

Green FormX - MIRAI

グリーンケミストリー / ギ酸 (Formic acid) / 未来

Keio University
Office of Innovation and Entrepreneurship
EIR (Entrepreneur in Residence)
Shogo SOMA

Keio University
Faculty of Science and Technology
Professor
Yasuaki EINAGA

The Time Has Come to Tackle CO₂ Reduction (CO₂削減への挑戦が求められる時代)

Addressing CO₂ emissions growth and the challenges of existing CCUS, we use diamond electrodes to efficiently convert CO₂ into formic acid, achieving both value creation and decarbonization.



Worsening global warming

Since the Industrial Revolution, atmospheric CO₂ has surged past 420 ppm. Without change, average temperatures could rise 1.5°C by 2050, triggering severe climate change.



Global Trend Toward Decarbonization

Since the Paris Agreement, over 150 countries have pledged carbon neutrality. Japan has committed to achieving it by 2050 and established its GX Basic Policy.



Ongoing Challenges and Opportunities in CCUS

Existing CO₂ capture and storage technologies face challenges in cost, efficiency, and scalability. Beyond storage, options for value-generating utilization are being explored.



The Importance of Turning CO₂ into Value

Transforming CO₂ into valuable chemicals and fuels, rather than merely storing it, enables economic viability and a circular economy.



Pioneering Carbon Recycling with Diamond Electrodes (ダイヤモンド電極が切り拓くカーボンリサイクル)

Boron-doped diamond (BDD) electrodes offer exceptional durability and high selectivity, enabling efficient conversion of CO₂ to formic acid, backed by strong patent protection.



Boron-Doped Diamond (BDD) Electrodes

A boron-doped diamond electrode with metal-like conductivity and unique electrochemical properties. Its wide potential window (3.2 V in aqueous solution) avoids hydrogen evolution



Unmatched Durability

Exceptional durability with no significant degradation after **1,000+ hours of continuous CO₂ reduction**. Unlike metal electrodes, diamond's robust crystal structure ensures long-term stability.



Exceptional Selectivity

In CO₂ electroreduction, achieves **95% efficiency** in producing only formic acid. Unlike other electrodes, BDD eliminates by-products, greatly simplifying purification.

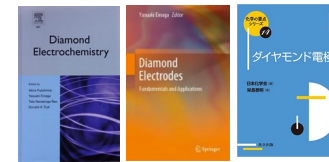
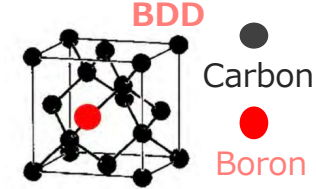


Robust Intellectual Property

Basic patents for CO₂ electroreduction diamond electrodes are secured in Japan. Know-how on design and operation is protected, ensuring a robust IP framework.

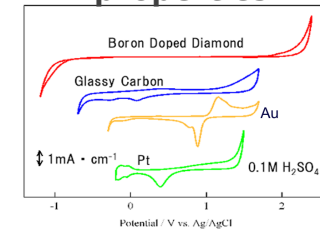
Key Features of BDD Electrodes

Boron Doped Diamond



Yasuaki Einaga is doing pioneering works

Unique electrochemical properties



Wide Potential Window
Excellent Durability
Controllable surface property
Generation of active species

CO₂ reduction

95%
Faradaic Efficiency
(formic acid)

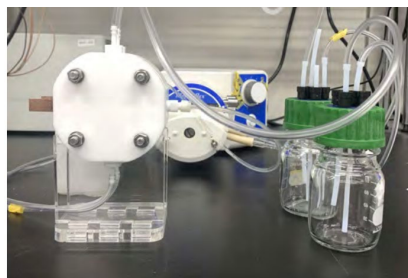
100%
Selectivity
(formic acid)

1000h+
Excellent
Durability

Core patent secured in Japan; global applications in progress

Progress & Achievements (2018–2025)

Scaled from a single cell to a validated **7-cell system**, achieving **250 kg/year** production and confirming **CO₂ conversion scalability** toward mass production readiness.

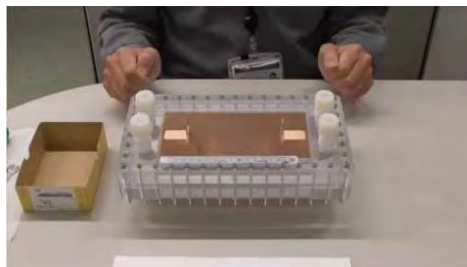


2018

Published a first paper
(*Angew. Chem. Int. Ed.*, 2018)
9.62 cm² BDD Electrode



2020~
(Fundamental)



2021

Prepared prototype of large scale
200 cm² BDD Electrode



2022~



**R&D and Demonstration Base
for Carbon Recycling**
(Osaki Kamijima, Hiroshima)



2023

Designed a **prototype
Cell System [Lab Scale]**



2024

Expanded to **7-Cell System
[Bench Scale]**

2018

Publish a first paper: 100% Faradaic Efficiency
(*Angew. Chem. Int. Ed.*, 2018)
9.62 cm² BDD Electrode

2020

NEDO Project start
(Development of **Fundamental Technologies**
for Carbon Recycling)

2022

NEDO Project start
(**Research and Development** for Carbon
Recycling in Demonstration Base)

2023-2024

Designed and built "Lab-scale system" and
"Bench-scale system" using BDD Electrodes
with 200 cm².

2025~

Toward commercial scale

Core Technology (私たちのコア技術)

Advancing CO₂ electrolysis from lab to industry through diamond electrodes and EPC collaboration. Building on the 7-cell demonstration, we target optimal unit design, cost efficiency, and scalable production.

Einaga Laboratory

Core Know-How

Accumulated know-how to maximize cell performance



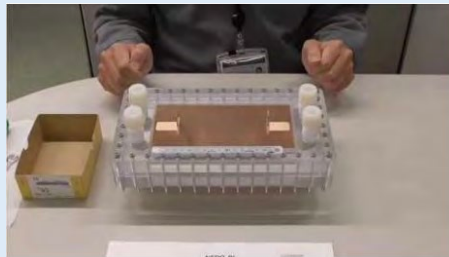
- CO₂ dissolution methods (gas dispersion, optimization of dissolution efficiency)
- Liquid flow control (optimized hydrodynamic design)
- Temperature and pressure control (precise management of reaction environment)

Core Technology



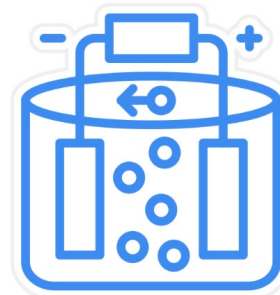
BDD (Boron Doped Diamond)

- World class selectivity
- Outstanding electrode durability (compared to competitors)
- Significant cell performance improvements every 2–3 years
- Core patents obtained



X

Partnership with EPC for Scale up

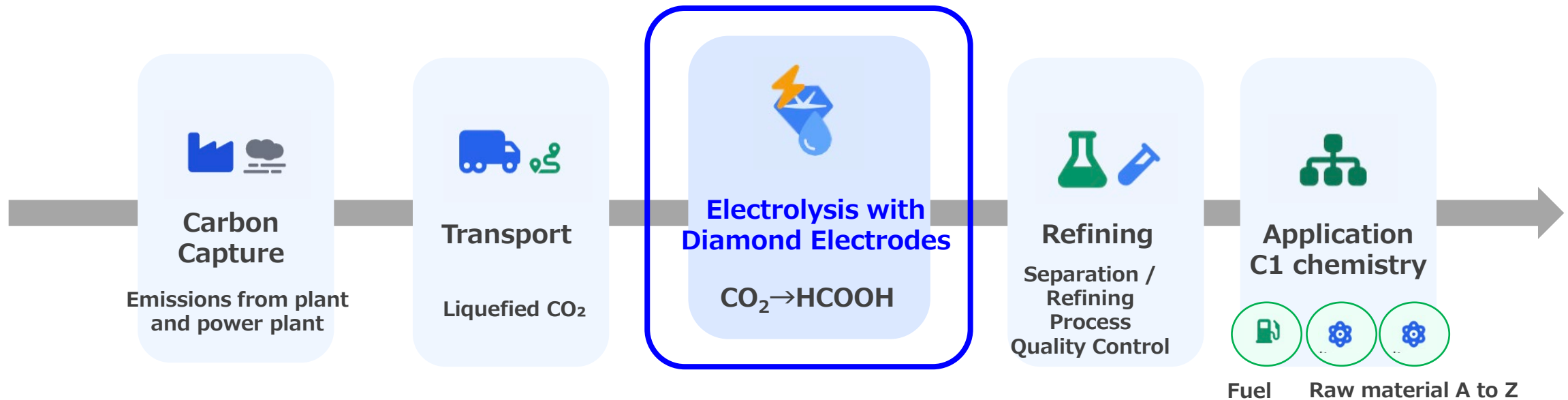


- Verified **7-cell parallel system**— beyond single-cell stage, entering mass-production stage.
- Next step: **collaboration with EPC partners** to scale up production capacity.
- **Determining optimal unit size** considering specifications, cost, and operating conditions.
- Target: **build a scalable, efficient, and cost-competitive system for industrial deployment.**

EPC companies

Business Model (ビジネスモデル)

Using diamond electrode CO₂ electrolysis with $\approx 100\%$ selectivity and over 1,000 hours durability, we are advancing a scalable carbon recycling value chain from capture to end use—enabling both industrial growth and environmental sustainability.



Core Technology

Electrolysis with Diamond Electrodes

- Uses a high-efficiency electrolytic cell equipped with boron-doped diamond (BDD) electrodes
- Selectively converts CO₂ to formic acid with $\approx 100\%$ efficiency
- Offers high durability (over 1,000 hours of continuous operation)
- Enables cost reduction and large-scale deployment

Our Challenges to come (これからの挑戦)

Driving CO₂ recycling toward social implementation through value chain building, module design verification with EPC partners, and customer development for market expansion.

Building and Connecting a Value Chain

Building an integrated CO₂ value chain through alliances, focusing on joint research with chemical manufacturers to develop formic acid applications and expand the market.

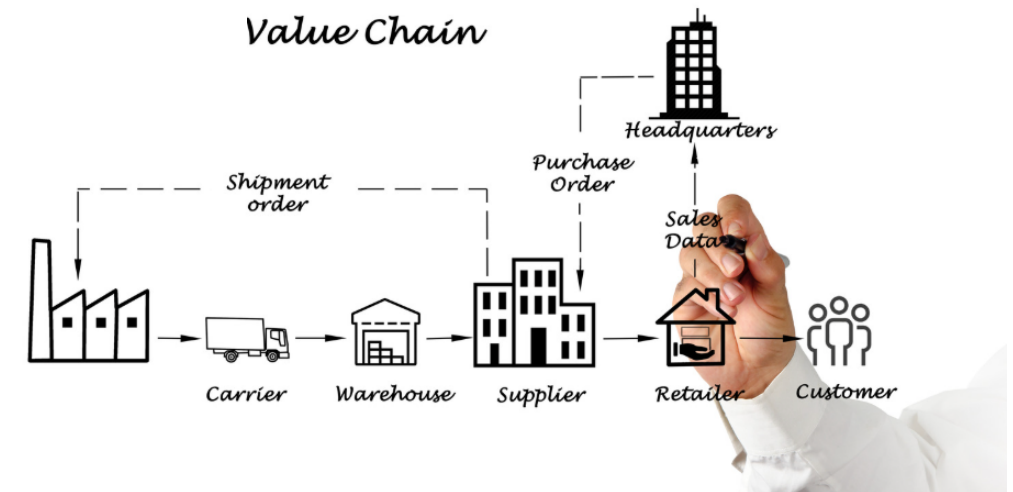
Customer Development

Identify and cultivate end-users for formic acid derived from CO₂, while advancing its downstream development in C1 chemistry.

Module Verification with EPC Companies *

With EPC partners, we are optimizing module size, cost, and operation for industrial-scale mass production.

* EPC companies :Engineering, Procurement, and Construction firms



Marketing Strategy (市場開拓戦略)

Expanding from existing formic acid applications to new high-growth markets, while addressing urgent decarbonization needs.

Existing Market

■ Current Formic Acid Market

The current formic acid market is seen not as competition but as partners. By forming alliances, CO₂-derived formic acid can be integrated into existing distribution channels.

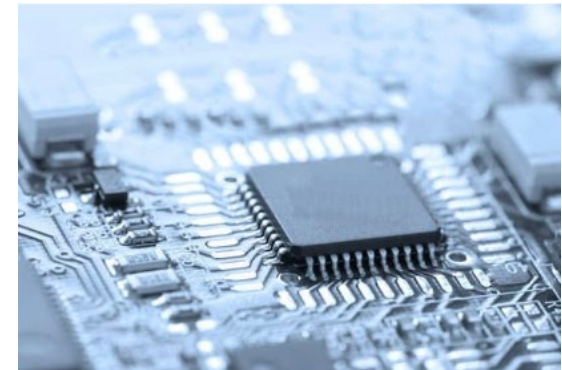
■ Chemical and Material Market

Explore markets that utilize CO₂-derived formic acid, such as cosmetics and functional materials.



Special Gas For Semiconductor

- Specialty gases for semiconductor manufacturing are rapidly growing.
- Manufacturers face urgent pressure to cut GHG emissions.
- On-site CO₂ recycling: capture CO₂ at fabs and directly reuse it in production.

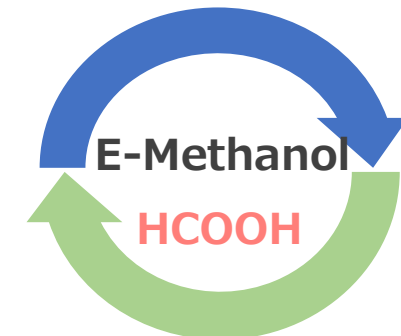


New Market

Long Term

■ E-Methanol Market

By utilizing formic acid and hydrogen, we can produce e-methanol as a new sustainable energy source. Aligned with the progress of e-hydrogen research, this approach enables efficient, decentralized production models to meet growing demand and contribute to a low-carbon society.



Project Organization and KSIP (プロジェクト推進体制とKSIP)

A powerful Keio ecosystem — uniting research, business, and investment to drive innovation from lab to market. Strengthened by KSIP adoption and alumni support, the project accelerates social implementation and sustainable growth.

KSIP (Keio Startup Incubation Program) is a university-wide program that supports Keio researchers and students in launching and growing deep-tech startups through business planning, fundraising, and mentoring.

