Green FormX - MIRAI

グリーンケミストリー / ギ酸（Formic acid）/ 未来

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The Time Has Come to Tackle CO_2 Reduction (CO_2削減への挑戦が求められる時代)

Addressing CO_2 emissions growth and the challenges of existing CCUS, we use diamond electrodes to efficiently convert CO_2 into formic acid, achieving both value creation and decarbonization.

Worsening global warming

Since the Industrial Revolution, atmospheric CO_2 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 CO_2 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 CO_2 into Value

Transforming CO_2 into valuable chemicals and fuels, rather than merely storing it, enables economic viability and a circular economy.

What is Formic Acid(HCOOH)? From By-Product to Key Player（ギ酸(HCOOH)とは何か？ 副産物から主役へ ）

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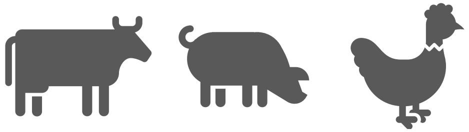
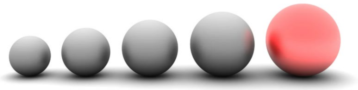
Formic acid was long a minor by-product with limited uses, but recent direct synthesis has enabled its production, and demand is expected to grow despite a small market.

Past

Leather tanning



For livestock

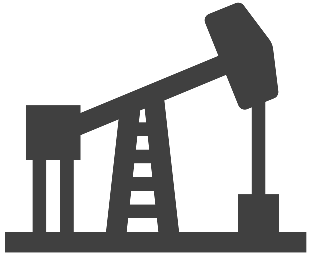


HCOOH(nich product)

- Leather tanning / Preservative in animal food
- By-product from petrochemical refining
- Small and niche role in industry

Present

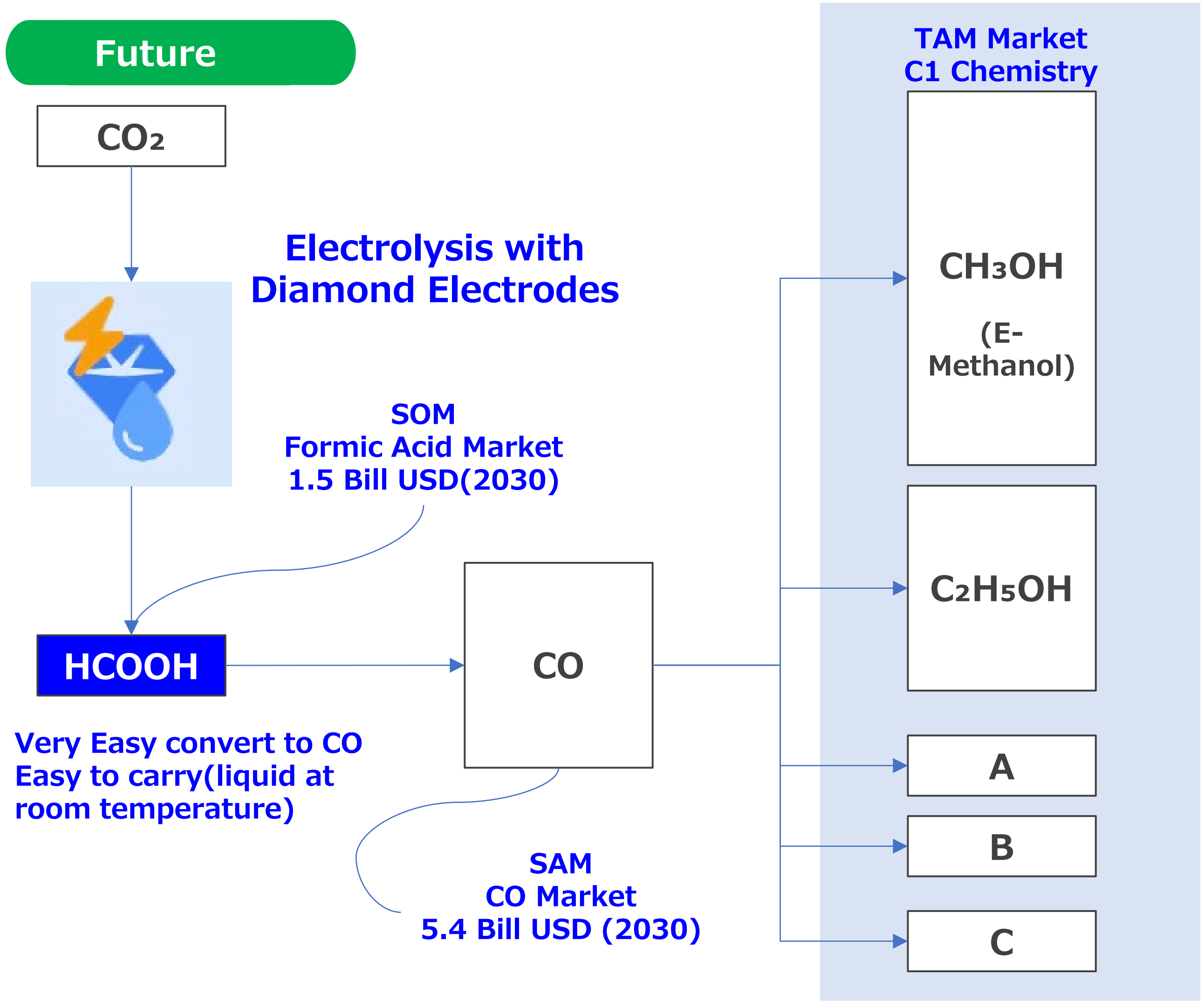
- Market size: approx. USD 1.5 billion (2024), expanding



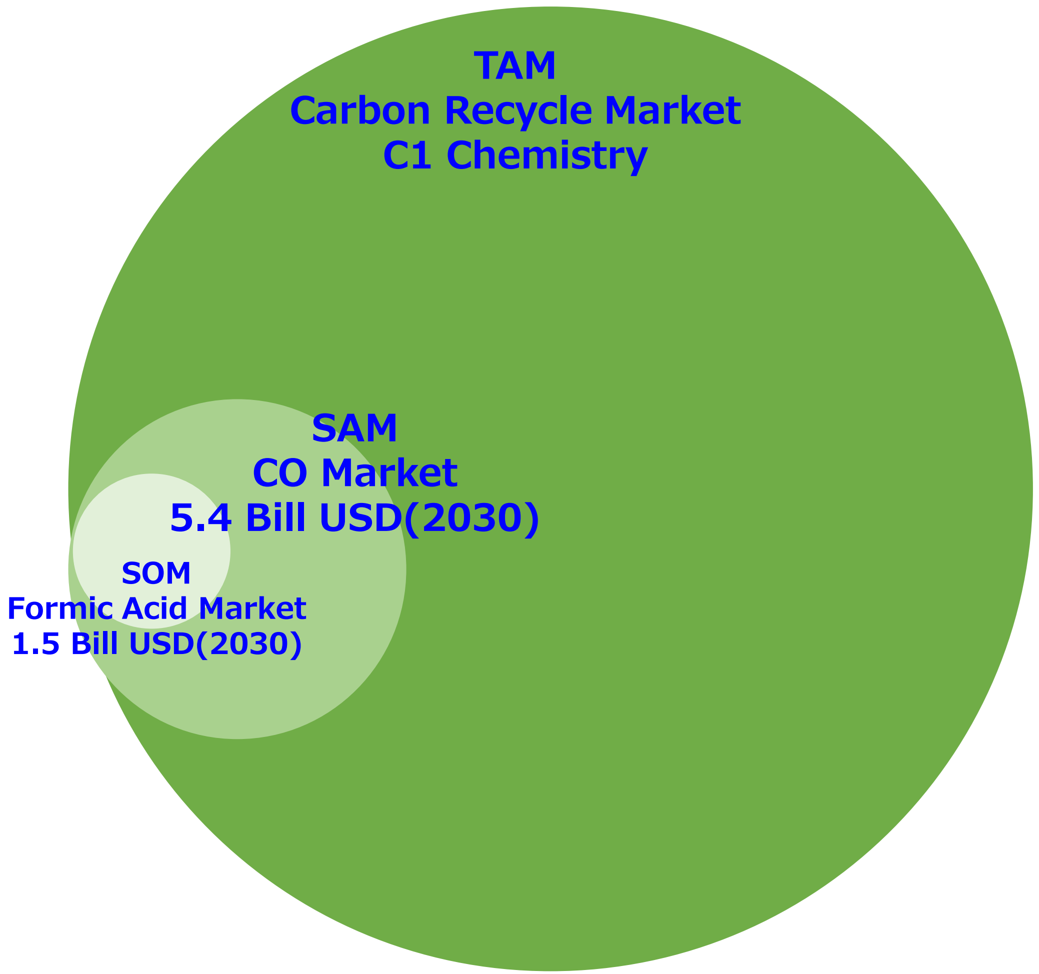
- Still fossil-fuel based, high CO2 burden
- Limited, specialized applications

What is Formic Acid(HCOOH)? From By-Product to Key Player（ギ酸(HCOOH)とは何か？ 副産物から主役へ）

Formic acid, the emerging cornerstone of C1 chemistry, is a liquid carbon carrier. Heated, it yields CO; with hydrogen, it becomes methanol. Combined with green hydrogen, it enables a new path to green methanol.



- Very Easy convert to CO
- Easy to carry(liquid at room temperature)



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)

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Boron-doped diamond (BDD) electrodes offer exceptional durability and high selectivity, enabling efficient conversion of CO_2 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 CO_2 reduction**. Unlike metal electrodes, diamond's robust crystal structure ensures long-term stability.

Exceptional Selectivity

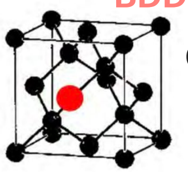
In CO_2 electroreduction, achieves **95% efficiency** in producing only formic acid. Unlike other electrodes, BDD eliminates by-products, greatly simplifying purification.

Robust Intellectual Property

Basic patents for CO_2 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 BDD

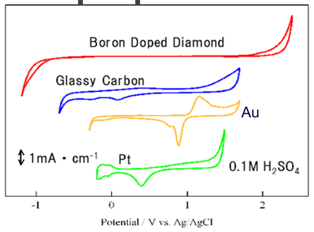


Carbon

Boron

Yasuaki Einaga is doing pioneering works

Unique electrochemical properties



Wide Potential Window

Excellent Durability

Controllable surface property

Generation of active species

CO_2 reduction

95%	100%	1000h+
Faradaic Efficiency (formic acid)	Selectivity (formic acid)	Excellent Durability

Core patent secured in Japan; global applications in progress

Business Model (ビジネスモデル)

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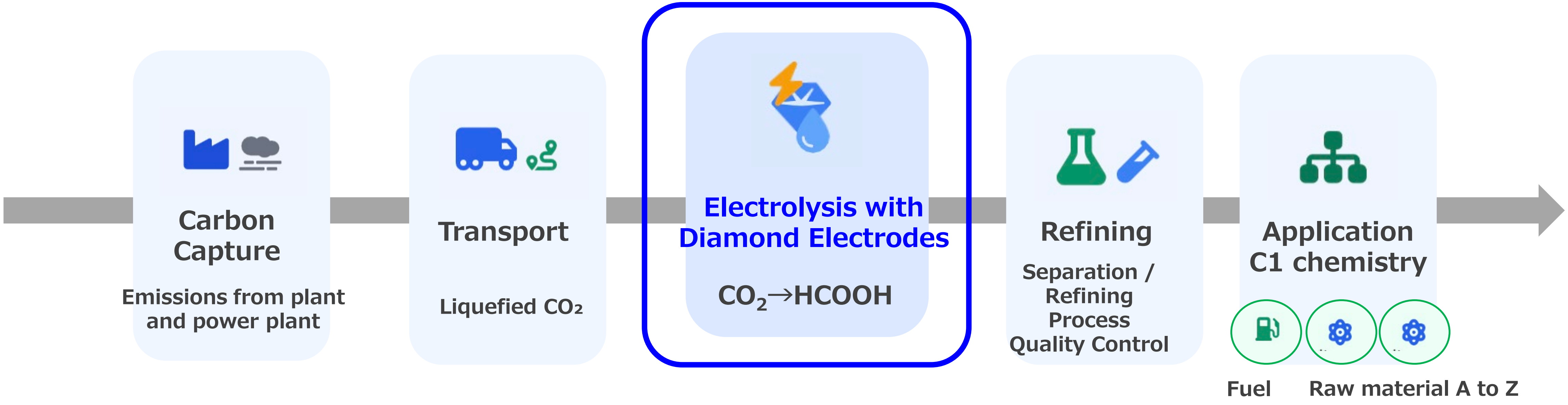
Using diamond electrode CO_2 electrolysis with ≈100% selectivity and over 1,000 hours durability, we are advancing a scalable carbon recycling value chain from capture to end use—enabling both industrial growth and environmental sustainability.



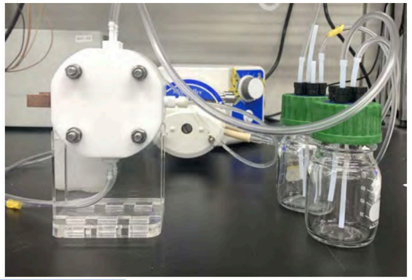
Core Technology

Electrolysis with Diamond Electrodes

- ■ Uses a high-efficiency electrolytic cell equipped with boron-doped diamond (BDD) electrodes
- ■ Selectively converts CO_2 to formic acid with ≈100% efficiency
- ■ Offers high durability (over 1,000 hours of continuous operation)
- ■ Enables cost reduction and large-scale deployment

Progress & Achievements (2018–2025)

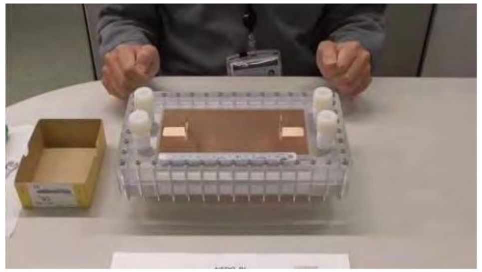
Scaled from a single cell to a validated 7-cell system, achieving 250 kg/year production and confirming CO_2 conversion scalability toward mass production readiness.



2018

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

NEDO
2020~
(Fundamental)



2021

Prepared prototype of large scale
200 cm² BDD Electrode

NEDO
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 CO_2 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

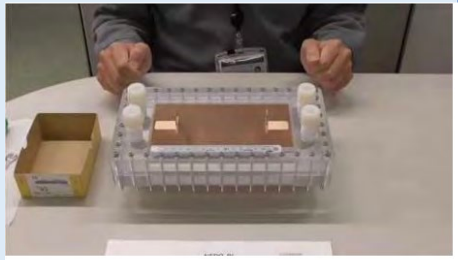
Core Know-How

Accumulated know-how to maximize cell performance

- CO_2 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



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Partnership with EPC for Scale up

EPC companies

- 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.**

Our Challenges to come (これからの挑戦)

Driving CO_2 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 CO_2 value chain through alliances, focusing on joint research with chemical manufacturers to develop formic acid applications and expand the market.

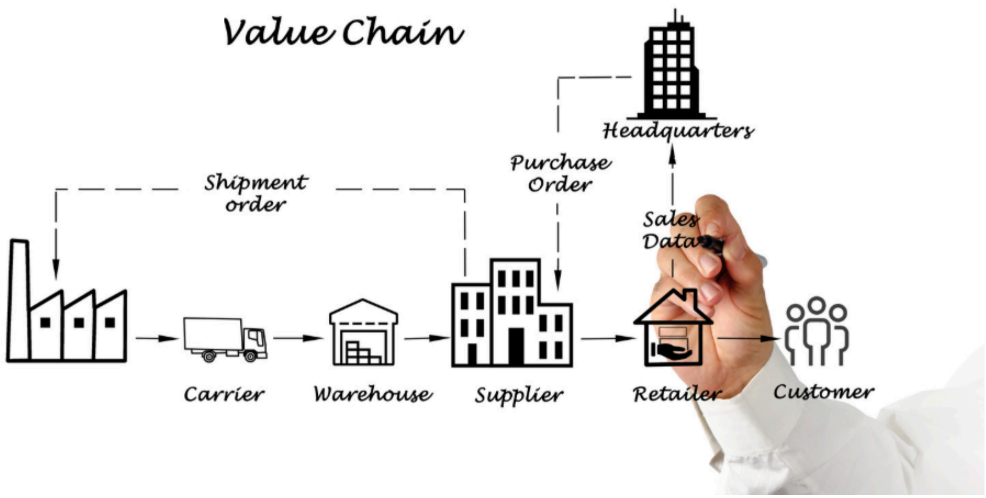
Customer Development

Identify and cultivate end-users for formic acid derived from CO_2, 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)

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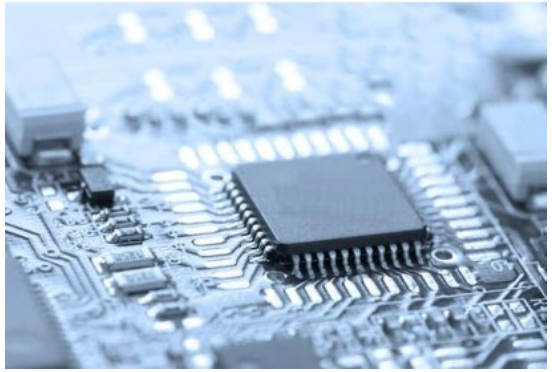
Expanding from existing formic acid applications to new high-growth markets, while addressing urgent decarbonization needs.

Existing Market

- **Current Formic Acid Market**
  The current formic acid market is seen not as competition but as partners. By forming alliances, CO_2-derived formic acid can be integrated into existing distribution channels.
- **Chemical and Material Market**
  Explore markets that utilize CO_2-derived formic acid, such as cosmetics and functional materials.

Special Gas For Semiconductor

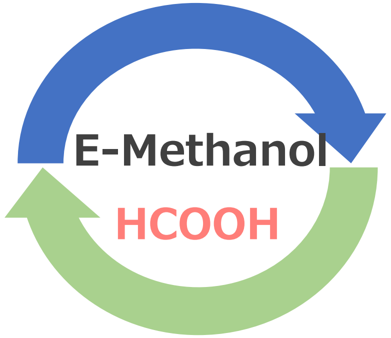
- Specialty gases for semiconductor manufacturing are rapidly growing.
- Manufacturers face urgent pressure to cut GHG emissions.
- On-site CO_2 recycling: capture CO_2 at fabs and directly reuse it in production.



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.

Keio University
Faculty of Science and Technology

- Creation of research seeds
- Advancement of fundamental research
- IP Strategy
- Technology partnership

Keio University
Office of Innovation and Entrepreneurship

- Individualized support for entrepreneurs
- Support for fundraising and business planning
- Recruiting and HR leadership support

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Keio Innovation Initiative

- Investment and fundraising for university-based ventures (University VC)
- Social Impact Investment
- Networking

KEIO INNOVATION INITIATIVE