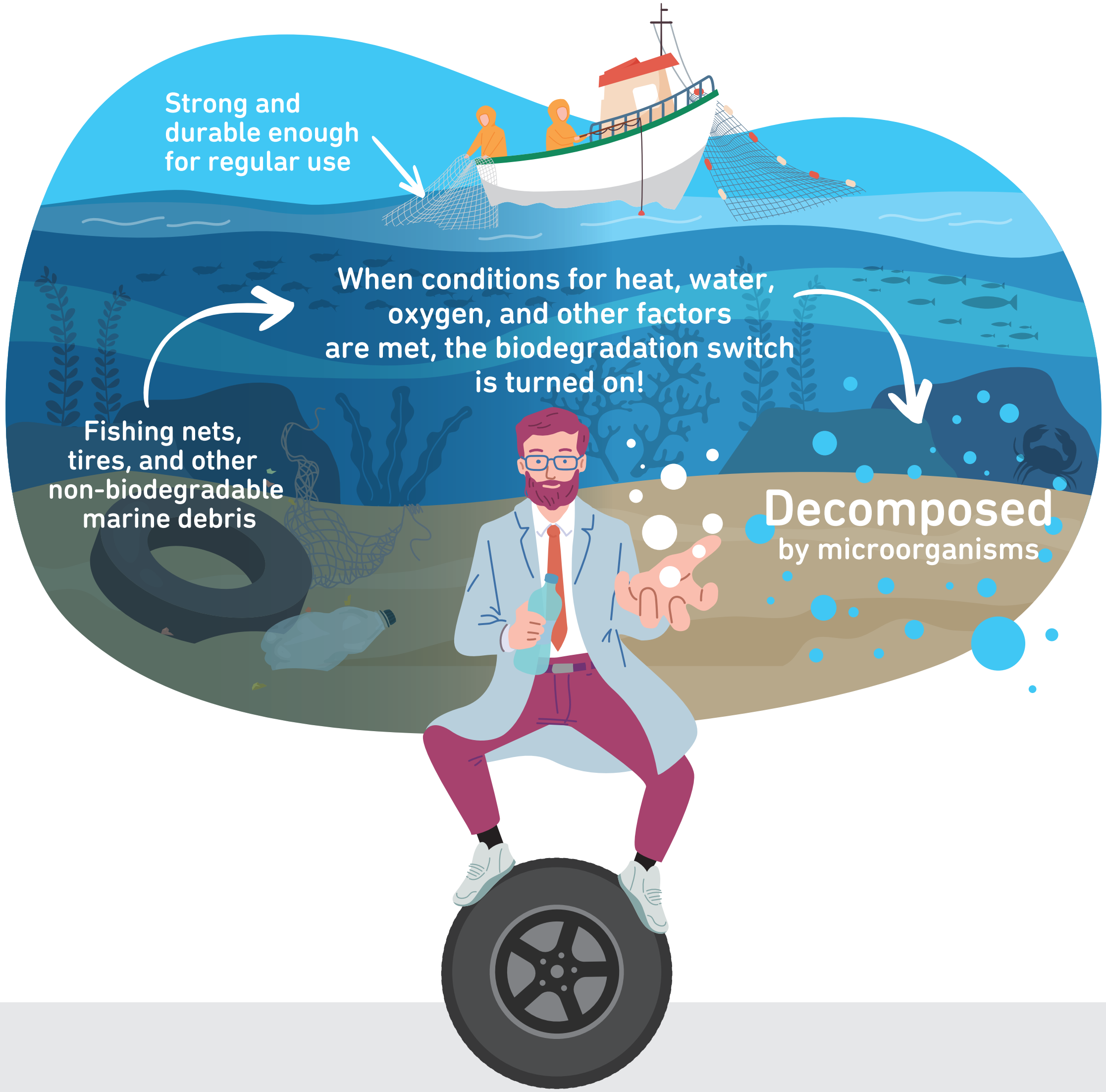
**Project Introduction Video** https://www.youtube.com/watch?v=7pLatx5dgmg&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

# 14 PROJECT

# New Material, Strong Yet Earth-Friendly, That Returns to the Ocean

## Multi-Lock Biopolymers Made From Biomass Break Down in the Ocean

Pollution from plastic waste in our oceans is a serious problem, with warnings that by 2050 the weight of trash in the seas will exceed that of fish. One initiative in the effort to solve this problem involves developing biodegradable materials that decompose naturally with the help of living organisms. While some of these materials have already been put into practical use, the challenge has been to find ones that are both durable and easily broken down. In this project, we are researching ***biodegradable plastic*** made from polymers with sufficient strength for practical use, but that decompose only under certain conditions.




## A Sign of Encouragement From an Unexpected Visitor

Dr. ITO Kohzo
Special Appointed Professor, The University of Tokyo
Fellow, National Institute for Materials Science

Although we have succeeded in developing extremely durable polymers, we are taking on the additional challenge of balancing durability and degradability. While conducting the world's largest field test of polymers that degrade in seawater, we had an unexpected, heartwarming encounter. We found squids had spawned in one of the experiment samples! Perhaps this meant the samples were welcome in the natural world. It gave us a sense of hope for the future, one presenting a fusion of technology and nature.

## New Material, Strong Yet Earth-Friendly, That Returns to the Ocean

### » The Difficulty of Achieving Both Durability and Degradability

There are serious concerns about the adverse effects of plastics such as fishing gear, nets, and polymer-coated fertilizers flowing into the sea. Research has been conducted on biodegradability, or the ability of materials to be decomposed naturally by microbes, but there is a trade-off between the strength that materials require for regular use and their ability to be broken down in the natural environment. Ideal biodegradability would mean that fishing gear, nets, or other materials stay strong as long as the material is fulfilling its role, but quickly and completely decomposes if it has unintentionally become marine debris.

### » Discovering the Key to Unlock the Solution

In our research, we aim to develop durable yet degradable plastic products and fishing gear for everyday use made from biomass, that is, raw materials derived from living organisms. A turning point came with the discovery of a unique, new material. A dynamic mechanism incorporated into the bonds connecting the polymers diffuses external forces applied to it. In other words, it's tough! At the same time, it features a decomposition trigger in the form of a multi-lock mechanism. This breaks the polymer bonds, but is initiated only when multiple stimuli in the ocean, such as warmth, oxygen, water, enzymes, certain microorganisms, and catalysts are simultaneously present. The result is a "two-way player" capable of both durability and degradability. Widespread adoption of this new material can contribute tremendously toward solving global environmental problems.


### KEYWORD

**Biodegradable Plastic**

This is a plastic made of a polymer that is decomposable by microorganisms, which turn it into $CO_2$ and water that are circulated back into the natural environment. For example, this type of plastic can be mixed into a compost pile and broken down by microbes for use as a fertilizer or soil amendment.

## FUTURE VISION

### 2025 — Narrow Down the Final Candidates

We are consulting with participating companies to narrow the range of products incorporating new materials and technologies developed by academic institutions. The criteria are whether they address current serious environmental hazards and if adopting them can be expected to have a major impact on society.

### 2027 — Achieve the Required Material Target Values

To manufacture specific final products, the individual companies require the polymer materials to hit certain numerical targets for toughness and degradability. In addition, we will develop manufacturing technologies using inedible biomass as a raw material.

### 2029 — Prototype and Assess Final Products

We will produce prototypes of specific final products that combine durability and degradability and evaluate their performance in real-world situations. We will also focus on establishing technologies for mass production and cost reduction methods to quickly commercialize products after the project ends.

**Implementation**: The University of Tokyo, Mitsubishi Chemical Corporation, Bridgestone Corporation, Kureha Corporation, Kyushu University, Nagoya University, Yamagata University, Research Institute of Innovative Technology for the Earth (RITE), National Institute of Advanced Industrial Science and Technology (AIST), Ehime University, Institute of Science Tokyo

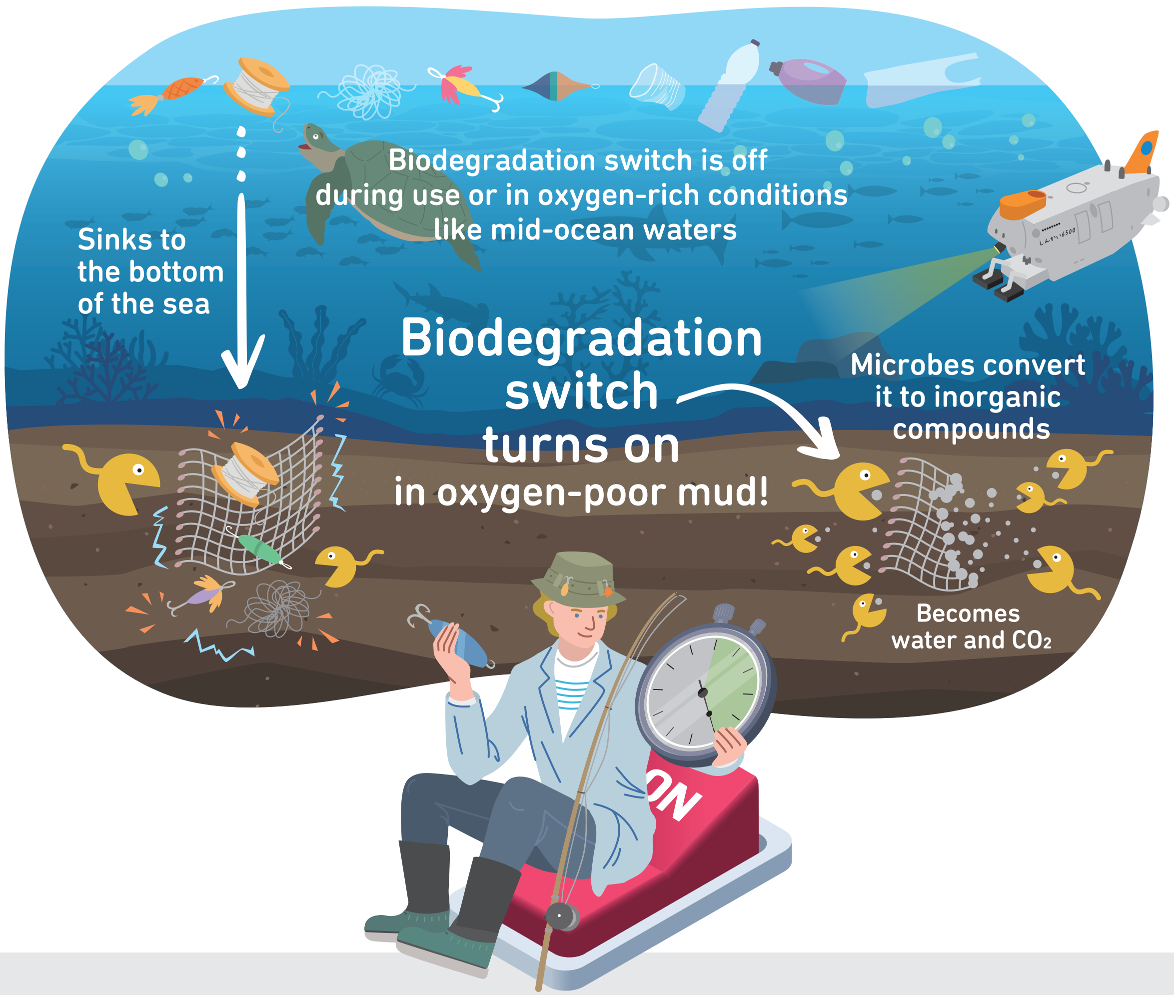
**Project Introduction Video**: https://www.youtube.com/watch?v=N-vs_T52F8o&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

# 15 PROJECT

# Durable Fishing Tackle and Gear That Biodegrade on the Seabed

## Research and Development into Marine Biodegradable Plastics With a Degradation Initiation Switch

Fishing lines and broken fishing gear that sink to the seabed can remain there for hundreds or thousands of years without decomposing. There have been reports of harm coming to marine life that ingest these plastics, and they break down into microplastics that have negative impacts on the ecosystem, including posing a risk to humans when we eat seafood. This research is a response to the SOS signals our oceans are sending out. Our aim is to develop a new plastic that quickly decomposes and is rendered harmless in the ocean.




## I Can't Ignore the Debris From Fishing I See All Over the Beach

Dr. KASUYA Ken-ichi
Professor, Division of Molecular Science,
Faculty of Science and Technology, Gunma University

Many people enjoy fishing as a hobby, myself included. My love of fishing and the sea makes me concerned about the fishing lines, lures, and trash now littering the waters. Feeling that I had to take action, my team and I started work on a material that completely biodegrades in the marine environment through a switch that triggers biodegradation at the right time. Our research is grounded in extensive data collection, and as we near the end of this journey, I can almost hear the sound of clean, clear waves.

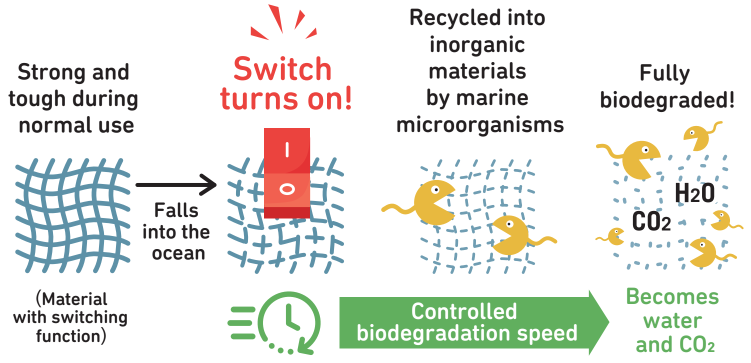
# Durable Fishing Tackle and Gear That Biodegrade on the Seabed

## Action Switches On When Plastic Reaches the Seabed

Biodegradable materials that lose strength with each use cannot be considered practical. Conversely, materials that can withstand the rigors of real-world use are not likely to biodegrade easily. An environmentally responsive switch function would combine these conflicting properties, and one switch we have discovered is triggered by the absence of oxygen. In oxygen-rich environments such as the ocean surface and midwaters, the strength of the polymer is maintained, but when the plastic reaches an oxygen-poor environment such as the muddy seafloor, this acts as a signal to start decomposition, and the material is broken down into smaller molecules.

## To Learn About the Ocean, Ask the Ocean!

Low molecular weight plastics can be broken down into tiny particles by enzymes that microorganisms produce, and when microorganisms then consume those particles, biodegradation is complete. In our research, we conducted tests under a variety of conditions to analyze ***plastispheres***, which are the microbial communities living on plastic. We looked at the number and type of flora, what enzymes they produced, their metabolic mechanisms, and other aspects at the genetic level, using a device called a next-generation sequencer. The database built through testing in a wide range of marine environments, including the deep sea, is proving useful in making plastics that are easily consumed by microorganisms. We plan to create fishing materials made from plastics that feature switching functions to help solve the problem of polluted oceans.




### KEYWORD

**Plastisphere**

It is the nature of microorganisms to attach to some kind of surface. The group of microorganisms that make plastic their home is called a plastisphere. Effectively managing the plastisphere plays a key role in promoting the biodegradation process.

# FUTURE VISION

**2025**

### Prepare to Incorporate Switches

We will test at least five types of degradation switches and establish technology to synthesize biomass-derived biodegradable substrate resins that incorporate at least three of them.

**2027**

### Add Functionality and Head Towards Implementation

We aim to establish nine or more types of synthesis technology for new biodegradable polymer materials with functional switching technology. We will also collaborate with companies to prototype two types of substances that control the makeup of the plastisphere and promote real-world social implementation based on the research results.

**2029**

### Continue to Improve Functionality

After the switching mechanisms are determined, we will develop at least three new plastics that exhibit 90 percent biodegradation after six months in seawater at 30°C. We will then demonstrate their biodegradability in the ocean, including the deep sea, and complete four prototypes with these switches using biomass and carbon-based materials.

**Implementation** Gunma University, The University of Tokyo, Institute of Science Tokyo, Institute of Physical and Chemical Research (RIKEN), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

**Project Introduction Video** https://www.youtube.com/watch?v=HUZI1udo3w0&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03