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

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.

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

Cool Earth

Mitigating global warming

By 2030
Developing technologies to fight global warming caused by greenhouse gases

Clean Earth

Tackling environmental pollution

By 2030
Developing technologies to neutralize or convert pollutants into useful resources

Planetary Boundaries

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

Cool Earth Projects

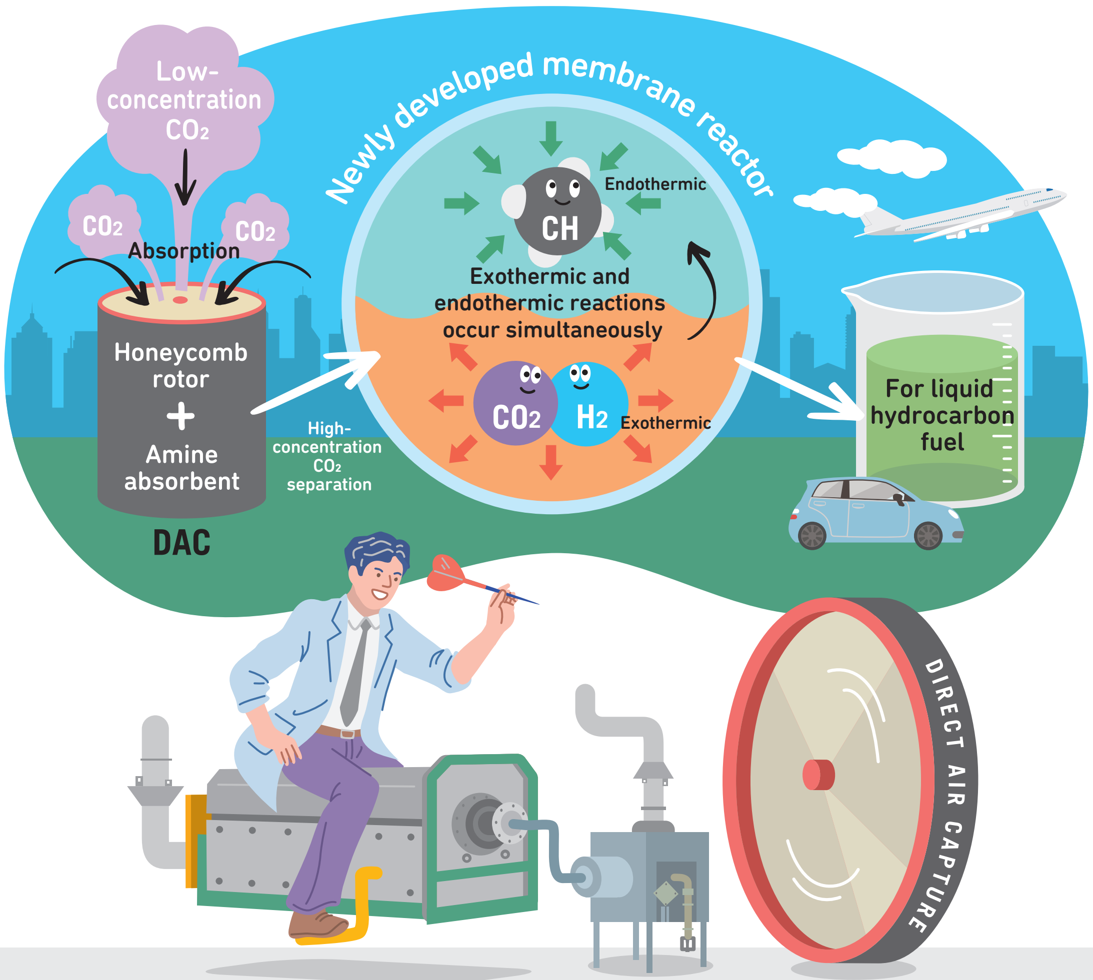
Clean Earth Projects

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.

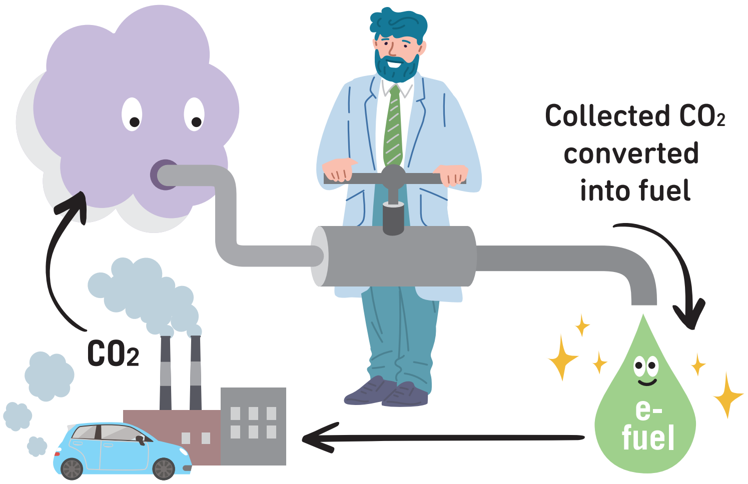
Effective Capture of Low-Concentration CO_2: Absorbents and Thermal Control Are Key

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)

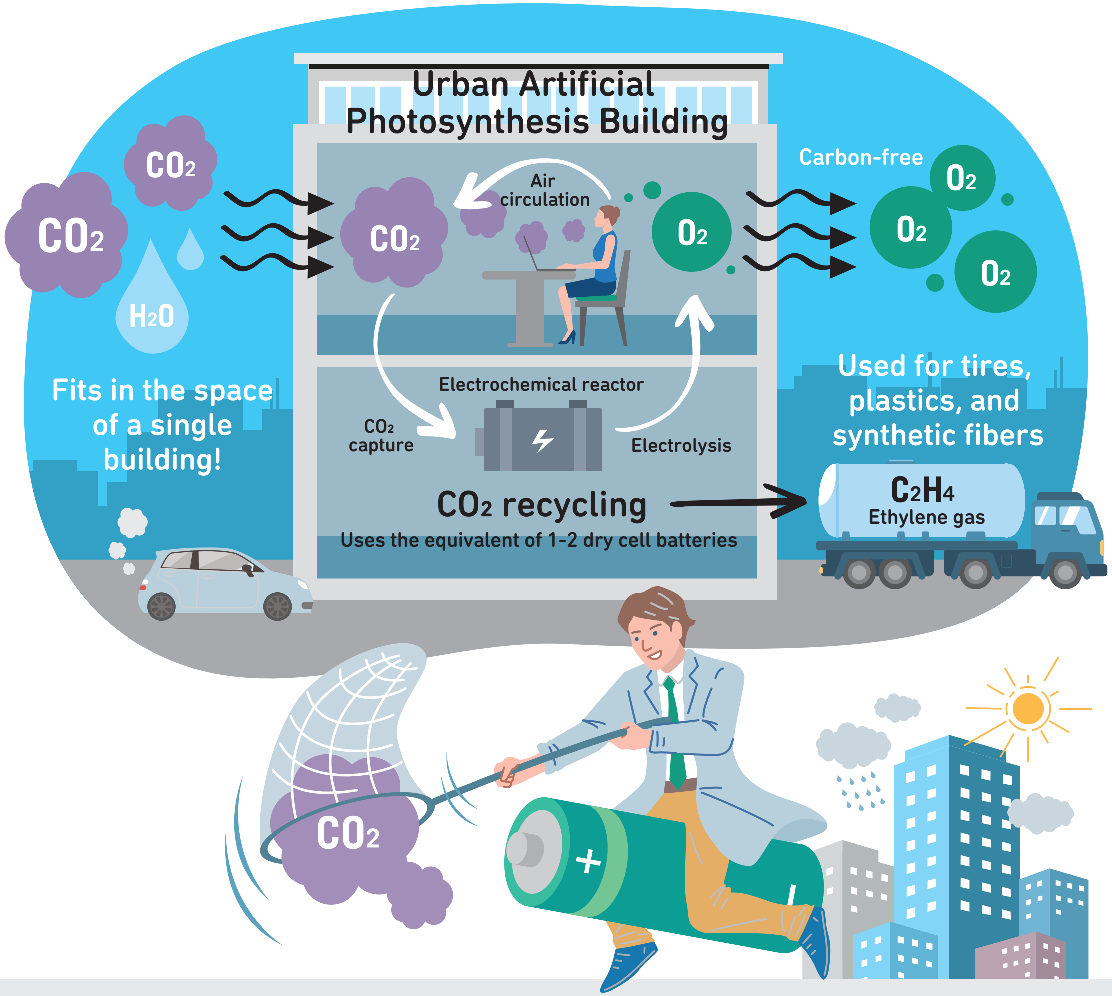
Project Introduction Video https://www.youtube.com/watch?v=hblRUkJjlx8&&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

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

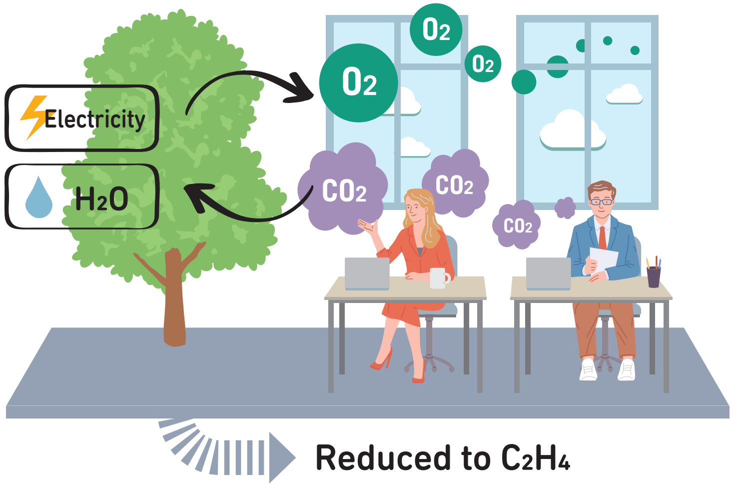
Everyone emits CO_2 when they breathe. CO_2 can return as oxygen and be converted into useful resources and used as a material for chemical products. It's not magic.

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.

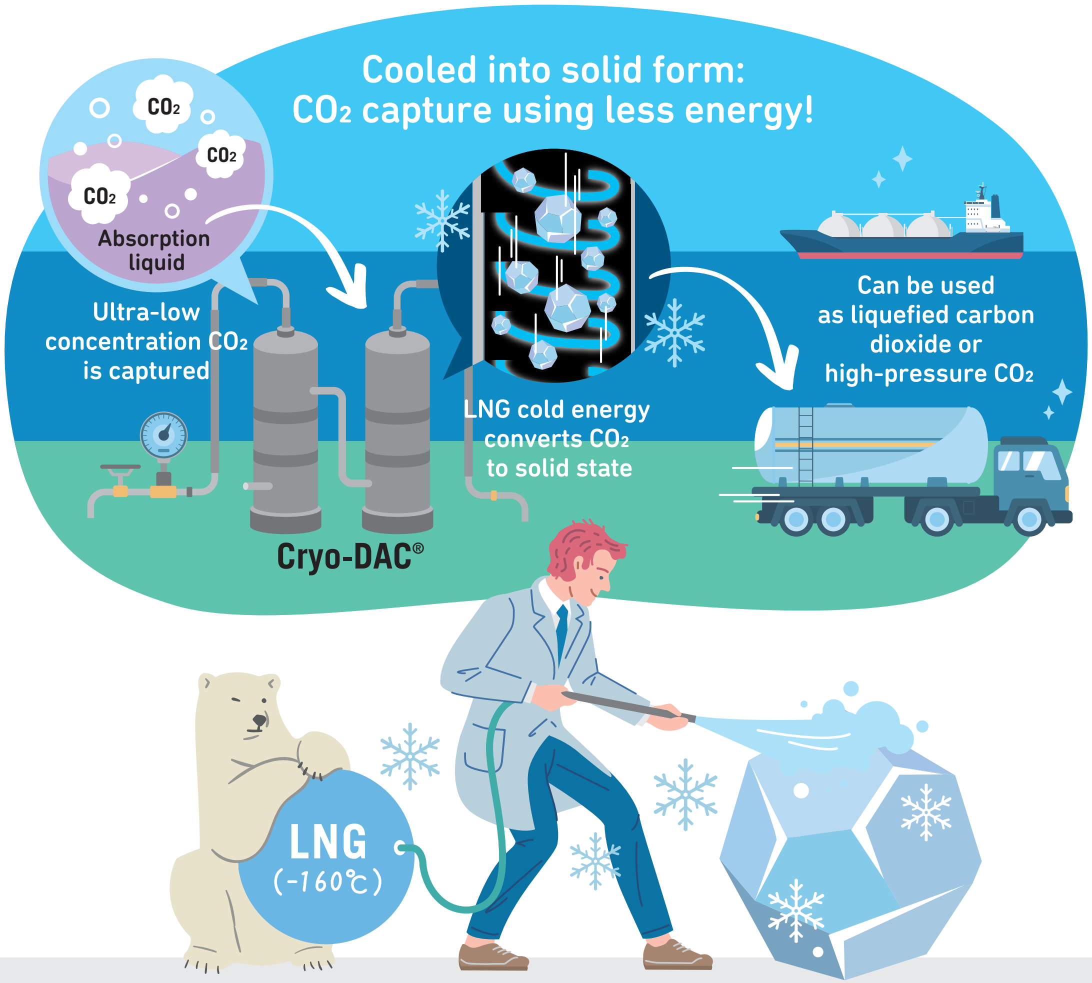
Project Introduction Video | https://www.youtube.com/watch?v=EGunSE1MOMc&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3&

03 PROJECT

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.

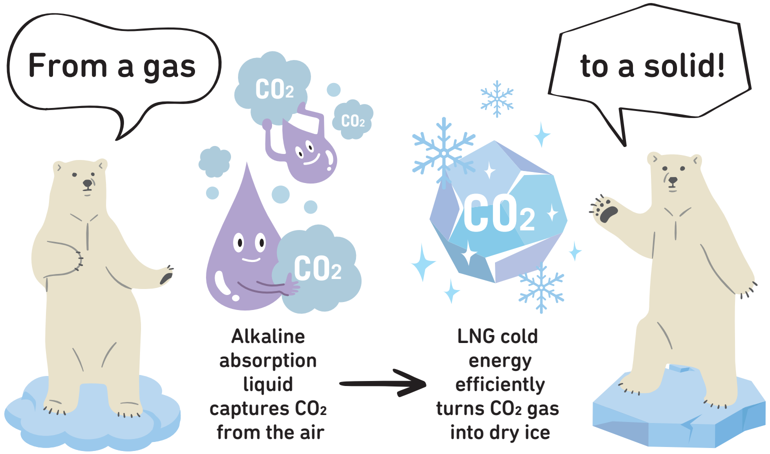
Using the "Power of Cold" to Convert Atmospheric CO_2 Into Dry Ice

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

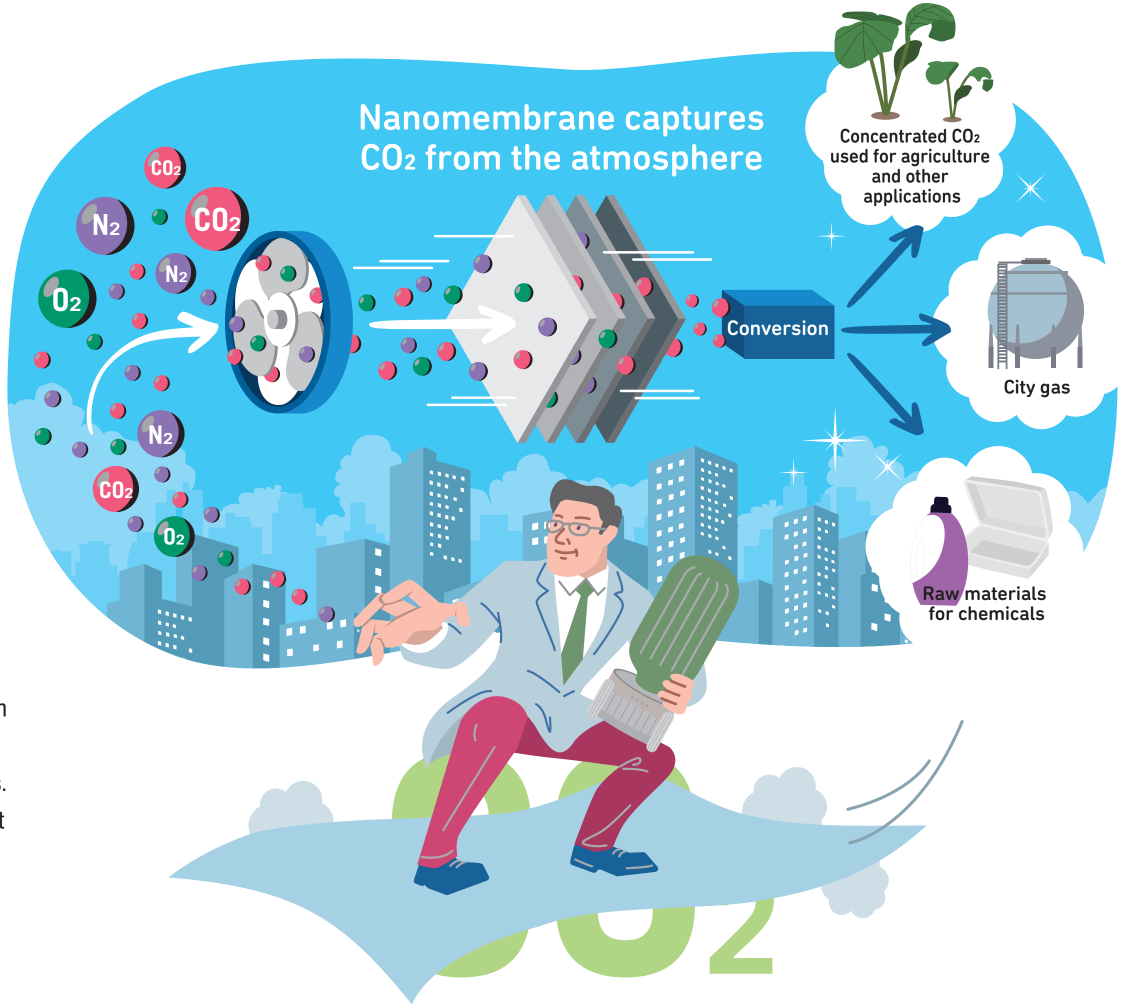
Project Introduction Video | https://www.youtube.com/watch?v=qV1py3OZwIM&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

04 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

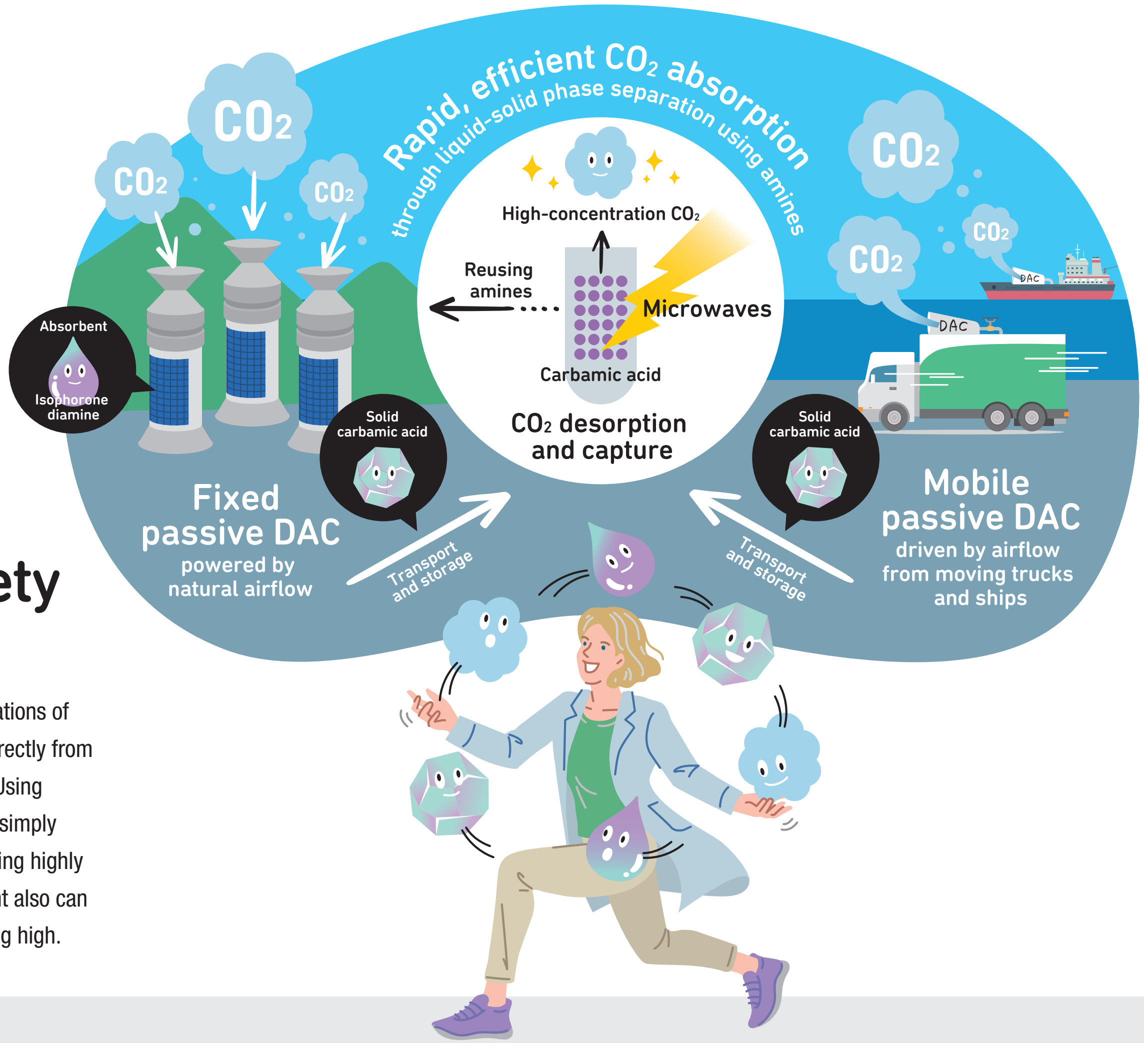
The objective is to gradually improve performance and enable more efficient capture of CO_2, specifically capturing about 2 kg per day, or enough to cover the daily energy needs of a family of four.

Implementation Kyushu University, Kumamoto University, Hokkaido University

Project Introduction Video https://www.youtube.com/watch?v=iNjqtC22C-g&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

05 PROJECT

World's Fastest Carbon Capture System Extracts CO_2 from Ambient Air Future Applications to Promote Full-Fledged Carbon-Recycling Society



Research and Development of Passive DAC Technologies

No method of countering climate change is as effective as Direct Air Capture, or DAC. However, concentrations of CO_2 in ambient air were previously thought to be too low to allow the CO_2 to be captured efficiently and directly from the air. There is a substance called isophorone diamine that turns this conventional thinking on its head. Using isophorone diamine as an absorbent in DAC systems allows even low-concentration carbon dioxide to be simply and easily solidified for capture. The passive DAC system currently in development is capable of maintaining highly efficient CO_2 absorption for extended periods of time without any forced air flow. In addition, the absorbent also can be reused after absorption and release of the CO_2. Expectations for practical use of this system are running high.

Fateful Encounter with Key Compound in Achieving CO_2 Capture

Dr. YAMAZOE Seiji

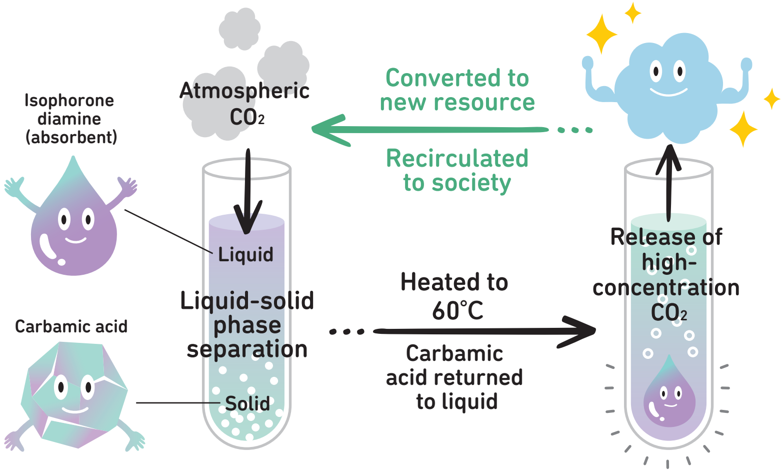
Professor, Department of Chemistry,
Graduate School of Science, Tokyo Metropolitan University

We were initially researching DAC using catalysts, but in a stroke of luck we happened to hit upon isophorone diamine. We then decided to change direction and began to work on absorption and solidification of CO_2 without a catalyst. While our initial goal is to solidify and collect CO_2 efficiently, in the future, we envision taking this a step further. Solidified CO_2 can be stored for extended periods, remains stable in transport, and can be extracted when needed, making it a prime candidate in supporting a carbon-recycling society as an alternative to conventional fossil fuel resources. As this carbon resource is obtained from the atmosphere, it has been dubbed SkyCarbon®.

World's Fastest Carbon Capture System Extracts CO_2 from Ambient Air Future Applications to Promote Full-Fledged Carbon-Recycling Society

» Presenting the Optimal CO_2 Absorbent

This passive DAC system captures air from all directions using only natural air flow, with no additional energy input required, resulting in a superior system that captures CO_2 without the additional costs required in forced-air systems. CO_2 absorbents used thus far have been hampered by slow reaction speeds and inefficiency, but we discovered that through the mechanisms of ***liquid-solid phase separation*** using isophorone diamine as the absorbent, CO_2 can be captured extremely efficiently and collected as a stable solid for storage and transport. This system has achieved capture rates among the highest in the world.



» The Earth's Atmosphere: A Resource Repository

Microwaves of wavelengths near those used in microwave ovens can be produced using electricity, with the further advantage of being able to heat objects efficiently and be targeted with pinpoint accuracy. Microwaves heating captured CO_2 separates the CO_2 from the absorbent, allowing recovery of nearly 100% pure CO_2. The highly concentrated captured CO_2 is repurposed when converted into energy, plastic materials, or other products. Furthermore, since the absorbent also can be reused after separation from the CO_2, completing development of this system can lead to a full-fledged carbon-recycling society. Incidentally, this DAC system can be installed in cities and other locations to gather ambient air from any direction, and it can also be used with cars and ships, so the system may become a common sight in societies of the future.

KEYWORD

Liquid-Solid Phase Separation

This is a process of separating substances in a mixture, for example the separation of water and oil in salad dressing. This phenomenon causes the liquid absorbent to separate from the solid material that has absorbed CO_2, giving the absorbent increased CO_2-absorbing capacity and allowing capture of even more low-concentration atmospheric CO_2.

FUTURE VISION

2025

Gather Knowledge and Create a Test System

We will first create a test system bringing together various technologies from the universities and companies involved in the project.

2027

Demonstrate Effectiveness with Twin Towers

We will verify the performance of a midsized, fixed passive DAC system using two towers: an intake tower and an exhaust tower. The goal at this point is to determine the prospects for achieving carbon neutrality or carbon negativity.

2029

Make DAC a Common Sight

We plan to complete the development of a system capable of capturing 100 kg of CO_2 per month using a single tower, integrating the functions of the intake and exhaust towers. This DAC system will be installed on a university campus.

Implementation | Tokyo Metropolitan University, Taikisha Ltd., Pantaray Co., Ltd., Nagaoka University of Technology, Kojima Industries Corporation, Kyushu University

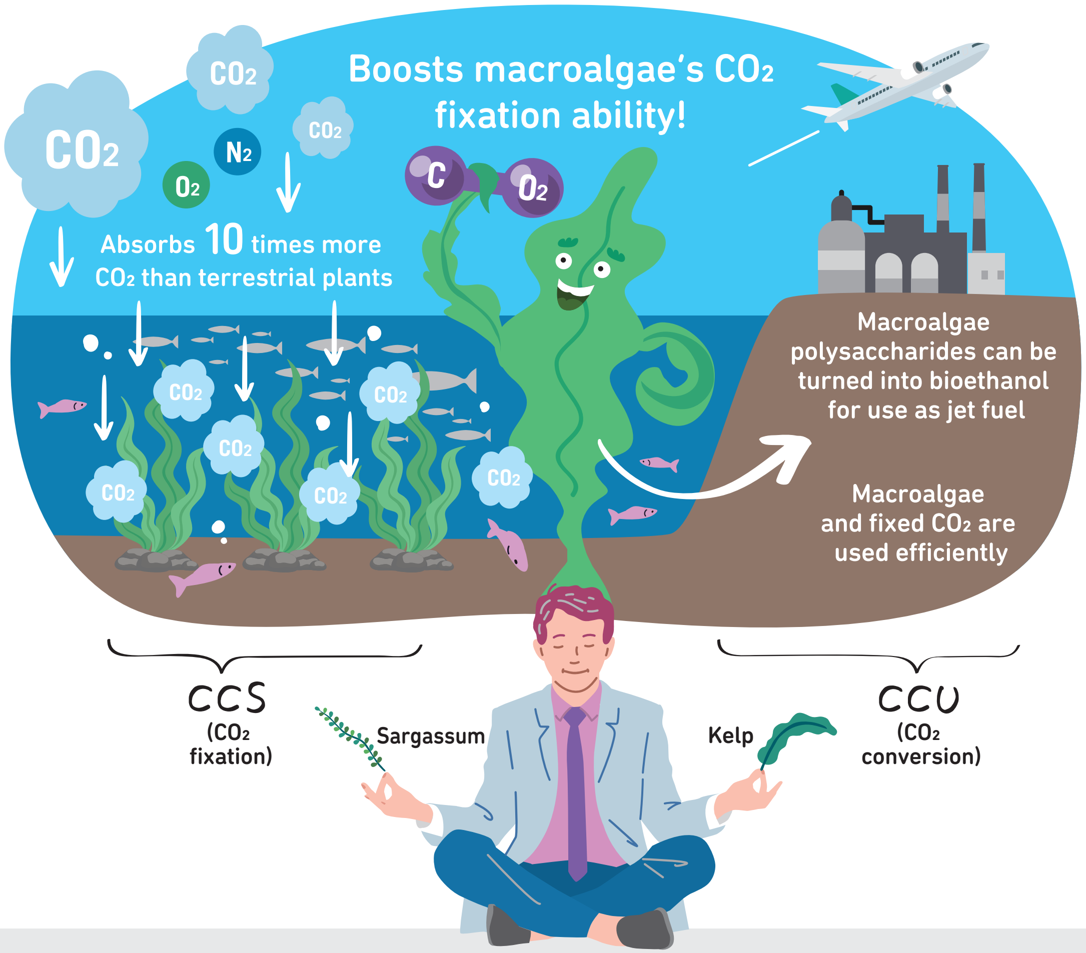
Project Introduction Video | https://www.youtube.com/watch?v=FRsc5-EJGLE&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

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.

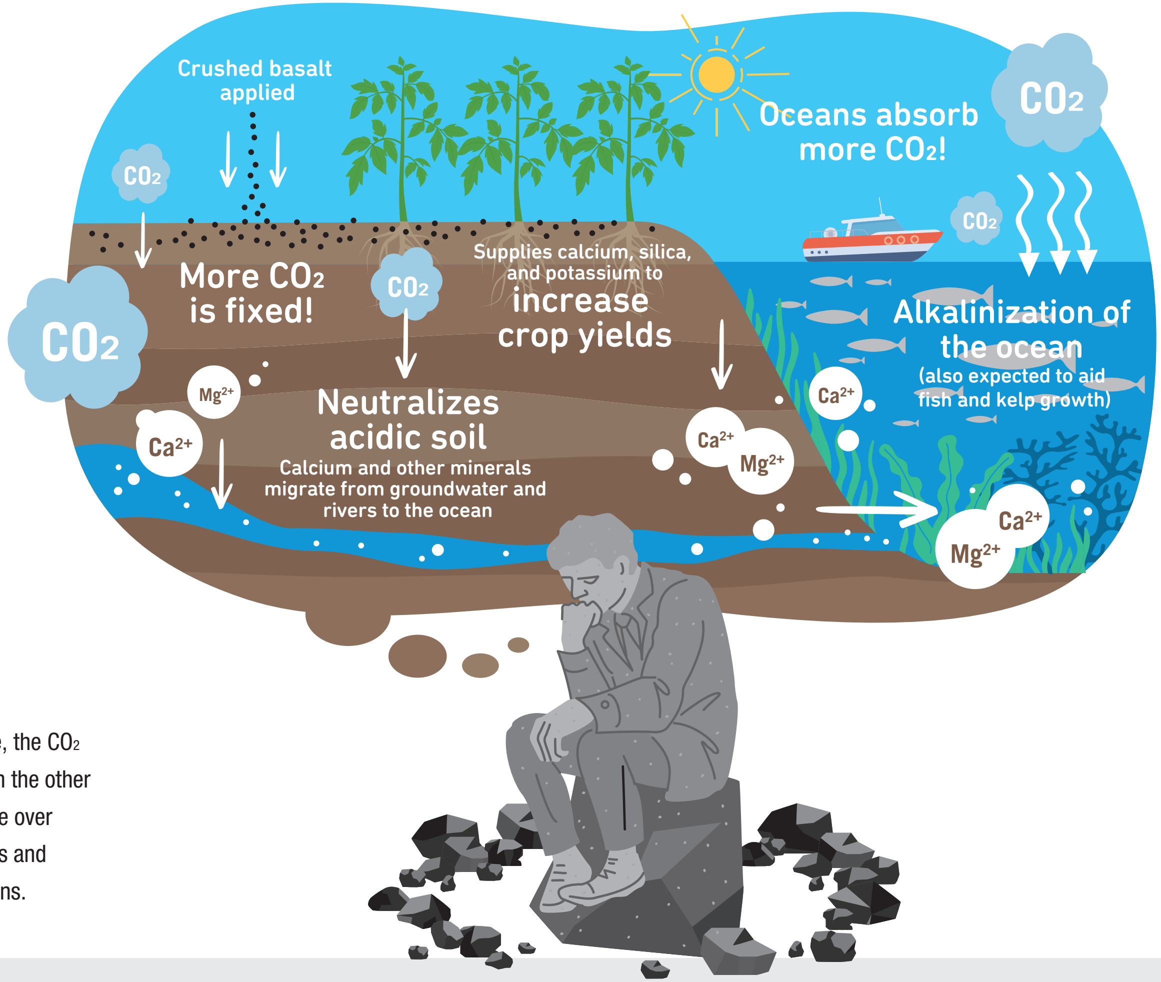
Project Introduction Video | https://www.youtube.com/watch?v=F95Kte8ZIno&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

07 PROJECT

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.

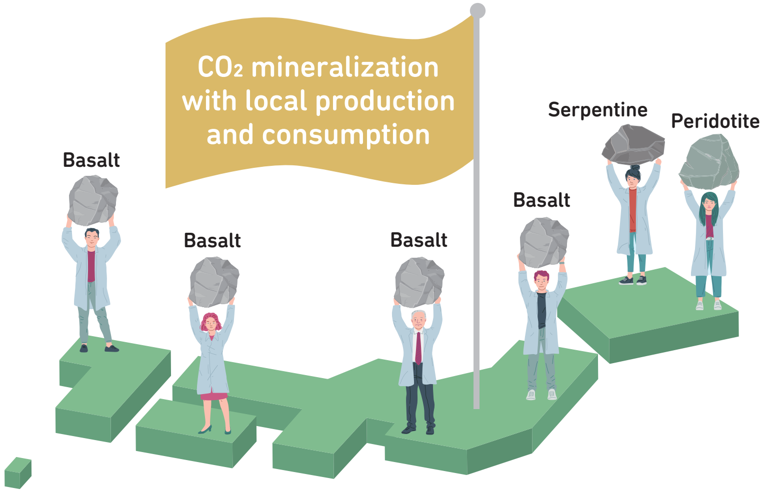
Advanced Enhanced Rock Weathering Technology Provides Rapid CO_2 Fixation and Accurate Carbon Accounting

>> 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.

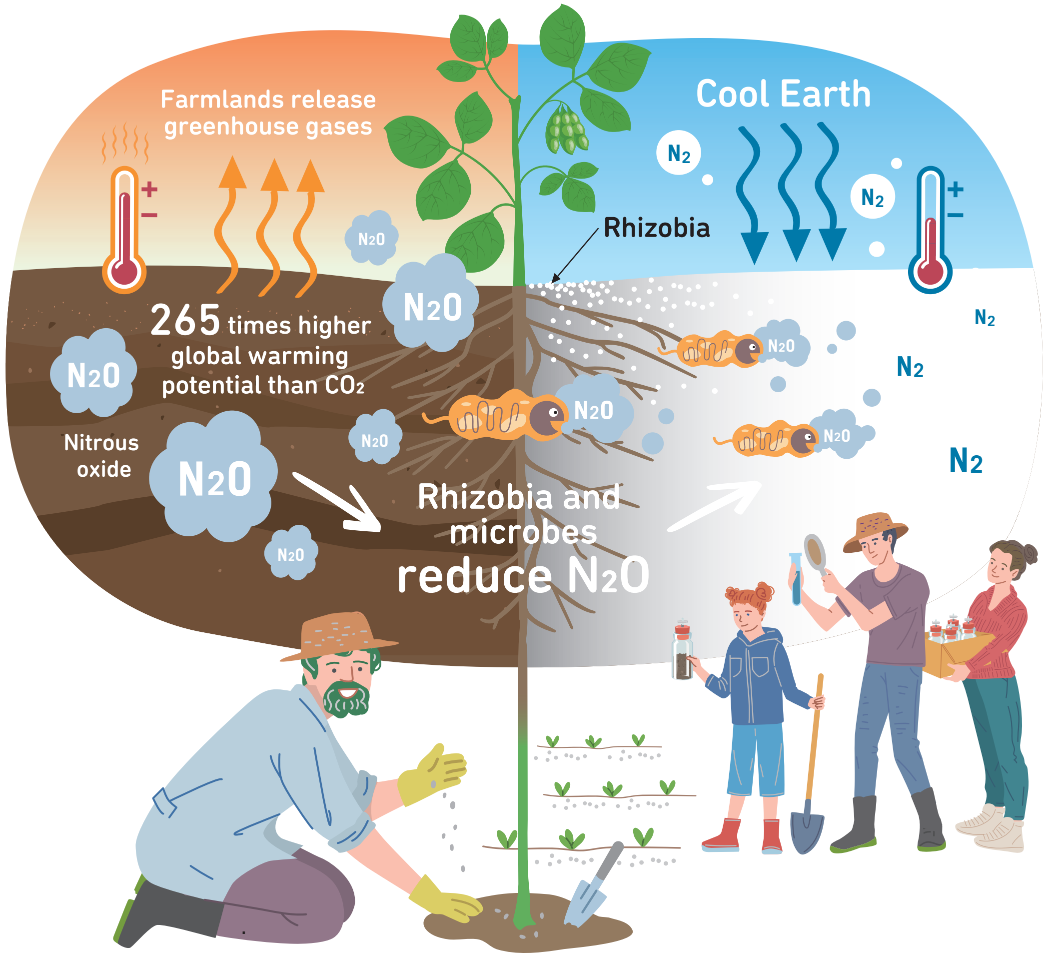
Project Introduction Video: https://www.youtube.com/watch?v=68dylv1Ajj0&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

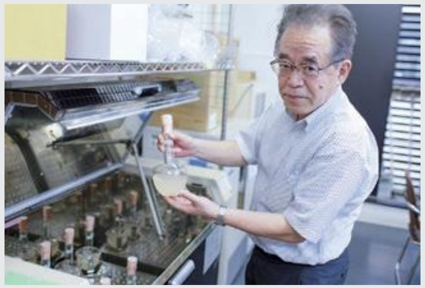
08 PROJECT

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.

Implementation | Tohoku University, National Agriculture and Food Research Organization (NARO)

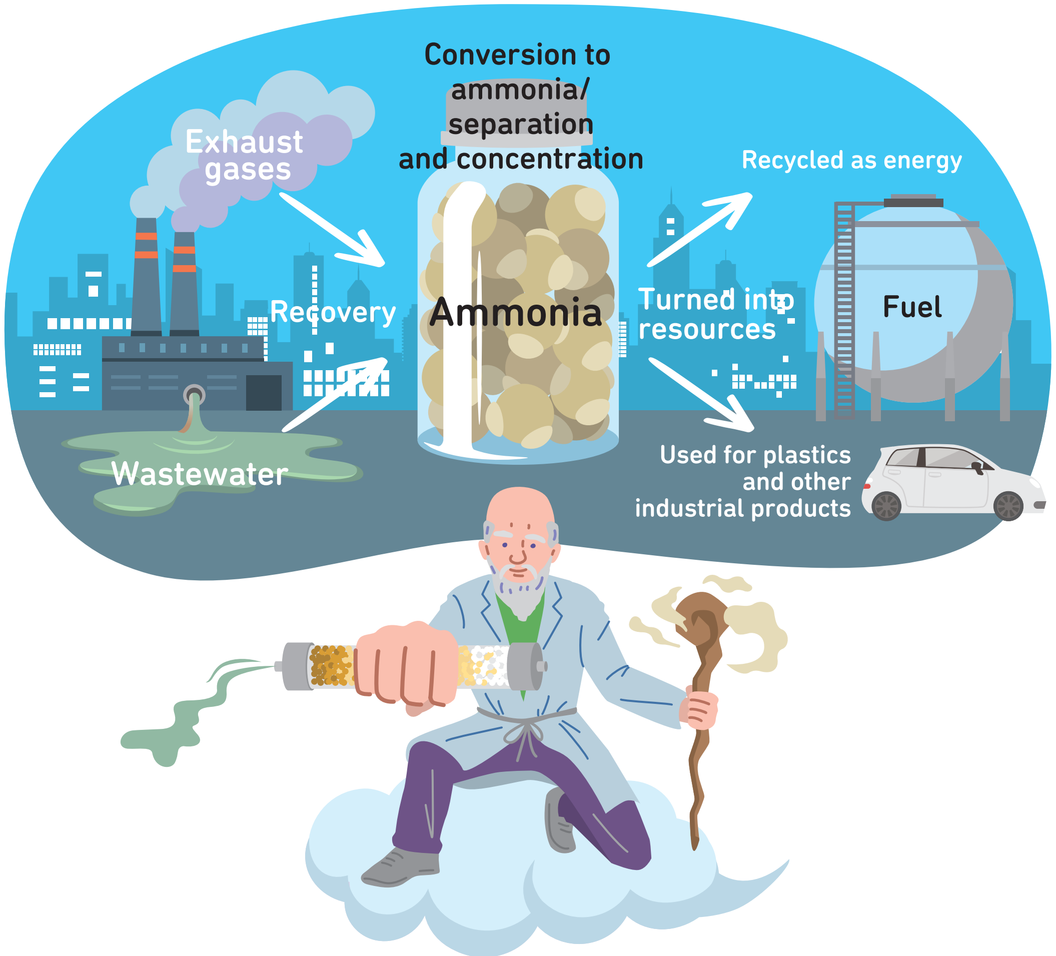
Project Introduction Video | https://www.youtube.com/watch?v=1Rqh-tcPerl&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXaoo3

09 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

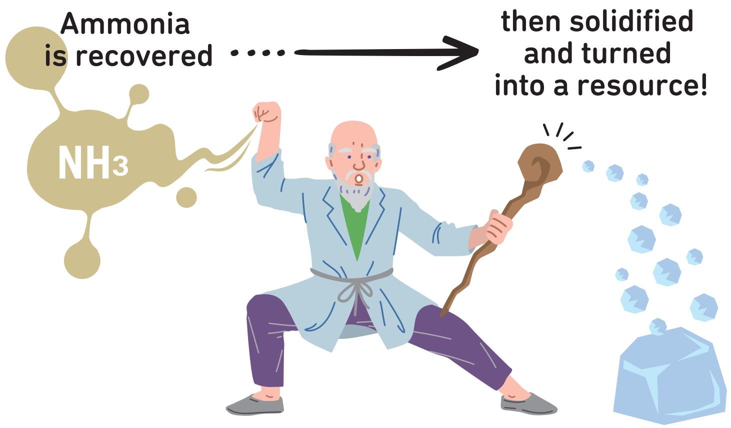
Dr. KAWAMOTO Tohru
Principal Researcher, Nanomaterials Research Institute, Department of Materials and Chemistry, National Institute of Advanced Industrial Science and Technology (AIST)

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

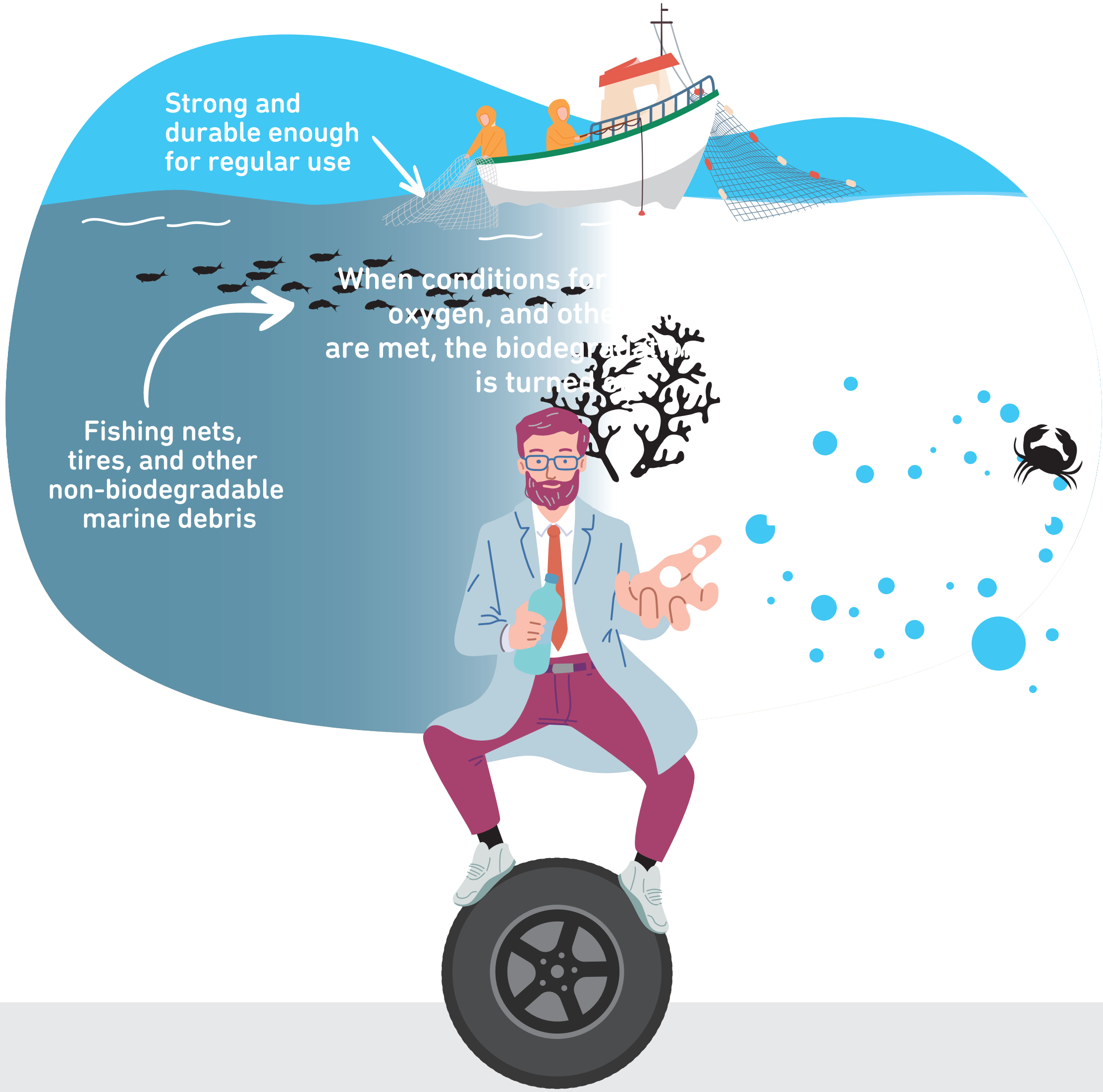
Project Introduction Video: https://www.youtube.com/watch?v=do3o39UaZFA&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

10 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 down 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

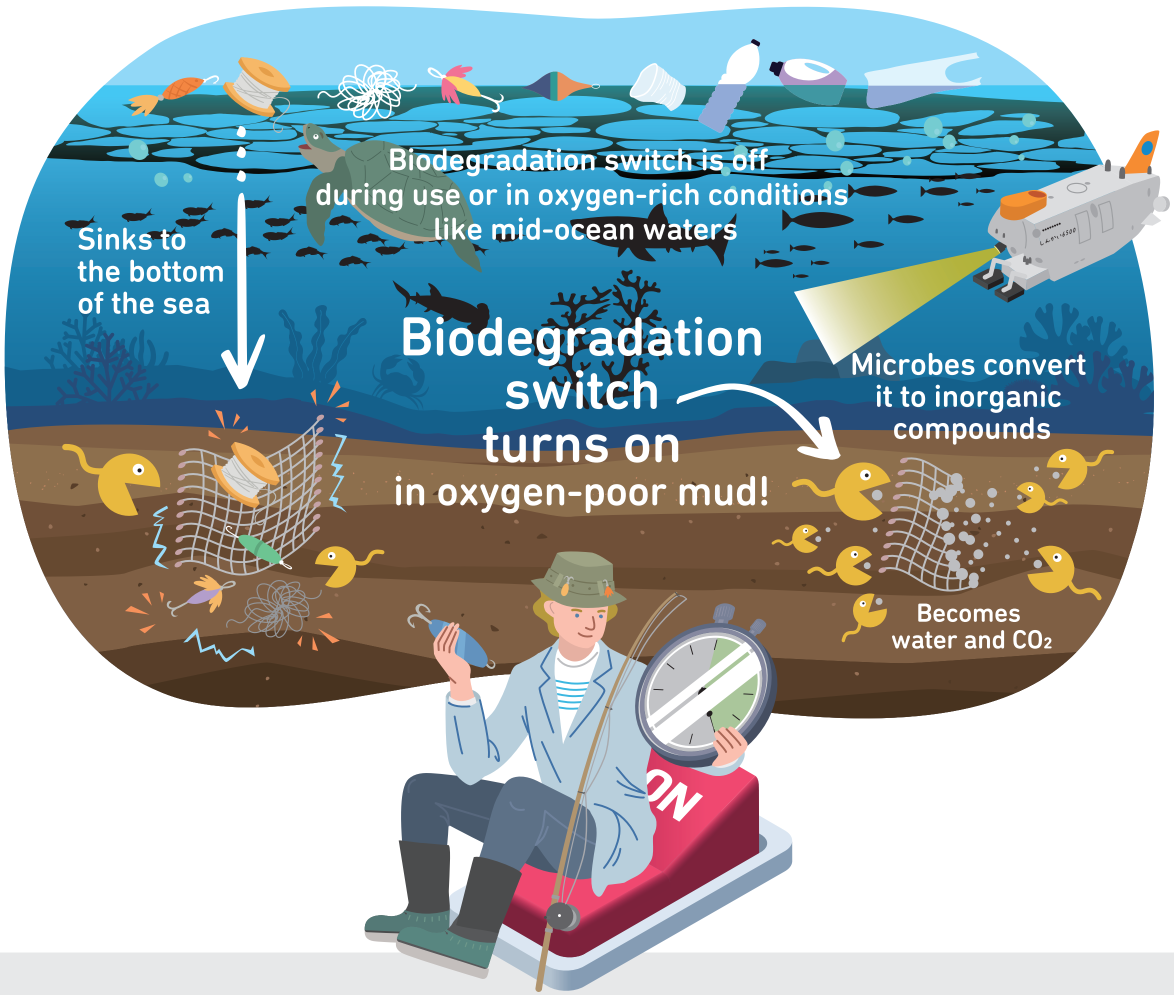
Project Introduction Video https://www.youtube.com/watch?v=N-vs_T52F8o&list=PLZH3AKTCrVsVm3UN1x40WW_QK-cEXao03

11 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.

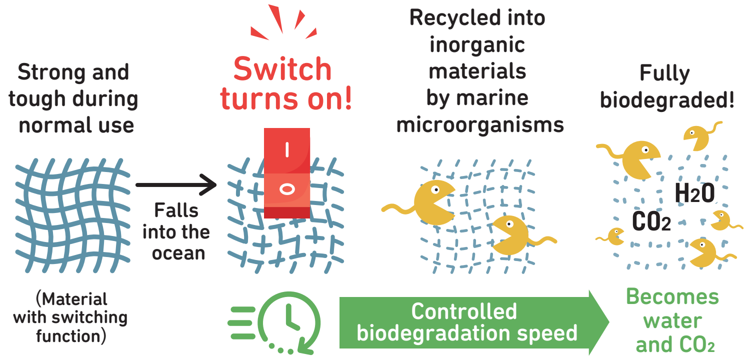
Durable Fishing Tackle and Gear That Biodegrade on the Seabed

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