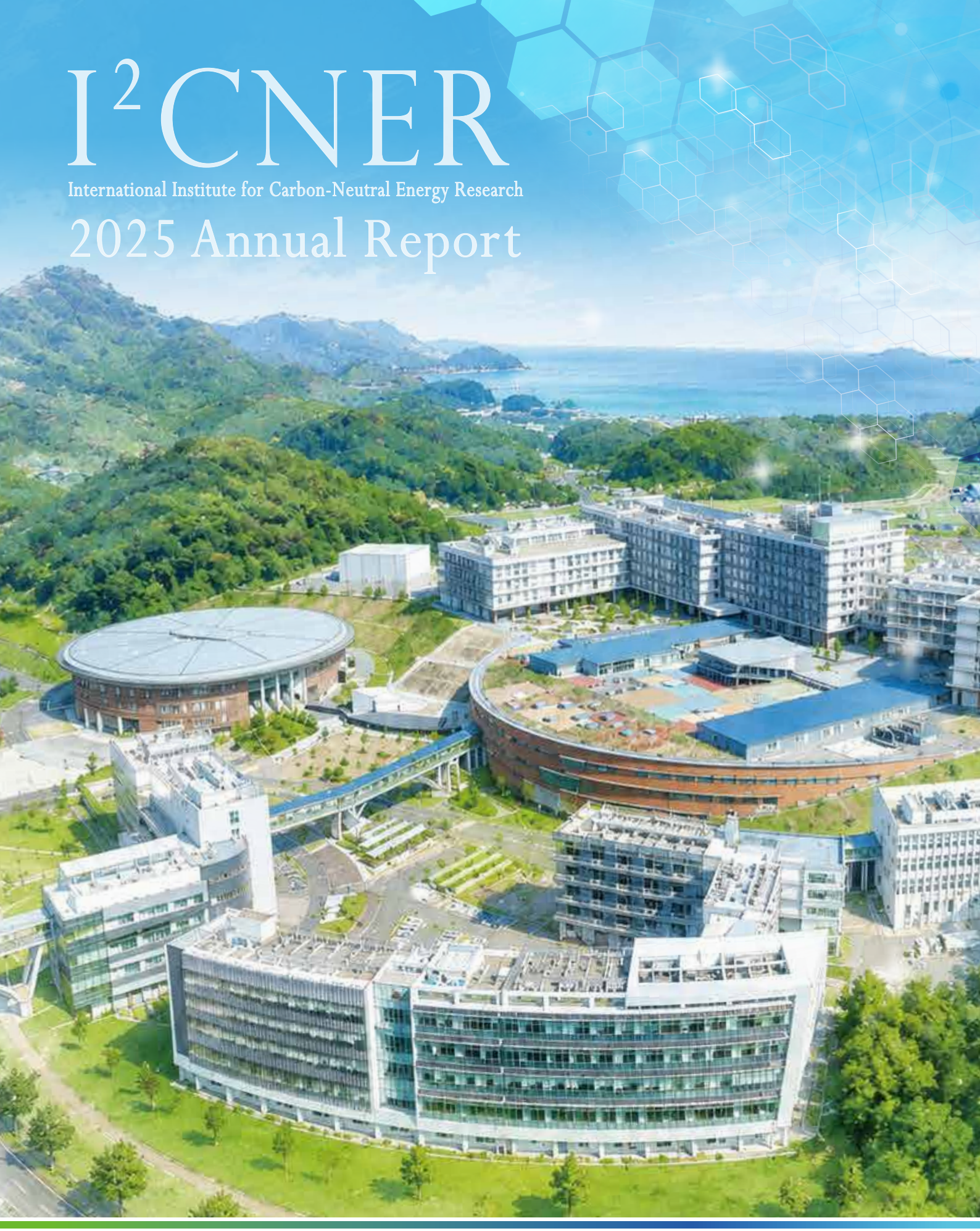
I²CNER

International Institute for Carbon-Neutral Energy Research

2025 Annual Report



I²CNER | wpi World Premier International Research Center Initiative | KYUSHU UNIVERSITY | ILLINOIS

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World Premier International Research Center Initiative (WPI)

wpi World Premier International Research Center Initiative

Background

An intensifying global demand for talented researchers is accelerating the need to circulate good brains among the world. This trend has prompted Japan to establish new research centers that attract top-notch researchers from around the world so as to be a hub within global brain circulation.

Program Summary

WPI provides concentrated support for projects to establish and operate research centers that have at their core a group of very high-level investigators. These centers are to create a research environment of a sufficiently high standard to give them a highly visible presence within the global scientific community—that is, to create a vibrant environment that will be of strong incentive to frontline researchers around the world to want to come and work at these centers.

WPI Mission

World-Leading Scientific Excellence and Recognition

- The Highest Level of Research Impact
- Expanding Knowledge Frontiers through Interdisciplinarity and Diversity

Global Research Environment and System Reform

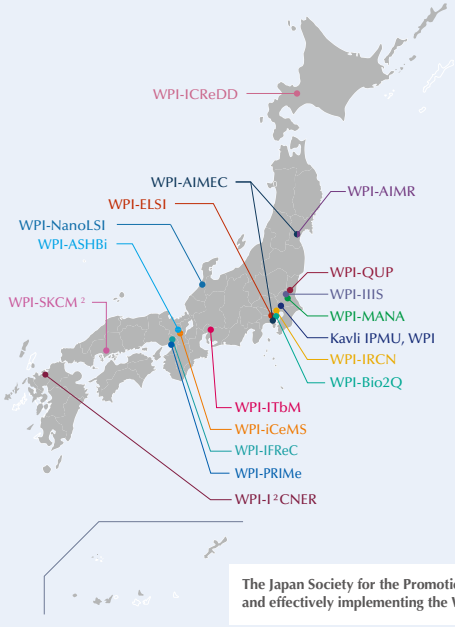
- Harnessing Talent and Potential through Global Brain Circulation
- Interdisciplinary and Inter-organizational Capacity Building
- Effective, Proactive and Agile Management

Values for the Future

- Societal Value of Basic Research
- Human Resource Building: Higher Education and Career Development
- Self-sufficient and Sustainable Center Development



WPI centers (total: 18 centers)



WPI Academy

Five centers adopted in 2007

- Tohoku University: Advanced Institute for Materials Research (WPI-AIMR)
- The University of Tokyo: Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU, WPI)
- Kyoto University: Institute for Integrated Cell-Material Sciences (WPI-iCeMS)
- The University of Osaka: Immunology Frontier Research Center (WPI-IFReC)
- National Institute for Materials Science (NIMS): Research Center for Materials Nanoarchitectonics (WPI-MANA)

One center adopted in 2010

- Kyushu University: International Institute for Carbon-Neutral Energy Research (WPI-I²CNER)

Three centers adopted in 2012

- University of Tsukuba: International Institute for Integrative Sleep Medicine (WPI-IIIS)
- Institute of Science Tokyo: Earth-Life Science Institute (WPI-ELSI)
- Nagoya University: Institute of Transformative Bio-Molecules (WPI-ITbM)

WPI Academy

WPI Academy, comprised of WPI centers which are certified as "world premier" status having achieved the WPI missions, was founded in FY2017 for maximizing the impact of WPI through enhancement of the WPI brand, international circulation of talented researchers, and spreading the experience and knowhow of WPI.

Centers Currently Receiving Funding

Two centers adopted in 2017

- The University of Tokyo: International Research Center for Neurointelligence (WPI-IRCN)
- Kanazawa University: Nano Life Science Institute (WPI-NanoLSI)

Two centers adopted in 2018

- Hokkaido University: Institute for Chemical Reaction Design and Discovery (WPI-ICReDD)
- Kyoto University: Institute for the Advanced Study of Human Biology (WPI-ASHBi)

One center adopted in 2021

- High Energy Accelerator Research Organization (KEK): International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (WPI-QUP)

Three centers adopted in 2022

- The University of Osaka: Premium Research Institute for Human Metaverse Medicine (WPI-PRIMe)
- Hiroshima University: International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM²)
- Keio University: Human Biology-Microbiome-Quantum Research Center(WPI-Bio2Q)

One center adopted in 2023

- Tohoku University & JAMSTEC: Advanced Institute for Marine Ecosystem Change (WPI-AIMEC)

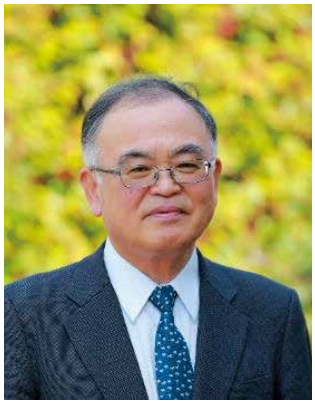
Program Contents

Funding period	10 years (up to 15 years for centers selected in or before FY 2012)
Project funding	About ¥700 million per fiscal year for each center (up to JPY 1.4 billion per year for centers selected in FY2007 and FY2010) (Multiple Host WPI, launched in FY 2023, is allocated JPY 1 billion per year)
Follow-up	Each year, a thorough follow-up review is conducted of the centers. These reviews are conducted by the Program Committee, comprising Nobel laureates and top-level researchers and by program directors and program officers.

The Japan Society for the Promotion of Science assists in smoothly and effectively implementing the WPI Program.

WPI Website→

Message from the Director



The International Institute for Carbon-Neutral Energy Research (I^2CNER) was established in 2010 as a WPI institute. At the time, it was the only institute in the world with “Carbon-Neutral Energy” in its name. I^2CNER later became a member of the WPI Academy in 2020. To date, I^2CNER has promoted the societal value of basic research as part of WPI's “Values for the Future” mission.

Climate change issues, including global warming, have become increasingly serious in recent years, making the transition to a carbon-neutral society based on renewable energy an important and urgent global issue. There are still many difficult challenges to overcome in transitioning from the current energy system, which relies primarily on fossil fuels, to a society based on renewable energy and materials. Achieving this transition requires not only novel energy conversion technologies but also the overall design of social systems in which materials and energy are interconnected.

Renewable energy sources, such as solar and wind power, are available across the globe without significant regional disparities. However, renewable energy is characterized by large fluctuations and low energy density, making it necessary to develop effective methods for energy leveling and increasing power density. At I^2CNER, we are developing innovative materials and processes, including solar cells that efficiently convert solar energy into electricity and steam electrolysis technologies that produce hydrogen as an energy carrier. We are also developing efficient processes for converting CO_2 into useful compounds by considering CO_2 as both a carbon resource and a hydrogen carrier. In particular, we are working to develop materials capable of separating dilute CO_2, such as that present in the atmosphere. At the same time, we are investigating new interdisciplinary approaches for developing innovative photocatalysts, including dye-modified and enzyme-based systems, that can directly convert solar energy into hydrogen. Finally, underground CO_2 storage will also be necessary to achieve a net reduction in CO_2 emissions. Therefore, we are further studying CO_2 storage technologies and the long-term stability of CO_2 stored underground.

Through a holistic approach, we aim to contribute to the realization of a carbon-neutral society by creating innovative science and engineering through interdisciplinary research across different temporal and spatial scales.

I^2CNER has focused on the development of highly efficient conversion technologies. As the next step, we have added “rapid conversion” as a new keyword and are pioneering a new academic field through the integration of disciplines. We aim to contribute to the realization of a carbon-neutral energy society by promoting the social implementation of the basic research developed through our work as a WPI institute, as well as by proposing novel concepts, including scenarios and designs for a renewable energy-based society.

Professor Tatsumi Ishihara
Director, International Institute for Carbon-Neutral Energy Research (I^2CNER)

About I²CNER

Mission

At I²CNER, our mission is to contribute to the creation of a sustainable and environmentally friendly society by conducting fundamental and cutting edge research for the advancement of carbon neutral and cost-effective energy systems, and development of high energy efficiency as well as energy conversion rate.
The array of technologies that I²CNER's research aims to enable includes solar energy conversion technologies, solid oxide fuel cells, polymer membrane-based fuel cells, solid oxide electrolyzer, oxide proton conducting cells, biomimetic and other novel catalyst concepts, and the production, storage, transport, and utilization of hydrogen and hydrogen carriers as energy carrier.
Our research also explores the underlying science of CO_2 capture, utilization and storage technology, the conversion of CO_2 to useful products, advanced materials for energy and environmental applications, and energy systems analysis that supports the transition to a carbon-neutral society.
Additionally, it is our mission to establish an international academic environment that fosters innovation through collaboration and interdisciplinary research (fusion).

As an inductee of the WPI Academy, we aim to continue to make disruptive advances in the international energy landscape, as well as strengthen the scientific advancements in Japan in collaboration with the United States and the world.

I²CNER's research is consolidated into three thrusts: Advanced Energy Materials (AEM), Advanced Energy Conversion Systems (AECS), and Multiscale Science and Engineering for Energy and the Environment (MSEEE).
These thrusts are directly linked to the "Platform for International Collaborations and Partnerships" that has been designed to maintain I²CNER's international identity and the "Platform for Societal Implementation and Industrial Collaboration," whose purpose is to ensure technology transfer through the large and growing network of I²CNER's industrial interactions.
Each thrust is led by a number of Principal Investigators, each with several dozen researchers working toward that thrust's stated research objectives.

Research Thrusts

Advanced Energy Materials (AEM)

The goal of the Advanced Energy Materials thrust is to develop molecular, nano, and bulk materials based on new science of surfaces, interfaces, and microstructures for applications involving H_2, H_2O, and CO_2. The research is directed to two classes of materials, catalytic and structural. In the area of catalytic materials, our objective is to develop bio-inspired molecular systems for fuel and energy generation that are centered on biological and synthetic catalysts. In addition, we explore the production of fuels and materials of added-value from ubiquitous chemicals through the use of solar energy. In the area of structural materials, the research focuses on the development of the fundamental science that enables optimization of the cost, performance, and safety of materials for H_2 technologies. This includes the association of basic science underlying deactivation of catalytic surfaces to industrial approaches for the mitigation of hydrogen embrittlement. In addition, we aim at advancing our mechanistic insight into the degradation of metals and alloys for technologies that operate at elevated temperatures in the presence of hydrogen. Lastly, it is our objective to develop next-generation tribo-systems with higher efficiency and durability to conserve energy, thus contributing to CO_2 emissions reduction.

Advanced Energy Conversion Systems (AECS)

The goal of the Advanced Energy Conversion Systems thrust is to develop economically feasible energy systems characterized by high efficiency, fast conversion kinetics, and long lifetimes. The focus is on electrochemical and photochemical conversion that serve for stationary power and fuel generation and mobility, and thermal energy conversion that enables efficient heat transport. For electrochemical conversion, fundamental advances in the understanding of electrocatalysis and oxide proton, oxide ion and electronic transport properties in solids are needed in order for high conversion rates between electrical and chemical energy to be obtained. The goal of photoelectrochemical conversion is the development of high-performance systems for photocatalytic splitting water, harvesting solar energy, and generating light by exploring inorganic, organic, and hybrid materials from physical, chemical, and biochemical perspectives and by elucidating potential

conversion roadblocks and causes of degradation.

Multiscale Science and Engineering for Energy and the Environment (MSEEE)

The Multiscale Science and Engineering for Energy and the Environment thrust pulls together the range of challenges facing Japan's and the world's energy transition, namely the transition from largely fossil fueled energy technology to a carbon-neutral or a carbon-free energy supply. In addition, this thrust enables the coordination of carbon reduction technologies, energy efficiency technologies, and guidance for social, political, and investment strategies to coordinate this transition.

This thrust includes the following 5 main clusters;

1. Carbon capture technologies based on membrane separation for zero and negative emission

We are developing technologies for CO_2 capture based on membrane separation, which is considered to have the lowest capture energy. In order to control global warming, CO_2 is not only captured from largescale emission sources, but also CO_2 from (1) air and (2) exhaust gas with diluted CO_2 by membrane separation for negative emission, and CO_2 removal at biogas upgrading. We are also considering modularization along with the development of these technologies.

2. Carbon storage and management using the earth

As a CO_2 reduction approach using the Earth, CO_2 geological storage that directly injects CO_2 into the subsurface reservoir has been recognized. By considering (1) amount of CO_2 reduction, (2) time to achieve CO_2 reduction and (3) cost for CO_2 reduction, CO_2 reduction and managements using the Earth could be a realistic approach.

3. Energy efficient technologies

To contribute toward the world's energy transition, we are working on the development of energy-efficient technologies, which includes heat mass transfer enhancement in adsorption systems, development of low-temperature thermally powered adsorption heat pump/refrigeration systems, and biofuel and edible protein production and negative CO_2 emissions.

4. Socio-techno-economic and policy analysis

In order to progress an energy transition that incorporates and develops technologies which can effectively deal with climate change, there is a need for analysis of technical, economic, and social aspects. I²CNER is furthering this analysis across the spectrum of available technologies, with a focus on the technologies being developed within I²CNER. In addition to the evaluation of the technical aspects such as technological applicability and efficiency, we also consider their economic and social merit. The analytical approaches we undertake include modeling, systems analysis, statistical analysis, applied mathematical analysis, social surveys, and stakeholder engagement.

5. Thermal energy conversion

Thermal energy conversion is studied by pursuing fundamental understanding of heat and mass transport phenomena in relation to nanoscale thermal transport, phase change heat and mass transfer, and the thermophysical properties of working fluids. Devices thus developed are essential to the integration of renewable energy to the electric grid and the advancement of new energy solution pathways, including hydrogen energy.

Research Platforms

Platform for International Collaborations and Partnerships

This platform is intended to maintain and foster I²CNER's international identity. The members of this platform, who are world experts with a solid record of international research experiences, collaborate with I²CNER's researchers from all three thrusts. Because this platform and the three thrusts are interwoven and the thrusts' themes overlap, this is an effective way to promote interdisciplinary collaborations across the Institute and around the world. In the last 15 years of I²CNER, we conducted international collaboration work with more than 600 international institutes and so environment of I²CNER is highly global and collaboration is the important policy.

Platform for Societal Implementation and Industrial Collaboration

The three major research thrusts contribute directly to the transition of future I²CNER scientific advances to applicable technology transfer through a large and growing network of I²CNER industrial interactions. This platform ensures a high level of tech transfer, provides policy guidance for science and technology investments, and addresses potential social acceptance and social impact issues. With its strengths in both advanced energy science and energy analysis, I²CNER provides critical direction and support to Japan's energy transition over the next 30 years to meet the 2050 net zero carbon society goals with minimal social and economic disruptions.

Affiliated Research Institutes

Research Center for Next Generation Refrigerant Properties (NEXT-RP) <launched in April 2016>

NEXT-RP is an international research center that develops and evaluates next-generation refrigerants to solve global environmental issues and future energy crises. Our essential duty is to find the following next generation refrigerants: (i) Lower ODP (Ozone Depletion Potential), (ii) Lower GWP (Global Warming Potential), (iii) Non-flammable or Mildly flammable, (iv) No toxicity or Lower toxicity.

Mitsui Chemicals, Inc.-Carbon Neutral Research Center (MCI-CNRC) <launched in November 2021>

MCI-CNRC, in collaboration with Mitsui Chemicals Inc., will develop and acquire cutting-edge environmental infrastructure technologies that will contribute to carbon neutrality, as well as pursue the practical use and commercialization of these technologies. By carrying out focused and efficient research into the elemental technologies needed to achieve carbon neutrality, the center will speed up the process of getting these technologies adopted in society. Contribute to achieving carbon neutrality through the social implementation of cutting-edge technologies developed in I²CNER with Mitsui Chemicals Inc.

Center for Energy Systems Design (CESD) <launched in November 2022>

CESD hopes to promote research on carbon-neutral technologies required for social implementation by collaborating with six research organizations (Hokkaido University, Tohoku University, Institute of Science Tokyo, Kumamoto University, RIKEN, and National Institute for Materials Science). This center consists of six research teams. The teams of “Light Energy Conversion”, “Electric Energy Conversion”, “Material Conversion”, and “Materials, Storage and Transport” conduct research to enable “high-speed conversion”. The “Energy Analysis” research team is responsible for the design of energy research by back-casting. The “Data Science” research team supports each research team by promoting data science, leading to discontinuous innovation. Not only achieving innovative outcomes, but the center also aims to foster the scientists of the future by making the center a field where young researchers can actively participate.

Centers For Common Education And Research

Research Center for Negative Emissions Technologies (K-NETs) <launched in April 2021>

This center aims to develop negative emissions technologies of greenhouse gases, i.e., developing technologies for CO_2 capture directly from the atmosphere, conversion and storage of the captured CO_2, and utilization of renewable energy. CO_2 can be captured anywhere since air exists ubiquitously on the earth. This nature of ubiquitous existence will enable the construction of an energy-robust society through local production for local consumption of carbon resources and contribute to the control of global warming by underground storage of excess emissions. This research project is supported by the Moonshot Research and Development Program launched by the Cabinet Office of Japan.

I²CNER Carbon Neutral Vision

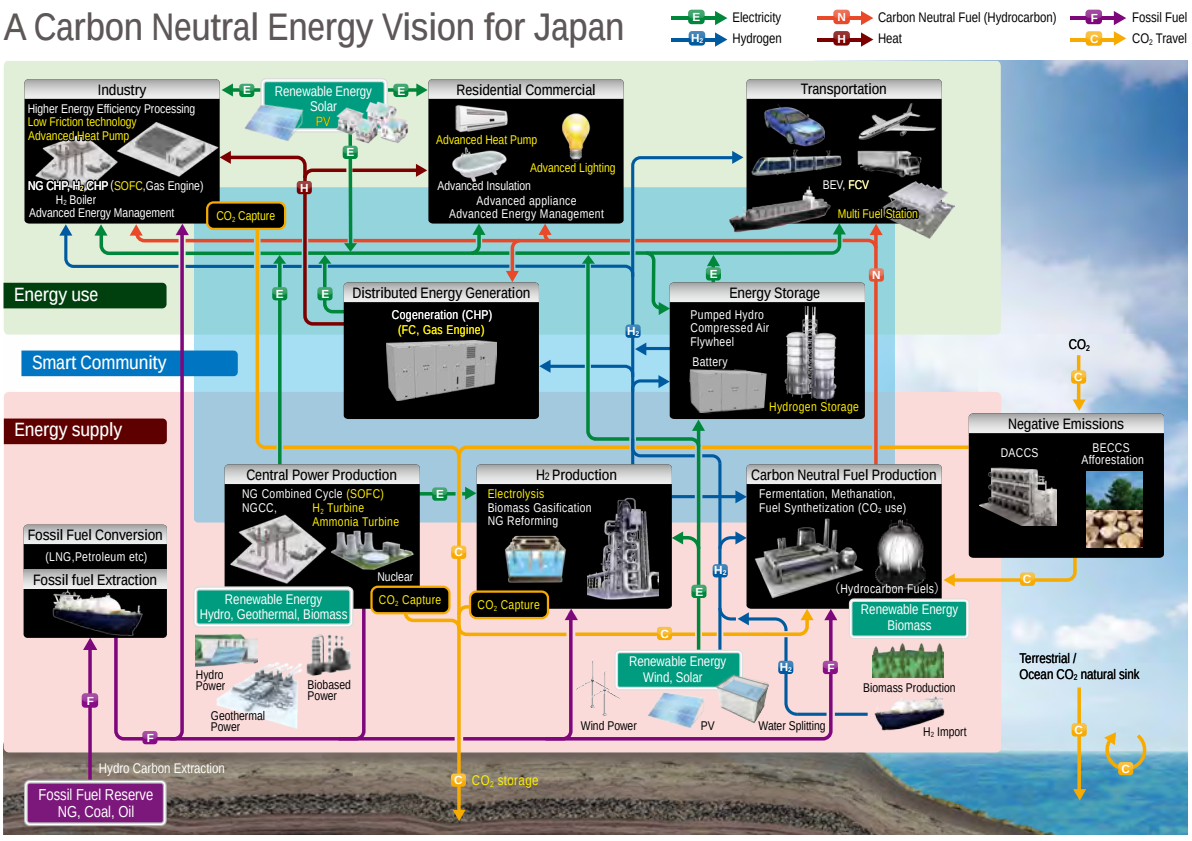


Fig. 4.1. Parameter Space of Technology Options.

Background

In October 2020, the Government of Japan formally committed to achieving carbon neutrality by 2050, marking a paradigm shift from the earlier 80% greenhouse gas (GHG) reduction target. This declaration has reoriented Japan's energy policy toward a zero-carbon energy regime, demanding accelerated reductions in emissions and a radical transformation of the current fossil fuel-based energy system. The I²CNER Carbon Neutral Vision aligns with this national goal and aims to serve as a scientific and strategic guide to realizing a sustainable, secure, and economically viable decarbonized society. At its core, the vision integrates technological innovation with societal needs by fostering a shared understanding of Japan's future energy system both within and beyond the academic community.

The I²CNER vision is structured around a 90–100% reduction in GHG emissions by 2050 and is built on the 3E+S principle: Environment, Energy Security, Economy, and Safety. These dimensions reflect the urgent need to address Japan's dependence on imported fossil fuels and to achieve climate goals without compromising reliability or affordability. The vision is underpinned by three key technological pillars: (i) Energy Efficiency Improvements (EI), (ii) Lowering Carbon Intensity (LCI), and (iii) Negative Emissions (NE). EI focuses on reducing energy consumption through innovation in industrial processes, buildings, and transport. LCI is pursued through large-scale deployment of renewables, low-carbon hydrogen, nuclear power, and CO_2 capture, utilization, and storage (CCUS). NE technologies, such as direct air carbon capture and storage (DACCS), bioenergy with CCS (BECCS), and land-use management, are introduced to offset unavoidable emissions from sectors like agriculture and waste.

I²CNER Strategic Scenarios for a Carbon-Neutral Energy Society

To assess feasible pathways toward carbon neutrality, I²CNER has developed two main energy transition scenarios. Scenario A, the baseline scenario, emphasizes maximum deployment of solar PV, gradual expansion of wind, and limited use of nuclear due to safety and societal acceptance issues. It includes moderate use of CCS, mostly for industrial processes and NGCC power plants, and assumes the phaseout of coal by 2040. Scenario B, the nuclear-intensive pathway, assumes a higher level of nuclear utilization by restarting all eligible reactors and extending their operational lifespans to 60 years. This scenario allows for more CO_2 storage capacity to be allocated to negative emissions technologies, thus enhancing net-zero viability. Both scenarios share common elements, including widespread electrification, extensive use of hydrogen, integration of EI, and limited, targeted CCS deployment.

The Role of Electrification and Hydrogen

Electrification plays a central role in the decarbonization of the residential, commercial, and transportation sectors. The transition to electric vehicles, heat pumps, and efficient appliances leverages decarbonized electricity and reduces final energy demand. In parallel, hydrogen emerges as a critical enabler in sectors less amenable to electrification, such as steelmaking, heavy-duty transport, and chemical manufacturing. Hydrogen also contributes to power system flexibility through its use in hydrogen-fueled turbines and seasonal energy storage. I²CNER's research supports this dual strategy through the development of hydrogen-compatible materials, high-efficiency electrolysis, and solid oxide fuel cells (SOFCs). These technologies enhance the system's resilience and ensure low-carbon performance across energy vectors.

Challenges and System-Level Integration

Achieving carbon neutrality is not without constraints. Japan's geological capacity for CO_2 storage is estimated at 200 million tons per year, which imposes a significant limitation on the extent of CCS deployment. This makes the prioritization of storage for NE applications and industrial CCS critical. Moreover, the long lead time for infrastructure development and limited availability of drilling equipment necessitate near-term investments and policy support. I²CNER scenarios account for these limitations by minimizing reliance on CCS for power generation and instead favoring solar and wind in the electricity sector, where faster deployment and cost declines are more achievable.

Technological Contributions by I²CNER

I²CNER's research plays a pivotal role in delivering the carbon neutrality vision. In addition to hydrogen-compatible alloys and advanced electrolysis, I²CNER has contributed to the development of CO_2 capture membranes and simulation tools for geological storage. Technologies such as PEM electrolysis, high-temperature steam electrolysis, hydrogen storage systems, and CO_2 monitoring via seismic imaging are central to both LCI and NE components of the vision. These innovations facilitate system-wide efficiency improvements and expand the feasibility of deep decarbonization strategies.

Outlook and Strategic Recommendations

I²CNER's Carbon Neutral Vision provides a realistic, technically grounded framework for achieving Japan's 2050 decarbonization goals. By balancing electrification and hydrogen deployment, prioritizing carbon-neutral fuels, and strategically deploying CCS and NE technologies, the vision offers a coherent pathway that accommodates technological constraints, social preferences, and economic realities. Scenario A achieves a 92% GHG reduction from 2010 levels by 2050, while Scenario B offers similar reductions with greater flexibility for offsetting residual emissions. Both scenarios highlight the necessity of a hybrid energy system that capitalizes on sector-specific strengths of electrification and hydrogen, guided by the principles of 3E+S.

Scenario A (Main Scenario): Development of important EI technologies and maximum deployment of solar power together with low carbon hydrogen energy system and NE. Approximately 92% reduction in GHG emissions by 2050, relative to 2010.

Contribution to EI

Heat pump (*GHG impacts of "Energy Efficiency"* *) and FC co-generation (*GHG impacts of "Power Generation"* *) for residential and commercial from 2020. Low-temperature heat utilization for industry from 2020, Fuel cell (*GHG impacts of "Power Generation"* *) for transportation from 2020.

Contribution to LCI through renewables

Low-cost and high-efficiency PV (*GHG impacts of "Renewables"* *) from 2030. Hydrogen storage and new battery technology (*GHG impacts of "Energy Carriers and Storage"* *) to adjust intermittent PV and wind power from 2030. High-efficiency electrolysis (PEM and high-temperature steam) (*GHG impacts of "Energy Carriers and Storage"* *) using renewable electricity to provide low-carbon hydrogen from 2030. SOFC using hydrogen and hydrogen turbine (*GHG impacts of "Power Generation"* *) for electricity generation industry from 2030 to 2050. I²CNER's hydrogen-compatible material research (*GHG impacts of "Hydrogen Compatible Steel"* *) and hydrogen physical property research (*GHG impacts of "Hydrogen Compatible Steel"* *) underpin the hydrogen energy systems.

Contribution to LCI and NE through CCS

Low-cost membrane CO_2 capture technology (*GHG impacts of "CO_2 Capture and Storage"* *) for NGCC, industrial CCS and DACCS and BECCS from 2030. Development of simulation technology for CO_2 monitoring and storage site characterization (*GHG impacts of "CO_2 Capture and Storage"* *) from 2030 through seismic approaches.

*The technology category in which I²CNER's research will produce CO_2 emission reduction impacts

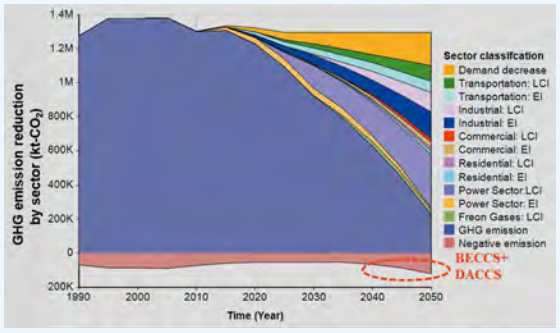


Fig. 4.2. CO_2 reduction relative to 2010 by sector in Scenario A.

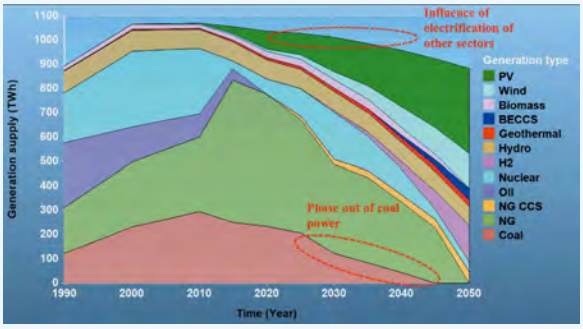


Fig. 4.3. Electricity mix by generation type in Scenario A.

Scenario B (Nuclear): Development of important EI technologies and maximizing use of existing nuclear plants together with low-carbon hydrogen energy system and NE. Approximately 94% reduction in GHG emissions by 2050, relative to 2010. If the public concerns on nuclear safety can be addressed, this scenario becomes more feasible, resulting in (i) providing more zero carbon electricity (nuclear) and reducing necessary renewable deployment; (ii) avoid employing CCS in the power generation sector; (iii) providing more CO_2 storage capacity for NE.

Contribution to EI

Heat pump (*GHG impacts of "Energy Efficiency"* *) and FC co-generation (*GHG impacts of "Power Generation"* *) for residential and commercial from 2020. Low-temperature heat utilization for industry from 2020, Fuel cell (*GHG impacts of "Power Generation"* *) for transportation from 2020.

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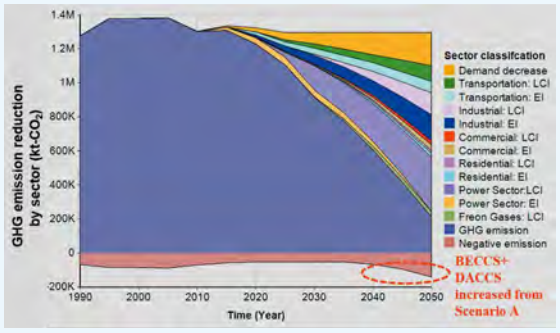


Fig. 4.4. CO_2 reduction relative to 2010 by sector in Scenario B.

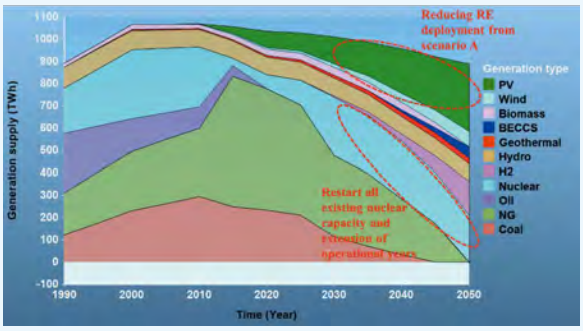


Fig. 4.5. Electricity mix by generation type in Scenario B.

The figure for CO_2 reduction in Scenario B is very similar to that of Scenario A. The difference in energy system makeup is defined in the electricity mix figures (Fig. 4.3 and 4.5). Both energy systems show strong CO_2 reductions in the Power Sector LCI wedge in the CO_2 reduction figures (Fig. 4.2 and 4.4) as nuclear and CCS are classified in the same Power Sector LCI wedge.

I²CNER's Contribution to the 2050 CO_2 Reduction Target

Introduction

Recently, the 7th Strategic Energy Plan was released by the Japanese Government, reiterating Japan's commitment to achieving carbon neutrality by the year 2050, and confirming the S+3E approach to energy policy.

Notably, the 7th plan includes a projected energy mix to the year 2040, outlining strong growth in renewables, and the use of nuclear power toward carbon neutrality, at least in the short term (Fig. 5.1).

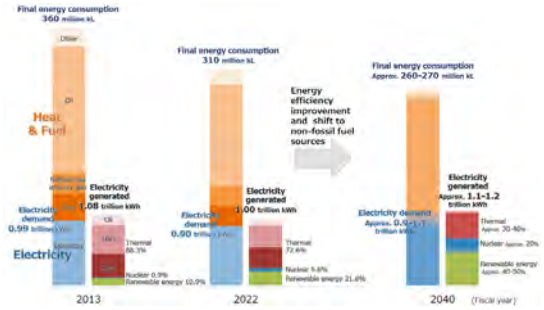


Fig. 5.1. 7th Strategic Energy Plan Energy Mix to 2040

As shown, it is anticipated that the contribution of thermal power will decline to between 30-40%, while renewable energy is slated to expand to an upper limit of 50%. Nuclear plays a modest role at 20% of electricity generation in 2040.

Alongside I²CNER roadmap revisions and research progress as reported by each thrust representative, the most recent Strategic Energy Plan is used to re-align our annual CO_2 reduction report for I²CNER and associated industries, outlined below.

CO_2 Reduction Report

Contrasting with the 2025 update on CO_2 reduction potential in I²CNER and associated industries, we note an additional anticipated contribution from research areas associated with renewable energy, and to a lesser degree, hydrogen related materials (Fig. 5.2).

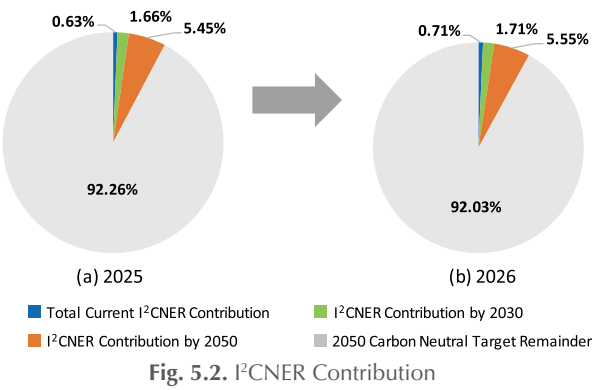


Fig. 5.2. I²CNER Contribution

As shown, the current estimated I²CNER contribution to carbon neutrality in Japan increased by 0.08% from 2025 to 2026, and an additional 0.05% is anticipated by 2030. With regard to the 2050 overall contribution from I²CNER, an additional 5.55% is anticipated via technological breakthroughs and technological transfers to industry. This is an increase of 0.1% compared to 2025. Overall, it is estimated that I²CNER's overall contribution to carbon neutrality by 2050 will be 7.97% (an increase of 0.23% from 2025). Although reported roadmap progress from I²CNER researchers were minimal or incremental this year, there are two key areas of improvement, notably in renewable energy and hydrogen, mostly due to exogenous factors, including the deployment of the 7th Strategic Energy Plan and hydrogen use estimates into the future (Fig. 5.3).

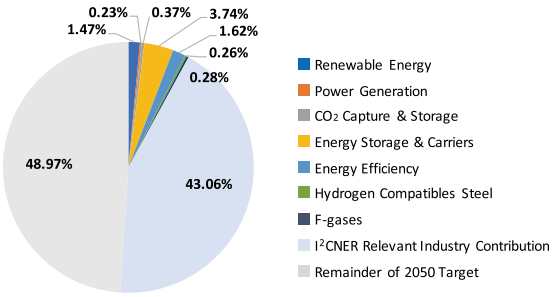


Fig. 5.3. Sector-based contribution breakdown

For renewable energy, the expected contribution due to I²CNER technologies such as the development of next-generation perovskite solar cells has revised upward the estimated contribution from 1.29% of 2050 emissions to 1.47% (a 0.18% increase). Further, the estimated contribution of hydrogen-compatible steels has slightly increased from 0.22% to 0.26% (a 0.04% increase). This change is supported by recent progress in hydrogen-based steelmaking technologies, including advancements in direct reduced iron (DRI) processes using hydrogen, improved material performance in hydrogen-rich environments, and successful pilot-scale demonstrations by top steel producers. Additionally, stronger policy backing through Japan's hydrogen strategy and the expected growth of green hydrogen infrastructure are likely to speed up adoption in the steel industry. These developments lessen technological and economic uncertainties, justifying the upward revision in the expected role of hydrogen-compatible steels. Other sectors showed only incremental improvement and remain at the 2025 level estimate for impact on future carbon neutrality goals.

Advanced Energy Materials (AEM)

Effect of water temperature in the deep sea on the mitigation of hydrogen embrittlement by O_2 impurity (PI Kubota M., PI Staykov A.)

The addition of trace amounts of oxygen (O_2) to hydrogen gas (H_2) can mitigate hydrogen embrittlement (HE) in steels by suppressing hydrogen uptake. In this study, the influence of temperature on the mitigation effect of O_2 was investigated through fracture toughness tests of SCM440 low-alloy steel in H_2 environments containing ppm-level O_2 at 293 K and 277 K, with consideration of subsea hydrogen gas pipeline conditions.

Lowering the temperature from 293 K to 277 K enhanced HE in pure H_2. However, the addition of O_2 effectively mitigated HE, and this mitigation became more pronounced at the lower temperature. This temperature-dependent behavior is attributed to differences in the adsorption characteristics of H_2 and O_2 on the iron surface.

O_2 adsorption on iron occurs without an activation barrier and is therefore essentially temperature-independent. In contrast, H_2 adsorption requires overcoming an activation barrier and thus decreases with decreasing temperature. Consequently, lowering the temperature selectively suppresses H_2 adsorption while leaving O_2 adsorption largely unaffected, thereby enhancing the relative influence of O_2.

Furthermore, the presence of O_2 increases the activation barrier for H_2 adsorption, which further amplifies the temperature dependence of H_2 adsorption. These combined effects contribute to the enhanced mitigation of HE by O_2 at lower temperatures.

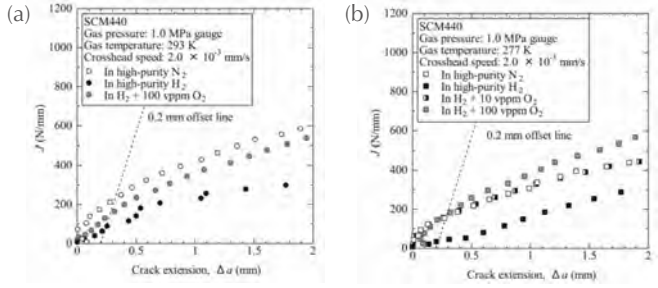


Fig. 6.1.1. Effect of O_2 addition to H_2 gas on fracture toughness at (a) 293 K and (b) 277 K. (a) At 293 K, the J–Δa curve in H_2 (●) is located significantly lower than that in N_2 (○), resulting in a substantial reduction in the JIC value from 238 to 82 N/mm. In contrast, the J–Δa curve in H_2 containing 100 vppm O_2 (◎) is positioned higher than that in pure H_2, leading to an increase in the JIC value to 154 N/mm. This demonstrates that the addition of 100 vppm O_2 to H_2 partially mitigates HE at 293 K. (b) At 277 K, the severity of the HE at 277 K was greater than at 293 K. In the H_2 containing 100 vppm O_2, the J-Δa curve closely matched that in the N2, and the JIC value was equivalent to that in the N_2. To further investigate, an additional experiment using the H_2 containing 10 vppm O_2 was conducted (◨). The result demonstrated the complete mitigation of HE. The HE mitigation effect of O_2 was significantly enhanced by the decrease in temperature.

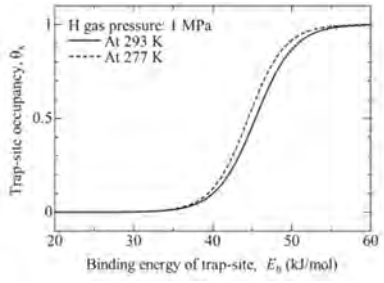


Fig. 6.1.2. Effect of temperature on hydrogen trap-site occupancy. It was found that trap site occupancy, θx, increased with a decrease in temperature within the binding energy range of 35 to 60 kJ/mol. This range is consistent with the binding energy of hydrogen at dislocations, which is approximately 20–60 kJ/mol. Therefore, it can be inferred that the increase in hydrogen trap site occupancy leads to the enhancement of the dislocation-hydrogen interaction, ultimately facilitating the HE.

References

Komoda R.; Kubota M.; Staykov A.; Zhang N.; Wada K. (2025), Effect of water temperature in the deep sea on the mitigation of hydrogen embrittlement by O_2 impurity, Engineering Failure Analysis, 180, DOI: 10.1016/j.engfailanal.2025.109885.

One-Pot Asymmetric Sulfoxidation Using in situ Generated H_2O_2 from H_2 and O_2 Catalyzed by Rhodium and Vanadium Complexes (PI Ogo S., Prof. Yatabe T.)

We report the first example of a one-pot asymmetric sulfoxidation using in situ generated H_2O_2. This reaction is catalyzed by two homogeneous catalysts: a Rh complex for the direct synthesis of H_2O_2 from H_2 and O_2, and a V complex for the asymmetric oxidation of sulfides. The maximum yield of this reaction was 77%, and the enantioselectivity was up to 69% ee. This work provides a general strategy for integrating incompatible H_2O_2-forming and asymmetric catalytic reactions in a single vessel, offering a foundation for the development of future one-pot asymmetric oxidation processes based solely on homogeneous catalysts. We anticipate that these principles will enable the development of a broader range of asymmetric oxidation processes driven by in situ H_2O_2 generated directly from H_2 and O_2.

References

Yatabe T.; Kanda N.; Tsuji M.; Sakogashira S.; Tashiro N.; Nakai H.; Ogo S. (2026), One-pot asymmetric sulfoxidation using in situ generated H_2O_2 from H_2 and O_2 catalyzed by rhodium and vanadium complexes, Chemical Communications, 62(15), 4605-4609, DOI: 10.1039/d6cc00169f.

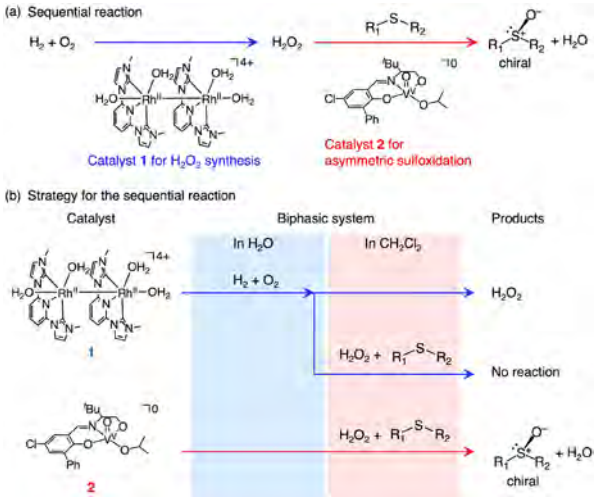


Fig. 6.1.3. (a) The target sequential reaction. (b) The strategy for the sequential reaction.

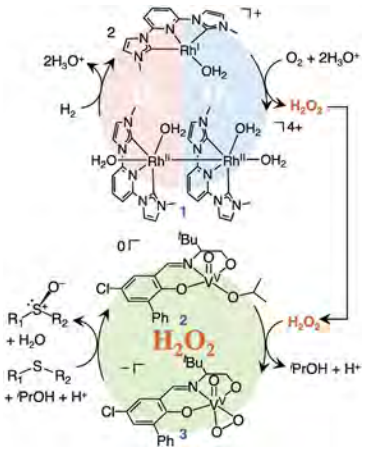


Fig. 6.1.4. Reaction cycle of a one-pot asymmetric sulfoxidation using in situ generated H_2O_2 from H_2 and O_2 by means of a Rh and V homogeneous catalysts.

Mechanistic Understanding of C-C Coupling Pathway in Electrochemical CO_2 Reduction Reaction (PI Yamauchi M.)

Electrocatalytic carbon dioxide (CO_2) reduction reaction (CO_2RR) has emerged as a promising strategy for sustainable energy conversion and carbon utilization. Despite intensive research efforts, the understanding of intermediates and pathways from CO_2RR to multicarbon (C_{2+}) chemicals remains incomplete. The challenge is to gain insight into the activation of adsorbed CO and the subsequent pathways. Here, we design a specially tailored Cu nanowire array facing a hydrophobic interface as an electrode to highly enhance Raman signals in the in-situ environment, allowing sensitive observation of the sequential change of various elusive intermediates during CO_2RR, such as CO, CH_2, CO coexisting with CH_2, CH_2CO, and CH_3. Density functional theory calculations reveal that the C–C coupling during CO_2RR originates from an asymmetric coupling between CH_2 and CO to form CH_2CO, identified as the rate-determining step in the formation of C_{2+} products formation. These results deepen the understanding of the C–C coupling processes, which is crucial for advancing catalyst development in electrochemical CO_2 upgrading.

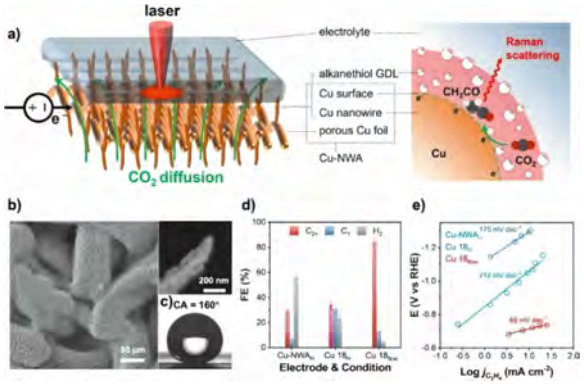


Fig. 6.1.5. Design strategy on Cu nanowire array (Cu-NWA) electrode for in-situ Raman spectroscopy (a) Schematic description of the Cu-GDL-electrolyte interface on Cu-NWA assembled in the reactor used for in-situ Raman spectroscopy. (b) SEM images of Cu modified with thiol (Cu 18) reveal the nanostructure composed of a two-dimensional array of Cu nanowires. (c) Contact angle (CA) of 160° reveals the superhydrophobicity on Cu 18. (d) FEs for C_{2+}, C_1 and H_2 on Cu-NWA (Cu-NWAH) and Cu 18 (Cu 18_H) in an H type cell and Cu 18 with a flow type cell (Cu 18_{flow}). (e) Tafel slope for C_2H_4 production on Cu-NWA_H, Cu 18_H and Cu 18_{flow}.

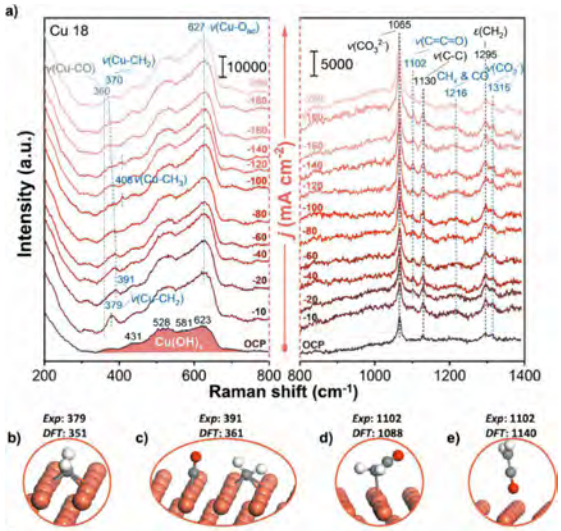


Fig. 6.1.6. In-situ Raman spectra on Cu 18 and DFT calculations of adsorbates on Cu(100) (a) Raman spectra in the 200–1400 cm^{-1} range. (b-e) Configurations of (b) adsorbed CH_2 (c) co-adsorbed CO and CH_2, and (d and e) adsorbed CH_2CO on Cu(100).

References

Sun M.; Rocabado D.S.R.; Cheng J.; Noguchi T.G.; Donoshita M.; Matsuu T.; Higashi M.; Fujigaya T.; Ishimoto T.; Yamauchi M. (2025), In Situ Observation of Post-CO Intermediates to Decode C–C Coupling Pathways in CO_2 Electroreduction, Angewandte Chemie - International Edition, 64(30), DOI: 10.1002/anie.202502740.

Low-temperature methanol synthesis in a temperature-decoupled internally heated reactor (Prof. Nakamura J., Dr. Yan M.)

This study explored low-temperature methanol synthesis from CO_2 and H_2 under ambient pressure using a $Cu/ZnO/Al_2O_3$ catalyst and a self-designed internally heated fixed-bed reactor. A systematic series of experiments clarified the temperature difference between the heater and catalyst bed, and revealed that the thermally decoupled reactor configuration shifted the methanol formation window to a lower measured catalyst temperature of about 130 to 140 °C. The work established the experimental basis, kinetic interpretation, and reactor concept reported in the FY2025 final report for Mitsui Chemicals. The project addresses carbon recycling and sustainable methanol production, which are globally important challenges in catalysis and chemical engineering.

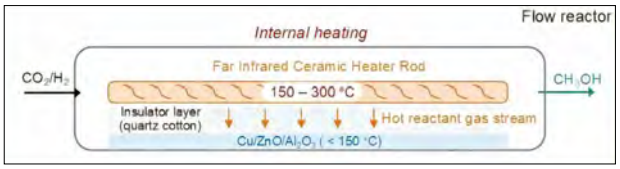


Fig. 6.1.7. Schematic of the self-designed internally heated fixed-bed reactor used for CO_2 hydrogenation to methanol. The reactor enables controlled separation between heater temperature and catalyst temperature.

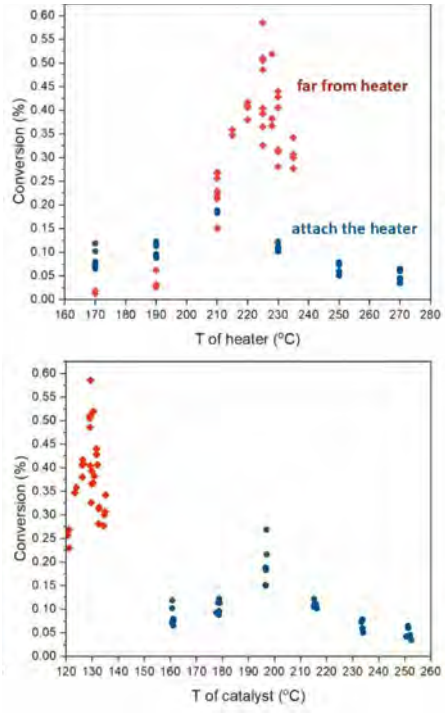


Fig. 6.1.8. Methanol conversion as a function of heater temperature and catalyst temperature. The decoupled Far configuration shows a distinct low-temperature reaction window, with the highest conversion concentrated around 130 to 140 °C at the catalyst bed.

References
Nakamura J. (2026), Low-temperature methanol synthesis, Final Report for Mitsui Chemicals.

Power-Free Gas-Phase CO_2 Hydrogenation to Formic Acid Using Immobilized Bacterial Plasma Membranes (Prof. Yoon K.-S., Dr. Edalati P.)

Biocatalytic CO_2 reduction offers exceptional selectivity under mild conditions, yet most enzymatic systems operate in aqueous media and require soluble cofactors or external energy input, limiting catalytic efficiency and scalability. Here we report a gas-phase, power-free biocatalytic platform for CO_2 hydrogenation to formate using plasma membranes isolated from Citrobacter sp. S-77. These membranes intrinsically co-localize [NiFe] hydrogenase and formate dehydrogenase, forming a native enzymatic cascade that directly couples H_2 oxidation with CO_2 reduction without external cofactors. Immobilization of the membrane on a PTFE-carbon support creates a heterogeneous bio–inorganic interface that enables direct contact between membrane-bound enzymes and gaseous substrates while preserving the hydration environment required for enzymatic activity. Structural characterization by SEM-EDS and Raman spectroscopy confirms successful integration of the membrane layer with the carbon framework. Systematic investigation of catalytic parameters shows that activity is governed by active-site accessibility, hydration-controlled proton transport, and the balance between electron donor (H_2) and acceptor (CO_2) concentrations. Under optimized conditions, the system achieves efficient gas-phase enzymatic CO_2 hydrogenation with formate production exceeding 1200 μmol g^{-1} h^{-1}. These results establish membrane-based gas-phase biocatalysis as a new strategy for autonomous biological redox catalysis and provide a promising route for sustainable CO_2 valorization.

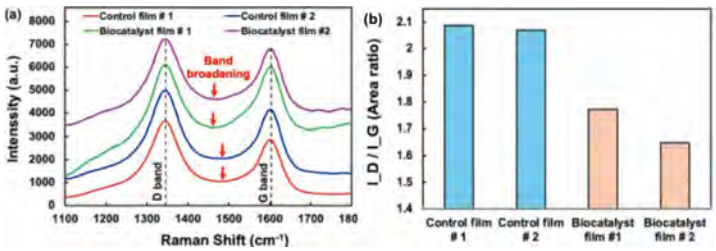


Fig. 6.1.9. Spectroscopic evidence of membrane-carbon interaction revealed by Raman analysis. (a) Raman spectra of control films and biocatalyst films containing immobilized *Citrobacter* S77 plasma membrane. (b) Corresponding I_D / I_G area ratios for control and biocatalyst films.

References
Moniruzzaman M.; Afrin S.; Hossain S.; Yoon K.-S. (2024), A Comprehensive Review of CO_2 Hydrogenation into Formate/Formic Acid Catalyzed by Whole Cell Bacteria, Chemistry - An Asian Journal, 19(22), DOI: 10.1002/asia.202400468.

All-solid-state Photovoltaic Cells Based on p-Type Plasmon-Induced Charge Separation for Efficient Photoenergy Conversion (Prof. Takahashi Y.)

Through the development of p-type PICS (p-PICS) combining metal nanoparticles and p-type semiconductors, I am advancing research aimed at realizing highly efficient photovoltaic systems. Specifically, for all-solid-state cells using Ag as the metal nanoparticle (Fig.6.1.9.), I systematically clarified the influence of interface characteristics with the p-type semiconductor NiO on conversion efficiency and published these results in a paper (ACS Appl. Electron. Mater., 2025). Furthermore, in an all-solid-state cell incorporating IrO_2 or RuO_2 as the p-type semiconductor, I achieved the world's highest efficiency for a p-PICS without bias application (Fig.6.1.10.) and published this as an invited paper (Electrochem., 2025). Achieving efficiency comparable to that of an n-type all-solid-state cell with a similar structure represents a result with significant international impact.

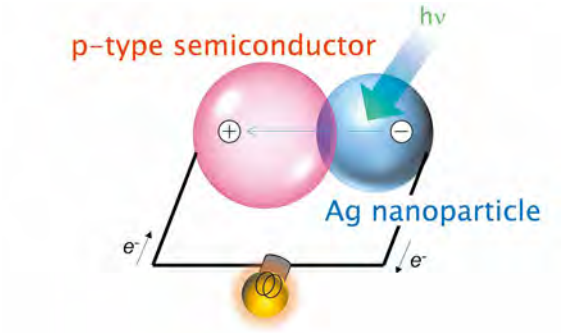


Fig. 6.1.10. Schematic illustration of all all-solid-state photovoltaic cell based on p-type PICS (p-PICS) combining Ag nanoparticle and p-type semiconductor.

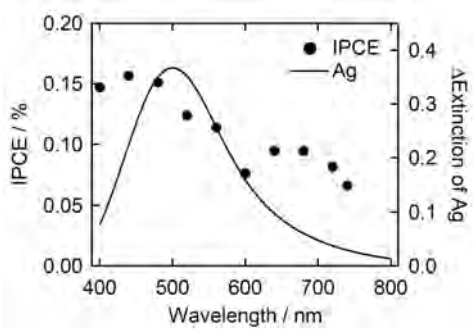


Fig. 6.1.11. IPCE action spectra under monochromatic light (3.5×10^{16} photons cm^{-2} s^{-1}) of the ITO/AgNP/IrO_2/Au cell with the Al_2O_3 nanomask. Extinction spectrum of AgNPs (= ITO/AgNP/IrO_2–ITO/IrO_2) is also shown.

References

[1] Takahashi Y.; Yamadori Y.; Murayama T. (2025), All-solid-state Photocurrent Generation System Based on p-Type Plasmon-induced Charge Separation, Electrochemistry, 93(9), 94003, DOI: 10.5796/electrochemistry.25-72096.
[2] Takahashi Y.; Yamadori Y.; Murayama T.; Shingo S.; Yamada S. (2025), Plasmon-Induced Charge Separation at Ag/p-NiO Nanocomposites for Solid-State Photodetectors, ACS Applied Electronic Materials, 7(12), 5412-5417, DOI: 10.1021/acsaelm.5c00378.

Development of novel proton-conducting solid electrolyte materials (Prof. Hyodo J.)

In this study, we developed novel proton-conducting ceramic electrolyte materials, $BaSn_{0.3}Sc_{0.7}O_{3-d}$ and $BaTi_{0.2}Sc_{0.8}O_{3-d}$, which exhibit proton conductivities exceeding 0.01 S/cm at 300 °C. These materials can contribute the ultimate targets of AECS Thrust of project 1 where “Degradation <0.5%/1000h Highly ion conductive solid: 10^{-2} S/cm at 300°C”. This discovery can be used to develop 300 °C-operable proton-conducting ceramic fuel cells and electrolysis cells.

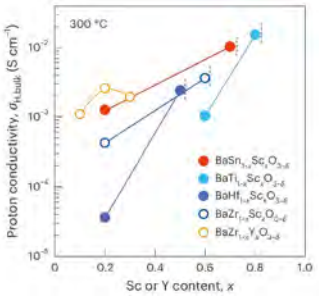


Fig. 6.1.12. The bulk proton conductivity as a function of dopant content in perovskite oxides. For Sc-doped perovskite, a monotonic increase with dopant concentration is found, although it is generally known that there is an optimum dopant content in a typical Y-doped system (orange plot).

References

Tsujikawa K.; Hyodo J.; Fujii S.; Takahashi K.; Tomita Y.; Shi N.; Murakami Y.; Kasamatsu S.; Yamazaki Y. (2025), Mitigating proton trapping in cubic perovskite oxides via ScO_6 octahedral networks, Nature Materials, 24(12), 1949-1956, DOI: 10.1038/s41563-025-02311-w.

Advanced Energy Conversion Systems (AECS)

Dye sensitized TiO_2 for improving efficiency of Photo-biocatalytic H_2 and NH_3 production (PI Ishihara T., PI Staykov A.)

In road map of Advanced Energy Conversion Systems, one of the important tasks is to develop highly active photocatalyst to convert solar energy to hydrogen or NH_3. In this study, we focused on bio enzymes such as hydrogenase and nitrogenase for H_2 and NH_3 formation. The principal design of bio photocatalyst is two steps, i.e. inorganic catalyst for reduction of redox mediator (Step 1) and the formation of H_2 on enzymes (Step 2). In this accomplishment in my group, we designed the photocatalytic activity of TiO_2 under irradiation of visible light by organic dye, in particular, Eosin based dye for increasing the efficiency to 10% solar to hydrogen efficiency (STH) which is objective value at 2040 and efficiency of electron injection from organic dye to TiO_2 was predicted by DFT calculation. Comparative studies on the hybrid interface of anatase and Eosin Y (EY) with carboxyl and pyridine anchors were performed, time-dependent density functional theory (TD-DFT) calculations and experimental photoreduction of methyl viologen (MV). The geometries, binding interactions between dyes and anatase, electronic structures and electron transfer as well as the effect of isomers (ortho, meta, and para) on the dye/anatase systems were investigated. Theoretical results indicated that EY with carboxyl and pyridine anchors had visible absorption and electron transfer from the dye to the anatase titania. Compared to carboxyl-para, which had the best optical performance among carboxyl groups, the adsorption strength of pyridine-ortho was close to that of carboxyl-para, while the oscillator strength increased significantly, which was more than 10 times higher than that of carboxyl-para. Corresponding with the theoretical estimation, EY pyridine linked TiO_2 is active to MV reduction under visible light irradiation by fast charge transfer, in particular, pyridine-ortho and para. Furthermore, high stability is also achieved for pyridine-para. An apparent quantum yield higher than 2.00% and 0.67% under 520 nm light was experimentally achieved in biocatalytic H_2 and NH_3 formation, respectively, for EY pyridine linked TiO_2, which was correctly predicted by the DFT calculations.

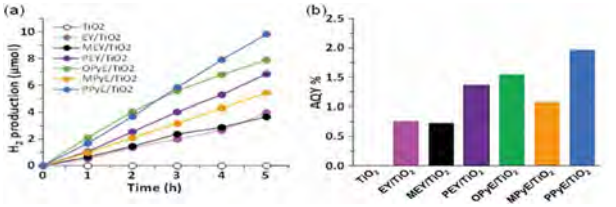


Fig. 6.2.1. Photobiocatalytic H_2 production of the dye/TiO_2 composite coupled with recombinant E. coli expressing [FeFe]-hydrogenase. (a) A time-course and (b) AQY analysis of H_2 production obtained from the reaction mixture including 100 mM L-cysteine pH 8, 3 mg per mL of the dye/TiO_2 composite, 5 mM MV^{2+} and 5 mg per mL cell mass of recombinant E. coli under visible light illumination at 520 nm.

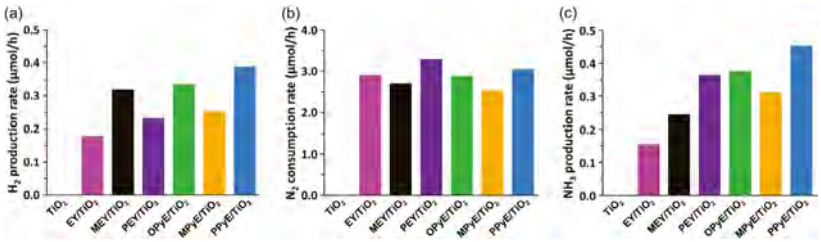


Fig. 6.2.2. Rate of (a) H_2 production, (b) N_2 consumption and (c) NH_3 production produced from the photobiocatalytic system of dye/TiO_2 coupled with cyanobacteria in the reaction system including 100 mM L-cysteine pH 7, 2 mg per mL dye/TiO2,10mMMV^{2+} and 50 mg per mL cyano-bacterial cell mass under visible light illumination at 520 nm.

References

Shang J.; Kosem N.; Kayo Y.; Shen X.-F.; Matsuyama S.; Watanabe M.; Inada M.; Ishihara T.; Staykov A. (2025), Improved charge transfer performance of eosin Y-sensitized anatase TiO_2 by anchoring group modification: from theoretical design to experiment, Journal of Materials Chemistry A, DOI: 10.1039/d5ta05712d.

Tailored Nickel Oxide Interfacial Layers Unlock Enhanced Charge Dynamics in LaTiOxNy Thin Film Photoanodes (PI Lippert T.)

$LaTiO_2N$ (LTON) is a very attractive visible light responsive semiconductor for the fabrication of photoanodes for H_2 production by solar. To design a feasible process, the other half of the water splitting reaction, the oxygen evolution reaction (OER), must be realized, and it is crucial to pair the photoanodes with appropriate OER catalysts such as nonstoichiometric nickel oxide (NiO_x). The application of NiO_x interfacial layers to LTON thin film photoanodes significantly enhances photocurrent performance by improving charge extraction and minimizing recombination. This work demonstrates that NiO_x functions as both a charge-selective layer and a recombination barrier, achieving record photocurrents for sub-50 nm LTON films in alkaline and sulfite-buffered electrolytes. Time-resolved and electrochemical analyses reveal that these improvements stem from effective Fermi-level de-pinning, bulk-to-surface charge transport enhancement, and the presence of scavengeable long-lived charges. These findings underscore the potential of NiO_x as a highly effective interfacial layer for solar water splitting utilizing LTON, a superior oxynitride.

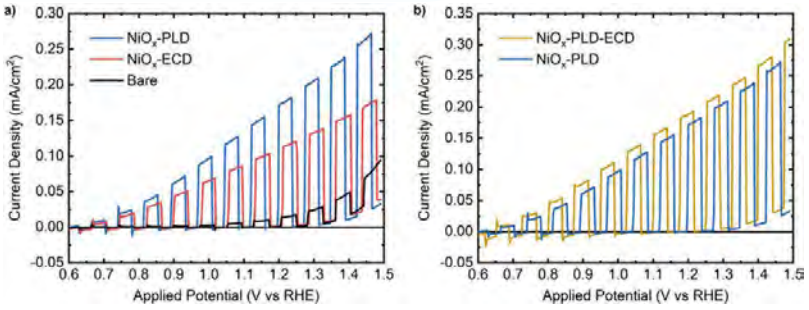


Fig. 6.2.3. Chopped light linear sweep voltammetry of (a) bare LTON, NiOx-PLD (pulsed laser deposition), and NiOx-ECD (electrochemical deposition), and NiOx-PLD, and (b) comparison of NiOx-PLD with NiOx-PLD-ECD. Scans were produced in pH 13.4 NaOH and 0.1 M sulfite with a scan rate of 0.01 V/s.
These results indicated tailored nickel oxide interfacial layers with enhanced charge separation at the NiOx and oxynitride interface.

References
Burns E.; Stephens K.J.; Federico Motti F.; Pergolesi D.; Lippert T. (2026), Tailored Nickel Oxide Interfacial Layers Unlock Enhanced Charge Dynamics in $LaTiO_xN_y$ Thin Film Photoanodes, Advanced Materials Interfaces, 13(4), DOI: 10.1002/admi.202500922.

Optimizing interlayer thickness for enhanced performance and chemical durability in sandwich-structured PEM fuel cells (Prof. Nishihara M.)

Polymer electrolyte fuel cells (PEFCs), one of the research topics of the AECS unit, are a promising clean energy conversion technology. However, their widespread adoption is hindered by the trade-off between high performance and long-term chemical durability. In this study, we designed and developed a multilayer PEM structure in which a gas barrier interlayer is sandwiched between cast Nafion outer layers. A blend of poly(vinyl alcohol) and poly(vinylsulfonic acid) (PVA/PVS) was employed as the interlayer material, designed to suppress gas crossover and mitigate chemical degradation while maintaining ionic conductivity.
The optimized membrane (PVA-100), with an interlayer loading of 100 μg/cm², exhibits a power density equivalent to that of pristine Nafion at 0.6 V. Furthermore, under accelerated stress testing, this membrane demonstrates 1.8 times higher chemical durability than a conventional membrane, maintaining superior voltage stability and power retention at 0.6 V.
These results demonstrate that interlayer engineering is a scalable and effective strategy to overcome the trade-off between durability and performance in PEM fuel cells, providing important insights toward the realization of "advanced fuel cells and electrolyzers with high durability and high efficiency".

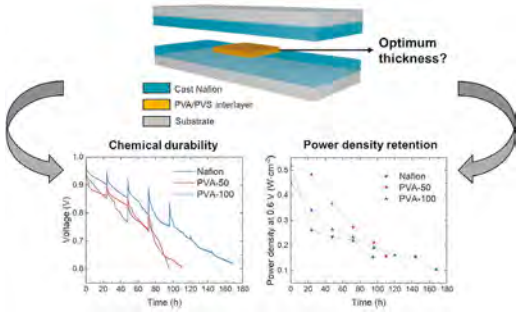


Fig. 6.2.4. A fabrication method for multilayer membranes incorporating a gas barrier interlayer, and the achievement of high chemical durability through suppression of oxygen permeation by the gas barrier layer.

References
Gautama Z.A.R.; Yang I.; Fukaya N.; Ercelik M.; Ismail M.S.; Lyth S.M.; Sasaki K.; Nishihara M. (2026), Optimizing interlayer thickness for enhanced performance and chemical durability in sandwich-structured PEM fuel cells, Journal of Power Sources, 661, DOI: 10.1016/j.jpowsour.2025.238654.

Oxygen activation on carbon-coated iron nanoparticles (PI Staykov A.)

This work explores the feasibility of molecular oxygen activation and dissociation on the sp2-hybridized carbon surface of carbon-coated iron nanoparticles. Using density functional theory with a generalized gradient approximation, we elucidate the geometry and electronic structure of these nanoparticles, highlighting the nature of the C–Fe binding interactions and the resulting modifications to the carbon surface electronic states. The enhanced catalytic activity of carbon induced by the underlying iron core is attributed to core–shell electronic interactions within the nanoparticles. Activation of molecular oxygen to superoxo and peroxo species was investigated using the nudged elastic band method, with electron transfer processes analyzed in detail and linked to the core–shell characteristics of the system. Additionally, we examined the effects of nitrogen doping in the carbon shell on the structural and electronic properties of the nanoparticles. Potential degradation pathways, including parasitic reactions during oxygen activation, were also identified. This study offers new theoretical insights into the functional behavior of Fe–C–N catalysts.

References
Staykov A. (2025), Oxygen activation on carbon-coated iron nanoparticles, New Journal of Chemistry, DOI: 10.1039/d5nj02903a.

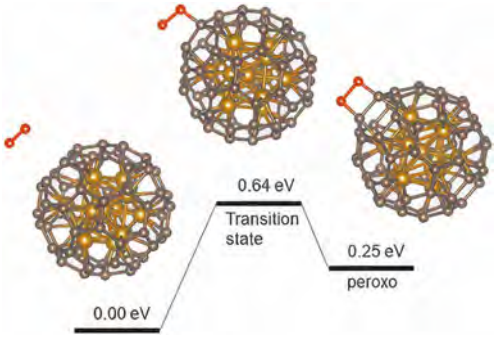


Fig. 6.2.5. Molecular oxygen interaction with C60@Fe13 obtained with the NEB method.

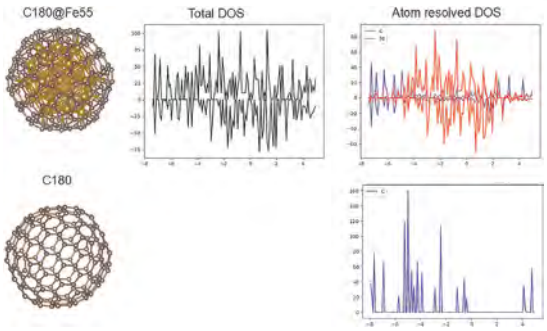


Fig. 6.2.6. Optimized geometries and DOS plots for C180@Fe55 and C180. DOS of iron and carbon atoms from C180@Fe55 and C180. Spin up and spin down states were plotted for C180@Fe55.

High-entropy perovskites as new photocatalysts for cocatalyst-free water splitting (Prof. Edalati K.)

The photocatalytic water-splitting process is thermodynamically challenging and requires catalysts with suitable band structures, as well as the presence of supporting cocatalysts. By considering the unique charge carrier mobility in perovskites, this study introduces three new ABO_3-type high-entropy perovskites $(Ba_{1/2}Sr_{1/2})(Ti_{1/3}Zr_{1/3}Hf_{1/3})O_3$, $(Ba_{1/2}Sr_{1/2})(Ga_{1/3}In_{1/3}Sn_{1/3})O_{3-\delta}$ and $(Ba_{1/2}Sr_{1/2})(Ti_{1/3}Zr_{1/3}Sn_{1/3})O_3$ for cocatalyst-free photocatalysis. The three catalysts, having a single-phase cubic structure, are designed by considering configurational entropy, tolerance factor, octahedral factor, ionic radius deviation and valence deviation of >1.5*R* (*R*: gas constant), 0.9-1.0, 0.4-0.8, >0.3 and >0.3, respectively. The perovskites exhibit similar valence band tops, while their bandgaps vary slightly depending on the composition at the B-site. Additionally, all three materials demonstrate effective hydrogen generation without the need for added cocatalysts. This investigation confirms that high-entropy perovskites are potential for cocatalyst-free photocatalysis, offering a step forward toward milestones of the green hydrogen production project.

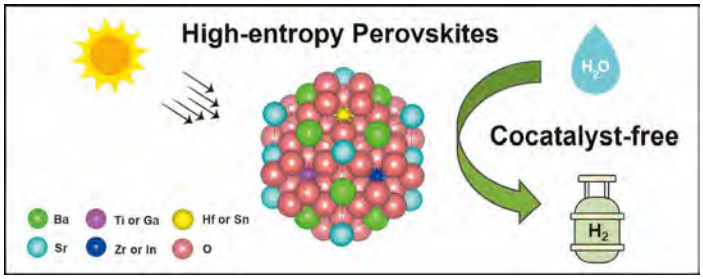


Fig. 6.2.7. High-entropy perovskites as new photocatalysts for cocatalyst-free water splitting to produce green hydrogen.

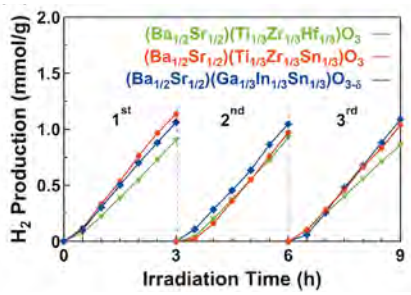


Fig. 6.2.8. Photocatalytic activity of three high-entropy perovskites $(Ba_{1/2}Sr_{1/2})(Ti_{1/3}Zr_{1/3}Hf_{1/3})O_3$, $(Ba_{1/2}Sr_{1/2})(Ti_{1/3}Zr_{1/3}Sn_{1/3})O_3$ and $(Ba_{1/2}Sr_{1/2})(Ga_{1/3}In_{1/3}Sn_{1/3})O_{3-\delta}$ for cocatalyst-free water splitting for three cycles.

References

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Molecular insight into visible light driven photocatalytic hydrogen peroxide synthesis using a heptazine-imide structure (Prof. Watanabe M.)

The photocatalytic activity of melamine, melem, and melem-phthalimide condensed molecules for hydrogen peroxide generation under visible light in the presence of ethanol as a sacrificial material was investigated. The catalytic activity tests were performed under heterogeneous conditions. Upon irradiation with visible light, melem-phthalimide condensed molecules produced 939 μM hydrogen peroxide, while melem produced 509 μM hydrogen peroxide. The melem-phthalimide condensed molecules were stable in repeated tests, which was confirmed by solid-state nuclear magnetic resonance. Furthermore, the reaction taking place on the surface of the melem-phthalimide condensed catalyst was revealed by electron spin resonance, X-ray photoelectron spectroscopy, and Raman spectroscopy. The reaction mechanism was confirmed by photoluminescence

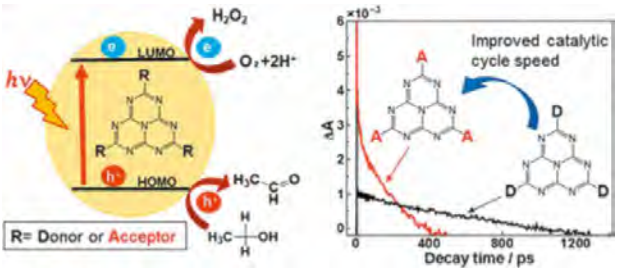


Fig. 6.2.9. This study suggests that the charge separation state formed by the heptazine-imide skeleton is useful for forming an effective photocatalyst. The results show that in hydrogen peroxide synthesis, the formation of a charge separation state by molecular level modification of the oxygen radical formation site contributes significantly to the reaction activity from a molecular point of view.

decay spectroscopy and transient absorption spectroscopy. This study revealed that the extended donor–acceptor type heptazine structure significantly contributes to the improved activity through charge separation at the molecular level.

References
Yamanaka Y.; Sawada K.; Nanke M.; Shen X.-F.; Song J.T.; Abe T.; Tanaka K.; Matsushima T.; Inada M.; Ishihara T.; Watanabe M. (2026), Molecular insight into visible light driven photocatalytic hydrogen peroxide synthesis using a heptazine-imide structure, Journal of Materials Chemistry A, 14(5), 3129-3137, DOI: 10.1039/d5ta06698k.

Multiscale Science and Engineering for Energy and the Environment (MSEEE)

Pressurized CO_2-activated functionalized biochar for enhanced porosity and carbon capture (PI Saha B.B.)

This study presents a sustainable pressurized-CO_2 activation route that converts waste jute sticks into ultramicroporous biochar for energy-efficient carbon capture. Activation at 800 °C under CO_2 pressures up to 1 MPa in a custom-designed Inconel reactor produced a clear pressure–structure–property relationship, where higher pressure improved both yield and porosity, contrary to the usual trade-off. At pressure 1 MPa, the biochar achieved a 57.4 wt% yield, 1182 m^2 g^{-1} surface area, and high CO_2 uptake of 141–149 mg g^{-1}. The results suggest that deep CO_2 penetration creates new micropores while preserving the carbon framework. Overall, this low-energy route enables scalable sorbent production from agricultural waste for carbon capture and other adsorption-based energy conversion applications.

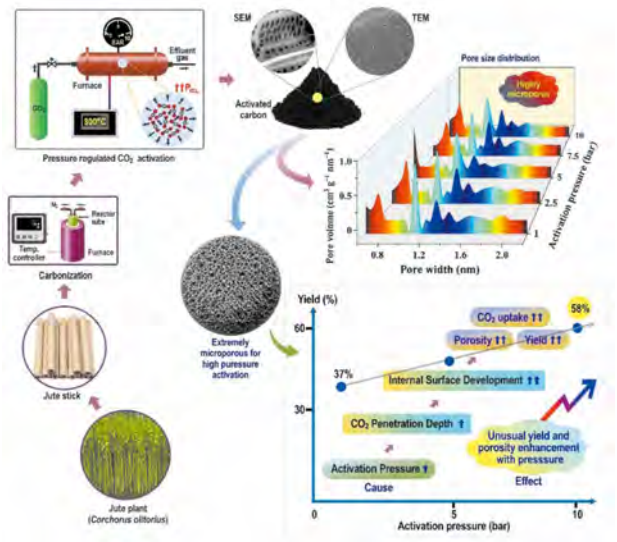


Fig. 6.3.1. This figure illustrates the synthesis and characterization of biomass-derived activated carbons produced through pressure-regulated CO_2 activation. It shows that increasing CO_2 pressure can simultaneously enhance activation yield and porous structure development. The results highlight the potential of pressurized activation for producing high-performance porous carbons.

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Islam M.A.; Saha B.B. (2026), Functionalized biochar with pressurized CO_2 activation: toward superior porosity, yield, and CO_2 capture efficiency, Carbon Research, DOI: 10.1007/s44246-026-00275-3.

Experimental investigation of spray cooling on steel plates with periodic micropillar structures (Prof. Kohno M.)

In this study, water spray cooling tests were conducted on stainless steel samples with laser-fabricated micropillars. The pillars had a pitch of 100 µm, with widths of 10–80 µm and heights of 30–150 µm.

Two quenching stages were observed during cooling from 700 °C to 100 °C. The first occurred above 400 °C at the pillar base, followed by a second at around 280 °C. The first quench was caused by stable liquid–solid contact at the pillar tips, while the wetting front later reached the base, leading to the second quench.

Taller pillars increased the apparent first quench temperature due to longer heat conduction paths, whereas shorter pillars showed no clear first quench. Increasing pillar width up to 30 µm improved cooling, but further increases reduced performance. The second quench temperature remained around 280 °C regardless of geometry.

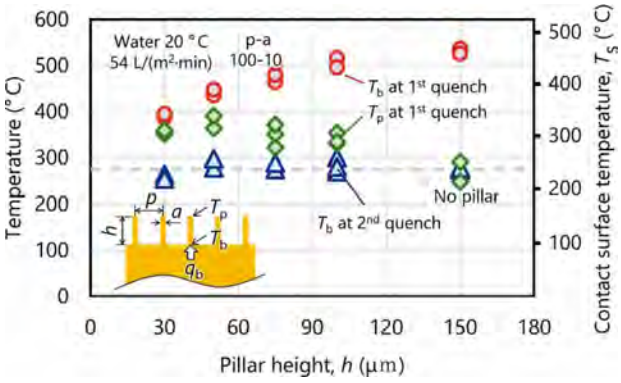


Fig. 6.3.2. Effect of micropillar height (h) on quench temperatures during spray cooling. The scale of the contact surface temperature Ts, converted from the temperature scale on the left vertical axis, is shown on the right vertical axis.

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Fukuda H.; Kita Y.; Ariyoshi T.; Takata Y.; Kohno M. (2025), Experimental investigation of spray cooling on steel plates with periodic micropillar structures: Two-stage quenching phenomenon, Applied Thermal Engineering, 275, DOI: 10.1016/j.applthermaleng.2025.126870.

Material development for membrane modules (Prof. Shundo A.)

For a reduction in the carbon dioxide (CO_2), thereby the suppression in global warming, it is necessary not only to develop high performance membranes but also to develop materials that can be utilized for their modularization. Thermosetting resins (TSR) can be considered as potential candidates for use as membrane supports, sealants, adhesives and coatings for membrane modules. For their practical applications, their long-term properties, which are closely related to their durability, are also of importance. Time–temperature superposition (TTS) principle is one of the methods to predict long-term behavior based on short-term experimental data. In this year, we applied the TTS principle to analyze the creep rupture behavior of TSRs with systematically varied cross-linking density.

Under a constant uniaxial stress (σ), creep compliance increased with time and eventually reached rupture at a rupture time (t_{rp}). The relationship between σ and t_{rp} was acquired at different temperatures (*T*s). The time-domain data obtained at each *T* were horizontally shifted to align with data at a reference temperature, using the horizontal shift factor (a_T). In master curves so obtained, all samples showed that t_{rp} scaled by a_T decreased with increasing σ. As the cross-linking density increased, *T* dependence of aT deviated from the Williams-Landel-Ferry (WLF) equation and exhibited Arrhenius-type behavior. The deviation was associated with differences in the fracture process involving chain scission, which became more pronounced as the cross-linking density increased. Since the materials for membrane modules which are subjected to a constant stress during their usage, the knowledge so obtained would contribute to the milestones of "establish CO_2 membrane module" in the roadmap.

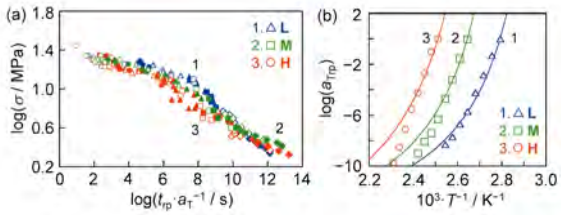


Fig. 6.3.3. (a) Master curves of σ–t_{rp} plots and (b) *T* dependence of a_T for TSRs (**L**, **M**, and **H**), where the suffix denotes low, medium, and high cross-linking densities, respectively.

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Psychological and socio-economic drivers of public acceptance for direct air capture and utilization technology (PI Chapman A.J.)

This paper examines the social feasibility of Direct Air Capture and Utilization (DAC-U), a critical but underexplored component of global decarbonization strategies. While achieving carbon neutrality by mid-century is a shared international objective, existing solutions such as renewable energy and conventional carbon capture face structural limitations, including intermittency, sectoral constraints, high costs, and uneven deployment. DAC-U offers a complementary pathway by directly removing CO_2 from the atmosphere and converting it into useful products, making it particularly valuable for addressing diffuse and hard-to-abate emissions. However, its scalability depends not only on technological and economic progress, but also on public acceptance, which remains insufficiently understood.

Using a large, nationally representative survey in Japan and Structural Equation Modeling (SEM), the study identifies technology acceptance and environmental awareness as the two primary drivers of public support for DAC-U. These factors operate both independently and interactively: environmental awareness enhances acceptance both directly and indirectly by increasing familiarity with related technologies. Socio-economic conditions such as housing characteristics and energy costs also shape acceptance, suggesting that practical, cost-related motivations are as important as environmental values. Demographic heterogeneity further complicates the picture, with older individuals showing higher acceptance despite lower environmental awareness, indicating diverse behavioral pathways to adoption.

The findings underscore that the transition to carbon-neutral systems is not purely a technical challenge but a socio-technical one with global implications. As DAC-U is expected to play a key role in meeting international climate targets, particularly for residual emissions, its success will depend on aligning policy design with public perceptions and lived realities. The study highlights the need for targeted interventions—such as subsidies, demonstration projects, and tailored communication strategies—to build both awareness and trust. Ultimately, it positions social acceptance as a critical bottleneck in scaling next-generation climate technologies, reinforcing that global climate goals hinge not only on innovation, but on societal readiness to adopt it.

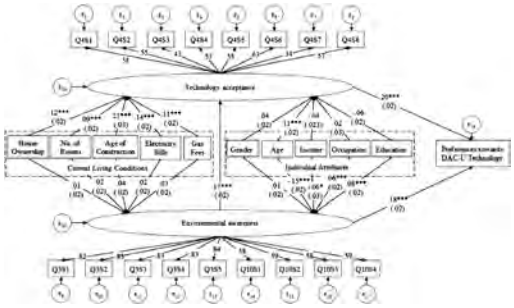


Fig. 6.3.4. SEM path diagram for carbon abating technology acceptance.

References
Keeley A.R.; Koo K.; Chapman A.; Managi S. (2025), Psychological and socio-economic drivers of public acceptance for direct air capture and utilization technology, Journal of Cleaner Production, 519, DOI: 10.1016/j.jclepro.2025.145962.

Operando spectroscopic analysis of CO ozone oxidation (Prof. Maeda N.)

Low-temperature catalytic oxidation of carbon monoxide (CO) remains a significant challenge in environmental catalysis, especially under the conditions where H_2O and sulfur dioxide (SO_2) are present. In this work, we demonstrate that Brønsted acid sites (BAS) in protonated zeolites can effectively activate ozone (O_3) to generate reactive oxygen species for efficient CO oxidation at temperatures below 150 °C. Systematic comparison among metal oxides, supported catalysts, and zeolites revealed that H-type beta zeolite (Hβ5, Si/Al = 5) exhibits the highest catalytic CO conversion, achieving >40% CO conversion at room temperature. Hβ5 showed higher resistance to deactivation in the presence of H_2O and SO_2 than Au and Pt-based catalysts. Kinetic studies revealed a linear correlation between CO conversion rates and the number of BASs, suggesting that BAS is active site for this catalytic system. Modulation Excitation Diffuse Reflectance Infrared Fourier Transform Spectroscopy (ME-DRIFTS) and DFT calculations suggested that O_3 interacts directly with a BAS to form reactive oxygen species, which react with CO to give CO_2. Our findings provide new insight into non-transition-metal- based oxidation catalysis and offer a promising strategy for designing robust catalysts for industrial CO abatement under harsh flue gas environments.

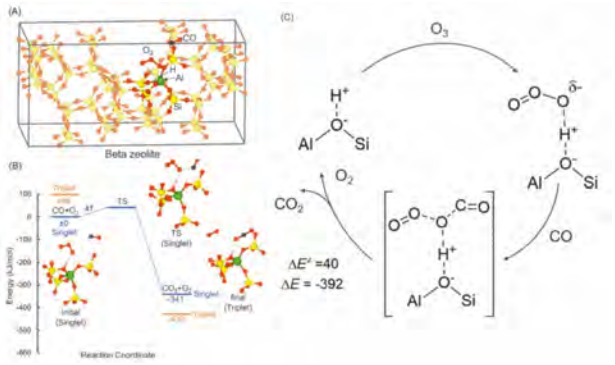


Fig. 6.3.5. (A) Used periodic model of Beta zeolites. (B) Energy diagram for CO oxidation by O_3 (brown: C, yellow: Si, green: Al, red: O, and white: H). (C) The schematic description of O-O bond activation scheme.

References

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A novel attention-enhanced LLM approach for accurate power demand and generation forecasting (Prof. Gao Y.)

This study developed a novel large-language-model-based forecasting framework, MultiAttLLM, for accurate electricity demand and generation prediction across multiple regions in Japan. The proposed method integrates cross-attention, a frozen pre-trained LLM, feature extraction, and self-attention to capture both temporal dependencies and cross-variable interactions without relying on prompt engineering.

Using hourly electricity demand, power generation, and weather data from Kyushu, Tokyo, Tohoku, and Hokkaido, the proposed model consistently outperformed benchmark models including LSTM, DLinear, Informer, Autoformer, iTransformer, TimesNet, and TimeLLM. Compared with LSTM, the model reduced MAE by 20.8%, and compared with previous LLM-based forecasting models, it reduced memory usage by 49.3% and shortened training time by 35.7%. The model also showed strong zero-shot generalization ability across unseen regions in Japan. This work advances the application of LLMs in energy forecasting and provides a practical methodology for next-generation smart grid management.

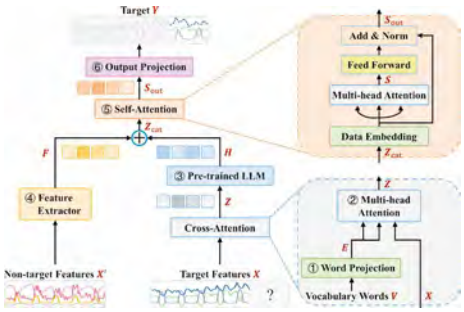


Fig. 6.3.6. Overview of the proposed MultiAttLLM framework, which combines word projection, cross-attention, a frozen pre-trained LLM, feature extraction, self-attention, and output projection for multivariate electricity forecasting. The framework enables effective feature interaction learning without prompt engineering.

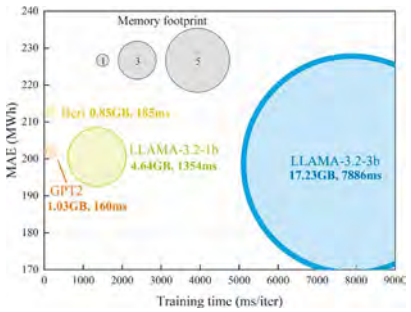


Fig. 6.3.7. Comparison of different LLM backbones in terms of forecasting accuracy, training time, and memory footprint. The results show that GPT2 achieved a strong balance between accuracy and computational efficiency, supporting its adoption in the proposed forecasting framework.

References

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Advanced Energy Materials (AEM)

Kinetic modeling of ammonia and hydrogen dissociative co-adsorption on iron surface and its effect on hydrogen embrittlement (PI Kubota M., PI Staykov A.)

In I²CNER, the effects of impurities in hydrogen have been systematically studied in accordance with the roadmap and milestones of the AEM Thrust. Previously, we reported three novel findings regarding the effects of ammonia (NH_3) on hydrogen embrittlement (HE): mitigation of HE by NH_3, induction of HE by NH_3, and an inverse concentration effect of NH_3.

To elucidate the underlying mechanisms, we conducted density functional theory (DFT) calculations in collaboration with theoretical chemists. For the mitigation effect, the calculations revealed that the preferential adsorption of NH_3 significantly reduces hydrogen coverage on the Fe surface, thereby hindering hydrogen uptake.

Regarding NH_3-induced HE, the results indicate that at sufficiently low loading rates, NH_3 decomposes into H and NH_2. The hydrogen generated from this decomposition then acts as a source of HE.

With respect to the inverse concentration effect of NH_3 on HE induction, the calculations show that the NH_3 decomposition rate ($NH_2 \rightarrow NH + H$) decreases markedly with increasing NH_3 partial pressure. This is because NH_3 decomposition requires vacant surface sites; thus, higher NH_3 concentrations reduce the availability of such sites. As a result, adsorbed NH_3 increasingly loses the opportunity to decompose at higher concentrations.

Condition	H_2 + 1000 ppm NH_3	H_2 + 10 000 ppm NH_3
θ_{NH_3}	10%	25%
θ_H	1.70%	0.01%

Fig. 7.1.1. Coverage of NH_3 and atomic hydrogen on Fe(110) surface non-dissociative NH_3. The hydrogen atom coverage on the Fe(110) surface is decreasing with the increase in NH_3 coverage.

	NH_3	NH_2	NH
k (1000 vppm NH_3) (s^{-1})	1.368×10^{8}	7.284×10^{5}	2.130×10^{-1}
k (10 000 vppm NH_3) (s^{-1})	6.656×10^{8}	1.459×10^{-1}	1.986×10^{-2}

Fig. 7.1.2. Reaction rate coefficient k of NH_3 decomposition. Our theoretical results at equilibrium show that the hydrogen coverage on Fe(110) surface increases with the increase in NH_3 partial pressure. However, the NH_3 reaction kinetics suggests that at short time intervals NH_3 will decompose to NH_2, NH and H at low partial pressure (1000 vppm) and only to NH_2 and H at high partial pressure (10 000 vppm). Thus, the H surface coverage will be kinetically locked to 8.42% at 1000 vppm NH_3 partial pressure and 4.37% at 10 000 vppm NH_3 partial pressure. As a result, increasing the NH_3 partial pressure would have a mitigating effect on HE.

References

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Enhanced Hydrogen Supply to Atomically Dispersed Copper Sites through Close Cooperation with Oxygen Vacancies in Black TiO_2 to Promote CH_4 Production in CO_2 Electrolysis (PI Yamauchi M., PI Kenis P.J.A.)

CO_2 electroreduction (eCO_2R) holds promise as an environmentally friendly approach to reducing greenhouse gas emissions. Cu is a representative catalyst with high eCO_2R activity. However, its selectivity for CH_4 synthesis is still insufficient due to the slow eight-electron transfer to a single carbon, the predominance of C–C coupling reactions towards C_{2+} products on Cu, as well as occurrence of the hydrogen evolution reaction. Here, for high CH_4 selectivity, we demonstrate a genuine hydrogen supply to atomically dispersed Cu sites (AD-Cu) via the cooperative function of oxygen vacancy (VO) formed on defective black anatase TiO_2 (Cu–TiO_2–H_2), that is prepared by exposing Cu-doped TiO_2 (Cu–TiO_2) to hydrogen gas. Cu–TiO_2–H_2 exhibited a remarkable Faradaic efficiency for CH_4 production of 63% and a partial current density of −120 mA cm^{-2}. The catalytic. mechanism for the high CH_4 selectivity was elucidated using a variety of spectroscopies, such as electron spin resonance, reversed double-beam photoacoustic spectroscopy (RDB-PAS) and in situ Raman measurements, with the support of quantum chemical calculations. In situ Raman measurements revealed that Cu–TiO_2–H_2 greatly accelerates proton consumption for the hydrogenation of *CO intermediates and that the surface pH on Cu–TiO_2–H_2 is sufficiently high to stabilize *CHO intermediates, key species for CH_4 formation. DFT calculations support the stability of the intermediates during the process of forming *CHO. All our results suggest that VO contiguous to AD-Cu on Cu–TiO_2–H_2 promotes water dissociation and smoothly supplies hydrogen to AD-Cu on Cu–TiO_2–H_2, thus facilitating CH_4 formation in eCO_2R

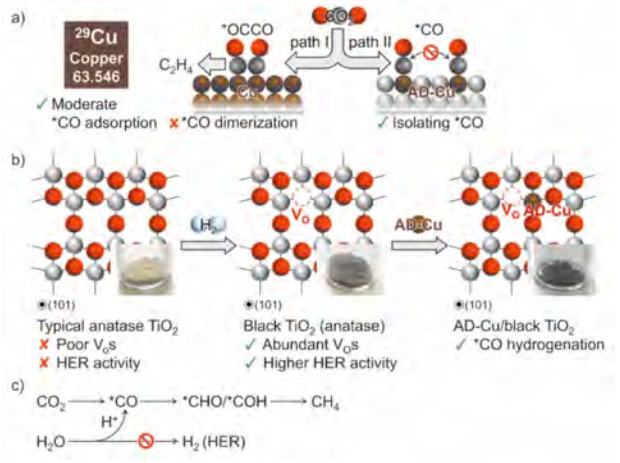


Fig. 7.1.3. Catalyst design concept of atomically dispersed Cu (AD-Cu) sites incorporated on black TiO_2. (a) Dimerization step of *CO to produce C_2 products on the Cu continuum surface (path I) and stabilization of *CO at AD-Cu (path II). (b) AD-Cu catalyst located in the vicinity of oxygen vacancies (VOs) on the oxide surface, which is used in this study. Black TiO_2 obtained by H_2 treatment of TiO_2 contains abundant VOs. (c) Expected synergistic effect of efficient *CO formation on AD-Cu sites and efficient H+ production on the adjacent VO sites.

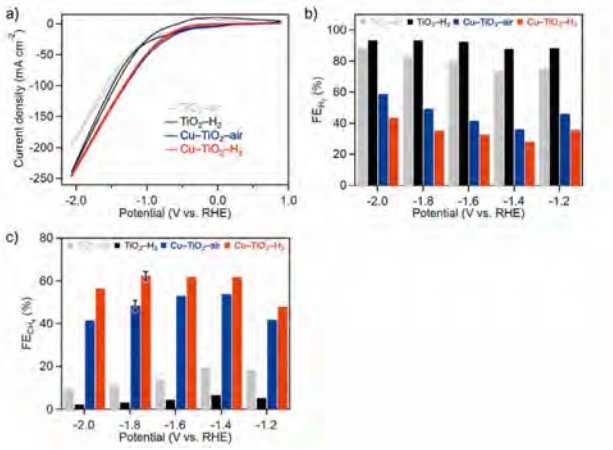


Fig. 7.1.4. (a) Cyclic voltammograms of the TiO_2–air (gray line), TiO_2–H2 (black line), Cu–TiO_2–air (blue line), and Cu–TiO_2–H_2 (red line) in 1 M KOH under CO_2 at 50 mV s−1 after three cycles. Faradaic efficiency (%) of (b) H_2 and (c) CH_4 during electroreduction of CO_2 as a function of the applied potential for TiO_2–air (gray bar), TiO_2–H_2 (black bar), Cu–TiO_2–air (blue bar), and Cu–TiO_2–H_2 (red bar).

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Interdisciplinary design of catalyst, heat transfer, and reactor architecture for low-temperature methanol synthesis (Prof. Nakamura J., Dr. Yan M.)

This research is interdisciplinary because it integrates heterogeneous catalysis, reaction engineering, heat transfer, and materials characterization. Catalyst synthesis and ex situ XRD and SEM were combined with dual-thermocouple temperature mapping, reactor geometry design, conversion measurements, and Arrhenius analysis. The study showed that the apparent activation energy depends strongly on the distance between internal heater and the catalyst surface. This combined surface science and engineering perspective enabled a clearer interpretation of low-temperature methanol formation and provides a framework for future optimization of catalyst and reactor design.

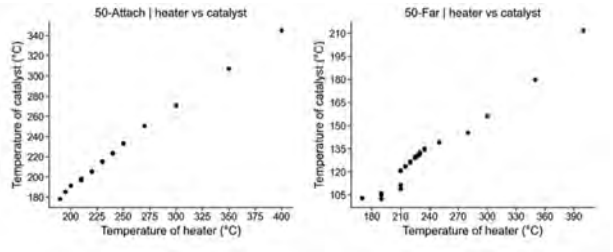


Fig. 7.1.5. Comparison of heater temperature and catalyst temperature in the Attached and Far configurations. The large configuration-dependent temperature offset demonstrates that reactor geometry controls the local thermal environment experienced by the catalyst.

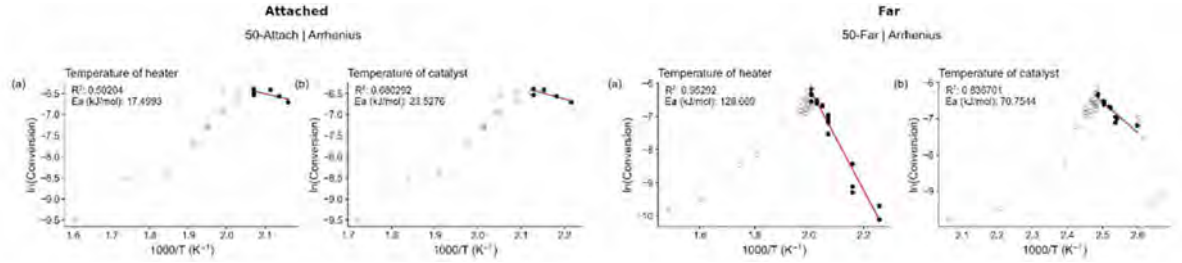


Fig. 7.1.6. Arrhenius analysis of the Attached and Far configurations. The dependence of the apparent activation energy on catalyst positioning demonstrates the importance of coupling catalytic kinetics with heat-transfer evaluations.

Enzymatic oxygen reduction dominates overpotential-driven thermogenesis in mitochondria (Prof. Nakamura J., Dr. Namari N.A.P.)

Understanding how chemical energy dissipates as heat in non-equilibrium redox systems is a fundamental problem in physical chemistry. While this phenomenon is well described in electrochemical systems such as fuel cells, its role in biological enzymatic systems remains underexplored. Mitochondrial thermogenesis has long been attributed to proton leakage, which correlates with heat generation but lacks a clearly defined physical mechanism. In fact, catalytic reactions—whether occurring on inorganic electrodes or in biological enzymes—inevitably require finite overpotentials, and quantifying these losses demands a site-specific kinetic descriptor. To this end, we introduce the electron transfer frequency (ETF), directly analogous to the turnover frequency (TOF) in heterogeneous catalysis, as a means to analyze enzymatic electron-transfer processes at the single-site level. Using ETF as the central descriptor, we develop a chemistry-based framework that models intracellular heat production as the dissipation of Gibbs free energy through enzymatic overpotentials in the mitochondrial electron transport chain, analogous to Joule heat in fuel cells. By treating each respiratory complex as a resistive kinetic step and calibrating the model with experimentally measured electrochemical parameters, we estimate that 45–71% of respiration energy is dissipated as heat. Among these, Complex IV alone contributes over 70% of the total dissipation, establishing it as the primary thermogenic site. This framework reproduces reported heat-to-respiration ratios across diverse cell types and demonstrates that overpotential dissipation, rather than proton leakage, represents a major and quantifiable pathway of heat generation. More broadly, it shows that analytical principles of electrocatalysis can be predictively extended to biological redox systems, establishing a common physical chemistry basis for energy dissipation in both.

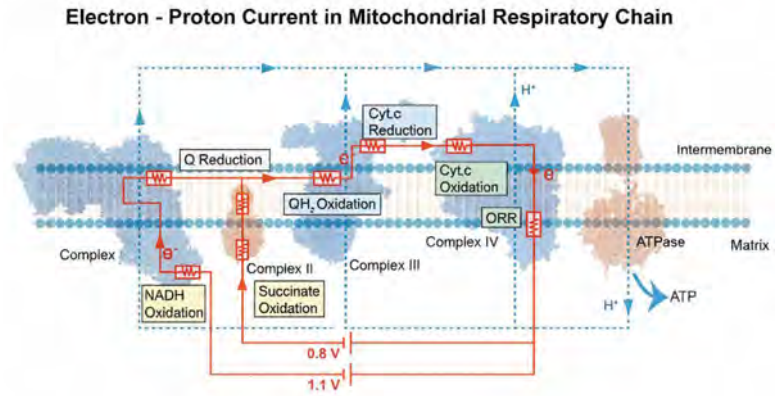


Fig. 7.1.7. Overpotential-driven thermogenesis model in mitochondrial respiratory chain. Red color is the electron current, and blue color is proton current. Each redox reaction in every complex regarded as resistor and proton pumping resistivity assumed to be negligible.

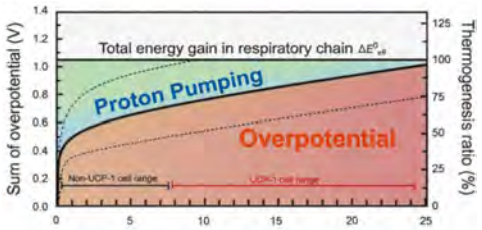


Fig. 7.1.8. Estimated total overpotential and thermogenesis ratio applied in a respiratory chain as a function of respiration activity.

References
Namari N.A.P.; Yan M.; Nakamura J.; Takeyasu K. (2026), Enzymatic oxygen reduction dominates overpotential-driven thermogenesis in mitochondria, Chemical Science, DOI: 10.1039/d5sc06693j.

Advanced Energy Conversion Systems (AECS)

Genetically Engineered E.coli for enhanced hydrogen production (PI Ishihara T.)

(This work is collaboration work with Prof. Yuki Honda in Nara Women's University.)

Whole-cell-based biohybrids, which integrate the light-harvesting capabilities of semiconductor nanomaterials with the highly efficient biocatalytic conversion of microorganisms, have garnered significant attention for the development of efficient solar energy storage systems. Notably, the use of bioprecipitation of nanomaterials for constructing biohybrid systems is an emerging trend due to its relative ease of preparation. This study presents a biohybrid system for light-driven hydrogen production by combining the improved bioprecipitation of cadmium sulfide (CdS) nanoparticles with the heterologous mass production of hydrogenase in Escherichia coli (CdS/E. coli). Specifically, the bioprecipitation capability was enhanced through heterologous expression of the gene encoding L-cysteine desulfhydrase (CysDSH). Enhanced sulfide formation in E. coli reduced the CdS bioprecipitation time and resulted in smaller CdS nanoparticles with a larger surface area, thereby improving the light-to-chemical energy conversion properties. The CdS/E. coli biohybrid constructed with CysDSH-gene-expressing cells exhibited approximately a 2-fold increase in light-driven hydrogen production, with an apparent quantum yield of 0.45% at 460 nm. This study demonstrates that genetic engineering can modify both semiconductor nanoparticle formation and material conversion in whole-cell-based biohybrids. These findings expand the current knowledge and offer guidelines for constructing biohybrids, providing strategies for enhancing solar-to-chemical energy conversion systems.

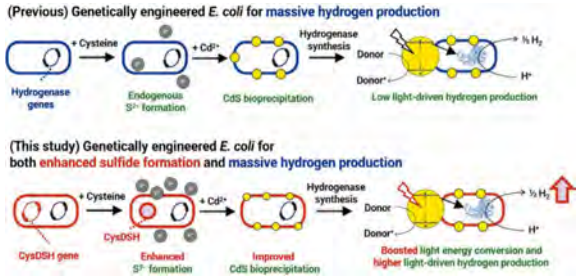


Fig. 7.2.1. Concept of this study. Blue and red rectangles represent E. coli cells expressing only [FeFe]-hydrogenase genes and both [FeFe]-hydrogenase and CysDSH genes, respectively. The yellow circles indicate bioprecipitated CdS particles.

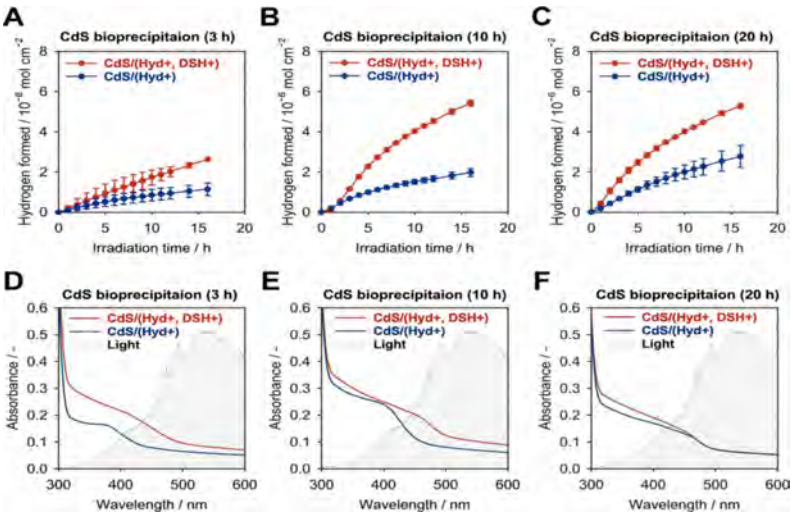


Fig. 7.2.2. Amounts of hydrogen formed under light irradiation and the absorbance spectra of the biohybrids, CdS/(Hyd+, DSH+) and CdS/(Hyd+), constructed after the 3-h (A, D), 10-h (B, E), and 20-h (C, F) CdS bioprecipitation periods. (A, B, C) The amounts of hydrogen formed, normalized by light irradiation area, from 30 mL reactions consisting of 0.5 g biohybrids, 100 mM BisTris-HCl (pH 5), and 5 mM methylviologen. Light source: AM1.5G solar light simulator (area, 3.5 cm × 3.5 cm; intensity, 1 sun = 100 mW cm−1). Plots and bars represent the average and the difference between the average and the maximum and minimum values calculated from two independent experiments. (D, E, F) Typical absorption spectra of the reaction suspension measured before the light irradiation reactions. The gray area represents the emissions from the light source.

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Honda Y.; Yamamoto M.; Shinohara Y.; Hatanaka Y.; Watanabe M.; Ishihara T.; Fujii H. (2025), Light-Driven Hydrogen Production in Genetically Engineered Cadmium Sulfide/Escherichia coli Biohybrids, ACS Applied Nano Materials, 8(44), 21294-21306, DOI: 10.1021/acsanm.5c03650.

Thin Film Ta-Oxynitride Semiconductor Architectures for Fundamental Investigations in Photoelectrocatalytic Water Splitting (PI Lippert T., Prof. Watanabe M.)

Hydrogen and its applications are very important technologies for our society, and possessing various methods for its production is key to security and economic stability in these sectors. Photoelectrocatalytic water splitting is a unique route for hydrogen generation in that it utilizes resources of abundant water, unlimited sunlight, and readily available materials such as oxynitride semiconductors. The ASPIRE project deals with charge transport at organic–inorganic interfaces, and it is important to understand how charges are transported in each material. This study addressed the interface between

oxynitride and NiO, which acts as a cocatalyst. Oxynitrides are popular candidates for photoactive material but suffer from degradation in corrosive electrolytes. In the endeavor to mitigate this, we employ crystalline thin film model systems fabricated by pulsed laser deposition to separate phenomena at interfaces from those in bulk. This work demonstrates novel fabrication, thorough characterization, and photoelectrochemical testing of two tantalum-containing oxynitride photoanodes, $CaTaO_xN_y$ (CTON) and $MgTa_2O_{6-x}N_x$ (MTON), in our specially designed multilayer architecture that involves TiN as a current collector and a NiOx overlayer as the oxygen evolution catalyst. The two systems show stability for over 4 h at 1.5 V_{RHE}, and the CTON photoanode possesses larger photoresponse. Subsequently, CTON is used to examine the effect of NiO_x overlayer thickness where it is found 2.5 nm maximizes photocurrent density. These results provide the scientific community with new model systems and demonstrate their use to improve catalysts for water splitting technology.

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Stephens K.J.; Worobiej E.; Streit Y.; Falqueto J.B.; Schneider C.; Müller A.M.; Vockenhuber C.; Yang D.; Watanabe M.; Pergolesi D.; Lippert T. (2026), Thin Film Ta-Oxynitride Semiconductor Architectures for Fundamental Investigations in Photoelectrocatalytic Water Splitting, ChemPhotoChem, 10(1), DOI: 10.1002/cptc.202500417.

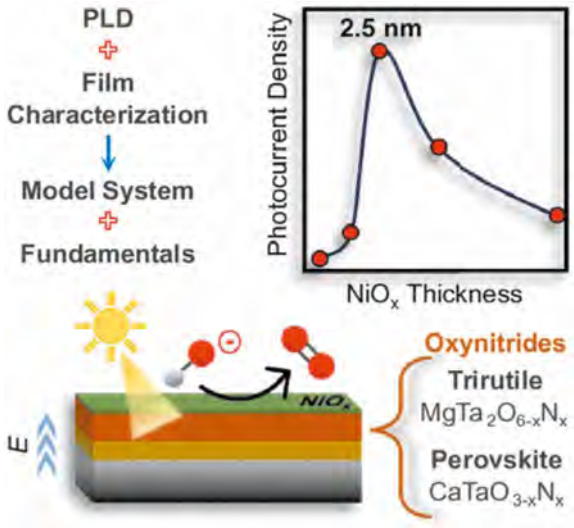


Fig. 7.2.3. This work incorporates crystalline thin films fabricated via pulsed laser deposition to study fundamentals of water splitting photoelectrocatalysis. Novel oxynitride films of perovskite $CaTaO_{3-x}N_x$ and trirutile $MgTa_2O_{6-x}N_x$ are paired with a NiO_x overlayer to test their performance and stability under oxygen evolution reaction conditions. The perovskite system is then utilized to discern the optimal thickness of NiO_x for the photoanode.

On the chemomechanics of bubble growth in hydrogen attack of plain carbon steels (PI Staykov A., PI Sofronis P., PI Kubota M.)

High temperature hydrogen attack (HTHA) is a form of degradation of carbon steels exposed to high temperature and high-pressure hydrogen whereby internal hydrogen reacting with carbides forms methane gas bubbles with an associated loss in strength and toughness due to decarburization. Grain boundary gas bubbles can grow and coalesce leading to microcrack formation and frequently to premature fracture. Current models mainly rely on the Grabke and Martin transient methane generation kinetics which is based on carburization/decarburization experiments on iron surface at temperatures between 600 °C and 800 °C, though those temperatures are much higher than those at which HTHA is observed in industrial processes. This work presents a coupled chemical kinetics and micromechanics model that addresses methane and hydrogen gas formation along with simultaneous decarburization and bubble growth over a wide temperature range. The energetics of the chemical reactions taking place at the ferrite-matrix/bubble interface are established through DFT calculations. Model calculations unveil the relationship between the rates of hydrogen migration to the bubble interface, carbon and hydrogen atom reactions for methane formation, and attendant volumetric bubble growth.

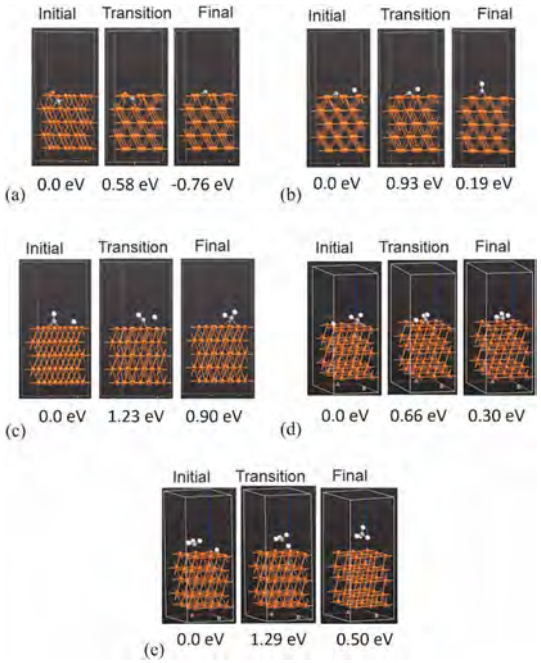


Fig. 7.2.4. Optimized initial and final geometries, and transition states for (a) carbon subsurface to surface migration, (b) CH formation, (c) CH_2 formation, (d) CH_3 formation, and (e) CH_4 formation.

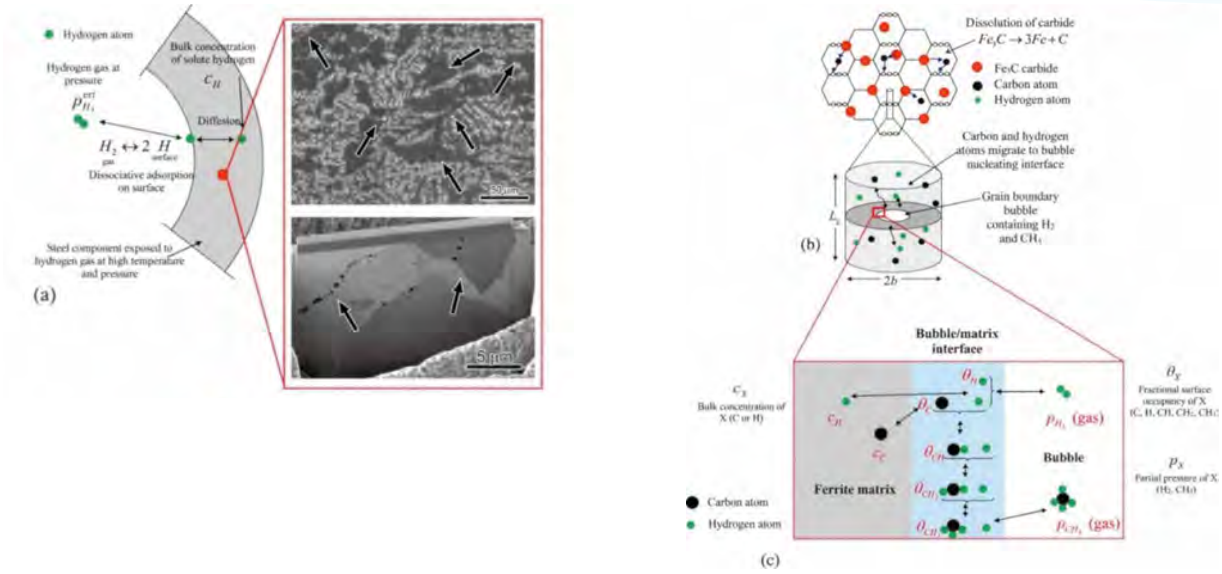


Fig. 7.2.5. Schematic of model to study the various processes during HTHA.

References
Vijayvargia K.; Nguyen T.; Dadfarnia M.; Staykov A.; Sofronis P.; Kubota M.; Martin M.L.; Pugh J.A. (2025), On the chemomechanics of bubble growth in hydrogen attack of plain carbon steels, Corrosion Science, 253, DOI: 10.1016/j.corsci.2025.112999.

Heterostructured oxides with d^{10} and s^0p^0 cations and high work function for photocatalytic CO_2 conversion (Prof. Edalati K., PI Ishihara T.)

Elements from the right side of the periodic table, including cations with d^{10} and s^0p^0 configurations, have been shown to improve photocatalytic activity either as dopants or principal elements. This study introduces the medium- and high-entropy oxide photocatalysts accommodating only d^{10} and s^0p^0 cations. The designated oxides, $AlZnGaO_4$ and $AlZnGaSnBiO_{7.5}$ (dual-phase heterostructure of $AlZnGaO_4$ and $1/2Sn_2Bi_2O_7$), demonstrate good optical properties and promising photocatalytic activity for O_2 conversion to methane compared to entropy-stabilized cations containing only d^0 or d^0+d^{10} configurations.

The good activity of these oxides was ascribed to their high work function, which was supported by experimental analysis and first-principles calculations. Moreover, $AlZnGaSnBiO_{7.5}$ exhibited enhanced activity compared to $AlZnGaO_4$ due to the creation of type II heterojunctions and resultant higher charge carrier separation and lifetime. This study, which combines materials science, theoretical chemistry and catalysis, introduces the significance of heterostructured d^{10}+s^0p^0 cationic configuration and high work function on the design of advanced photocatalysts with high activity for CO_2 conversion.

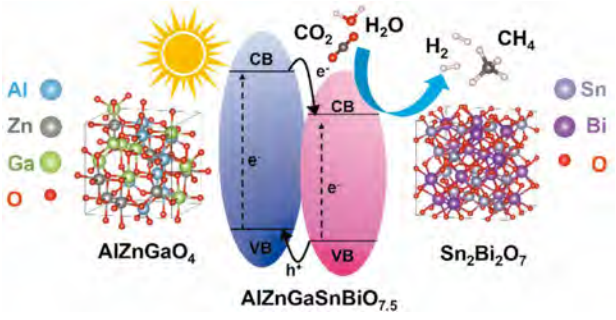


Fig. 7.2.6. Heterostructured oxides containing d^0 and s^0p^0 cationic configurations, as effective photocatalysts for CO_2 conversion.

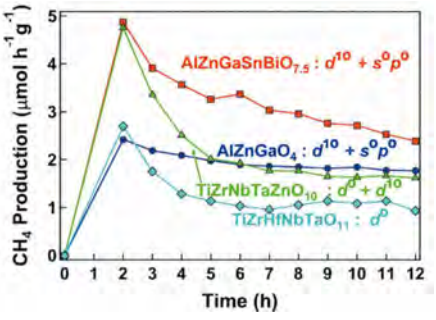


Fig. 7.2.7. Comparison of photocatalytic activity of $AlZnGaO_4$ and $AlZnGaSnBiO_{7.5}$ (d^{10}+s^0p^0 configuration) with $TiZrHfNbTaO_{11}$ (d^0 configuration) and $TiZrNbTaGaO_{10.5}$ (d^0+d^{10} configuration) for CH_4 generation from CO_2 conversion.

References
Hidalgo-Jiménez J.; Akbay T.; Watanabe M.; Saito K.; Guo Q.; Ishihara T.; Edalati K. (2025), Entropy-stabilized oxides with d^{10} and s^0p^0 cations as heterostructured photocatalysts with high work function: Experiments and first-principles calculations, Journal of Energy Chemistry, 111, 954-968, DOI: 10.1016/j.jechem.2025.08.033.

Anchor effect in photocatalytic water splitting using boron dipyrromethene-sensitizing dyes (Prof. Watanabe M.)

Regarding hydrogen production from water splitting using dye-sensitized photocatalysts, forming a stable organic-inorganic interface is an issue that must be achieved as a milestone at I^{2}CNER. Therefore, in this study, Professor Yuan Jay Chang from Tunghai University in Taiwan, who has deep knowledge of dye-sensitized solar cells and perovskite solar cells, was invited through a travel program (the National Science and Technology Council of Taiwan (113-2113-M-029-005 and 113-2113-M-029-001), and joint research was conducted.

Photocatalysis is an effective method for efficiently using solar energy and producing hydrogen through water splitting. In this study, we investigated an anchor group, chosen from carboxy, pyridyl, and tetrazole moieties, that easily attracts electrons from boron dipyrromethene (BODIPY) and injects them into titanium oxide (TiO_2) to synthesize a new dye-sensitized material for photocatalytic hydrogen production. The coordination of the sensitizers onto TiO_2 was examined through attenuated total reflection Fourier transform infrared spectroscopy. The energy potential of BODIPY sensitizers with respect to TiO_2 was analyzed using cyclic voltammetry and differential voltammetry. The molecular orbitals of the BODIPY sensitizers were analyzed using density functional theory. Visible-light-driven photocatalysis with ascorbic acid as the sacrificial electron donor demonstrated hydrogen production. The photocurrent test showed that photo-induced electrons were injected into TiO_2under visible light irradiation which supported dye-sensitized photocatalytic hydrogen production. The absorption spectra after the photocatalytic reaction showed no change in the pyridyl anchor group system, which suggested that the pyridyl-anchored dye-sensitized photocatalyst showed a good hydrogen production rate and stability.

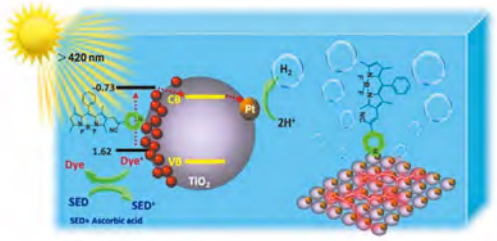


Fig. 7.2.8. Visible light–driven photocatalytic hydrogen production with ascorbic acid as the sacrificial electron donor showed the production of hydrogen. The photocurrent test showed photo-induced electrons into titanium oxide under visible light irradiation, which supported dye-sensitized photocatalytic hydrogen production. After the photocatalytic reaction, absorption spectra showed no change in the pyridyl anchor group system, suggesting that the pyridyl anchored dye-sensitized photocatalyst showed a good hydrogen production rate and stability.

References

Watanabe M.; Ono Y.; Shen X.-F.; Takagaki A.; Song J.T.; Chang Y.J.; Inada M.; Ishihara T. (2025), Anchor effect in photocatalytic water splitting using boron dipyrromethene-sensitizing dyes, Journal of the Chinese Chemical Society, 72(10), 1229-1237, DOI: 10.1002/jccs.70098.

Interdisciplinary Design of Perovskite Photodetectors with Ultrahigh Sensitivity and Wide Dynamic Range (Prof. Matsushima T.)

I am studying perovskite-based photodetectors to achieve high performance in light sensing, especially under low-light conditions. This research is inherently interdisciplinary, as it integrates chemistry, materials science, physics, and device engineering. I designed and synthesized functional materials, investigated their electronic and optical properties, and incorporated them into working devices to evaluate their performance. In addition, advanced characterization and analysis were conducted using state-of-the-art facilities at The University of Queensland, enabling a deeper understanding of device operation mechanisms across multiple scientific domains. Through this approach, I also extended knowledge developed in perovskite solar cells to photodetector systems, demonstrating the transfer of concepts across different device platforms.

In this study, I developed a photodetector with a wide dynamic range and high sensitivity to very weak light. I systematically investigated how different hole-transport materials influence device performance, linking molecular design to macroscopic device behavior. One material enabled efficient charge extraction but required additives, while another provided better intrinsic stability with suitable charge transport properties. As a result, the devices achieved detection of extremely weak light down to the picowatt per square centimeter level and exhibited a wide dynamic range of up to 200 dB. Furthermore, comprehensive analysis revealed that electrical conductivity, energy level alignment, and ion migration play critical roles in determining device performance. These findings highlight how the integration of multiple disciplines is essential to understand and optimize complex optoelectronic systems.

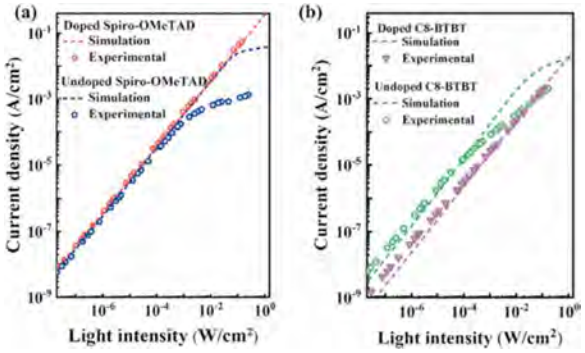


Fig. 7.2.9. Realization of excellent photodetector performance from perovskite solar cells

References
Khanikar P.D.; Shah S.; Shukla A.; Cole C.M.; Guo Z.; Das S.; Lo S.-C.; Matsushima T.; Namdas E.B. (2025), Unified Approach to Sensitive and Fast Perovskite Photodetectors Featuring an Ultrawide Linear Dynamic Range, Advanced Optical Materials, 13(36), DOI: 10.1002/adom.202501967.

Prospective Techno-Economic Analysis of Scalable Protonic Ceramic Fuel Cell Fabricated via Strontium Substrate-Mediated Co-Sintering (Prof. Kwati L.)

One of the main challenges with PCFC/PCECs is the high sintering temperature of electrolyte-electrode assemblies. This limitation affects material performance and raises production costs. In this study, we proposed co-sintering the electrolyte with the strontium-containing porous fuel electrode as a viable solution. Additionally, we determined the acceptable manufacturing cost for a 5 kW-class PCFC module, with a focus on social implementation. The assessment accounts for a scalable tape-casting process and a detailed manufacturing process design.

Co-sintering our $BaZr_{0.44}Ce_{0.36}Y_{0.2}O_{3-\delta}$ electrolyte with a Sr-based substrate at 1350°C significantly shapes the microstructure and transport properties of the final half-cell assembly. This effect directly impacts proton transport, fuel cell performance, cell stack efficiency, and, ultimately, the cost of module production. Electrochemical tests at 600°C indicate power densities of 630 mW/cm² at 0.7V for half-cells sintered at 1350°C, while those sintered at 1450°C show a peak of 530 mW/cm².

Using data from the as-fabricated cells, we estimated the manufacturing costs for a residential 5-kW AC module. The base-case production cost per module, assuming hydrogen as the fuel and an annual production rate of 10k units, is $3,290. However, this cost drops to approximately $1,570 per module when production scales to 50k units per year. Cells sintered at 1350°C achieve 2% pt higher efficiency and reduce module manufacturing costs by 0.2% compared with those sintered at 1450°C. This improvement is supported by electrochemical modeling that accounts for leakage current at OCV and polarization at 0.5 A/cm². At a higher current density of 1 A/cm², these differences in efficiency and module production cost were more pronounced, 9% and 8%, respectively, due to a preserved anode microstructure and reduced Ni degradation, which enhances proton conductivity in the electrolyte.

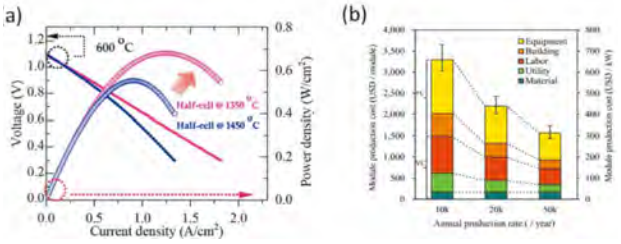


Fig. 7.2.10. (a) *I–V* and the corresponding power density comparison at 600°C for the half-cell sintered at 1350°C and 1450°C (b) Production costs of a 5 kW (AC) class PCFC module (FC: fixed cost, VC: variable cost). (footnotes) Note Error bar: The fixed costs (FC), including equipment and building costs, have an accuracy range of −15% on the low side and +20% on the high side.

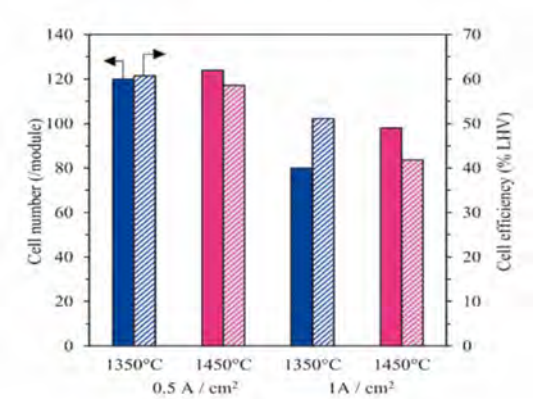


Fig. 7.2.11. The effects of sintering temperature on cell performance and the required number of cells at 600°C. (blue) The case of PCFCs with the half-cell sintered at 1350°C and (pink) 1450°C.

References
Kwati L.; Yamate S.; Menzler N.H.; Meulenberg W.A.; Otomo J. (2026), Prospective techno-economic analysis of scalable protonic ceramic fuel cell fabricated via strontium substrate-mediated co-sintering, Applied Energy, 416, DOI: 10.1016/j.apenergy.2026.127950.

Discovery of effective passivation molecules for perovskite solar cells using generative AI (Prof. Fajar A.T.N., Prof. Matsushima T., Prof. Guo Z.)

*Interdisciplinary: *Integration of advanced AI* methods *(generative language models) to accelerate innovation in perovskite solar cells.*

Molecular passivation is an effective strategy to suppress interfacial defects in perovskite solar cells (PSCs), yet the discovery of new passivation molecules remains limited by empirical design and narrow chemical libraries. Here, we present an AI-driven framework that integrates discriminative and generative language models to accelerate the discovery of effective passivators. A SMILES-X classifier trained on literature data achieved strong predictive performance (F1 = 0.80, ROC–AUC = 0.88). In parallel, a GPT-2–based generative model iteratively produced over 100,000 novel molecules, more than 80% of which were predicted to be effective. Multi-criteria filtering reduced this pool to ~8,000 high-quality candidates, and clustering analysis further identified ten diverse representatives. From these, three molecules were prioritized for experimental

validation, and all exhibited clear passivation effects. In particular, 4-maleimidobutyric acid increased the open-circuit voltage from 1.08 V to 1.12 V and improved power conversion efficiency from 19.3% to 22.2%, while markedly reducing hysteresis. This study demonstrates that generative AI can autonomously propose synthetically accessible and functionally effective molecules for PSC passivation, offering a powerful paradigm for accelerated materials discovery beyond conventional chemical space exploration.

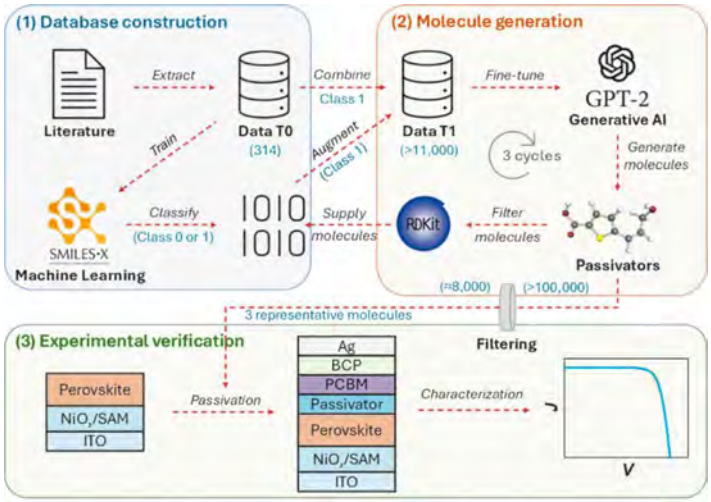


Fig. 7.2.12. Workflow of the AI-driven framework for passivation molecule discovery and experimental validation, including (1) database construction and classifier training (SMILES-X), (2) GPT-2–based molecular generation with iterative filtering, and (3) experimental verification in perovskite solar cells.

References

Fajar A.T.N.; Lambard G.; Manopo J.; Guo R.; Septioga K.; Pari R.F.; Matsushima T.; Guo Z. (2026), Generative AI-Driven Accelerated Discovery of Passivation Molecules for Perovskite Solar Cells, Advanced Science, DOI: 10.1002/advs.202523042.

Multiscale Science and Engineering for Energy and the Environment (MSEEE)

Comparative analysis of MOF-303 and silica gel adsorption cooling in a novel bed design (PI Saha B.B.)

Adsorption cooling is a promising sustainable technology, but its performance is often limited by bed-scale heat and mass transfer and the low uptake of conventional adsorbents such as silica gel. Here, a transient two-dimensional model was developed in Ansys Fluent to simulate adsorption, preheating, desorption, and cooling for a complete bed. The model shows that MOF-303 delivers an adsorption-capacity swing about three times higher than silica gel, reaching ~0.06 versus 0.02 kg/kg under identical conditions. Performance improves with external heat transfer up to about 700 W m^{-2} K^{-1} and is strongly influenced by heating water temperature. At 90 °C, MOF-303 achieves a specific cooling power of about 241 W kg^{-1}. This interdisciplinary work integrates materials science, thermal engineering, and energy science to advance efficient adsorption cooling and sustainable energy system design.

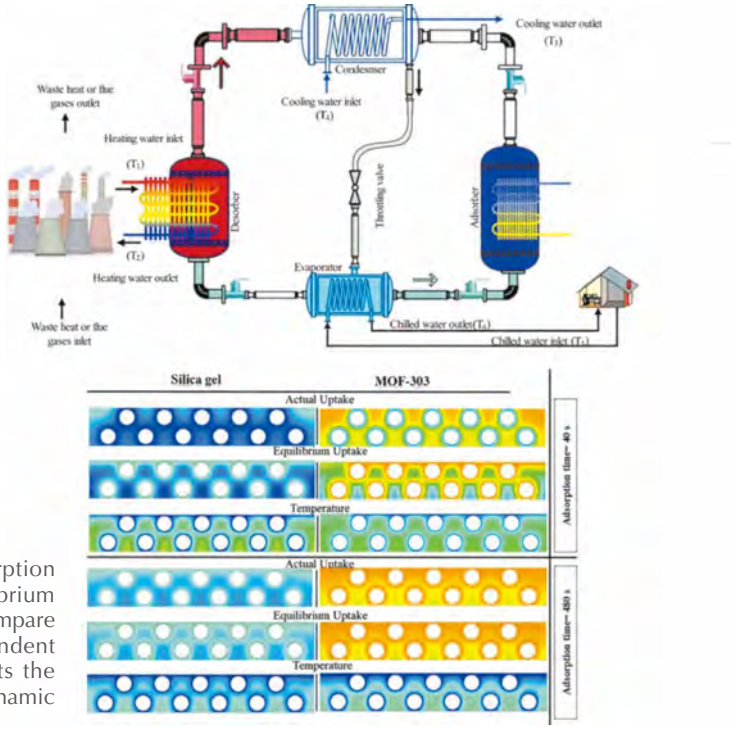


Fig. 7.3.1. The figure presents a solar-powered innovative adsorption cooling cycle, together with the contours of actual uptake, equilibrium uptake, and temperature for silica gel and MOF-303. The results compare adsorption behavior at 40 s and 480 s, showing the time-dependent development of mass transfer and thermal fields. This highlights the distinct performance characteristics of the two adsorbents under dynamic operating conditions.

References

Abu El-Maaty A.E.; Ben-Mansour R.; Saha B.B. (2026), Comparative analysis of MOF-303 and silica gel adsorption cooling system using cycle-resolved CFD modeling of a novel bed design, Energy Conversion and Management, 356, DOI: 10.1016/j.enconman.2026.121382.

Upcycling waste polyoxymethylene to value-added chemicals using reusable polymeric acid catalysts at ppm levels (PI Chapman A.J., Prof. Maeda N. Dr. Carlson J.T.)

This work presents a scalable and chemically efficient strategy for the upcycling of waste polyoxymethylene (POM) into value-added chemicals using a reusable polymeric acid catalyst (PAFR II) under mild, solvent-free conditions. The study demonstrates that extremely low catalyst loadings (ppm-level sulfur content) can achieve near-quantitative depolymerization of POM into useful products such as cyclic acetals, dialkoxymethanes, and higher-value compounds (e.g., pillar[5]arenes, insecticides, herbicides). The process is versatile across feedstocks, including consumer plastics, microplastics, and carbon-fiber-reinforced polymers (CFRPs) and is effective at scales up to 40 g, while maintaining catalyst recyclability over multiple cycles without loss of activity. Microwave-assisted heating further enhances efficiency, achieving up to 99% conversion while reducing energy demand.

The interdisciplinary nature of this research is central to its contribution. From a chemistry perspective, it develops a novel heterogeneous catalytic system with high activity, stability, and mechanistic insight into acid-catalyzed depolymerization pathways. From a plastic recycling and engineering standpoint, it tackles real-world waste streams, scalability, and process design (including microwave-assisted energy input and catalyst reuse), bridging laboratory chemistry with practical waste management challenges. Finally, the integration of life cycle assessment (LCA) provides a systems-level evaluation of environmental performance, quantifying a substantial reduction in greenhouse gas emissions (1.88 vs. 6.08 kg CO_2-eq per kg product compared to conventional synthesis).

By combining these domains, the study moves beyond isolated technical innovation to demonstrate a viable pathway toward carbon-neutral plastic recycling. The coupling of catalytic efficiency, process scalability, and quantified environmental benefits exemplifies how interdisciplinary approaches are necessary to transition from linear plastic use toward a circular, low-carbon materials economy.

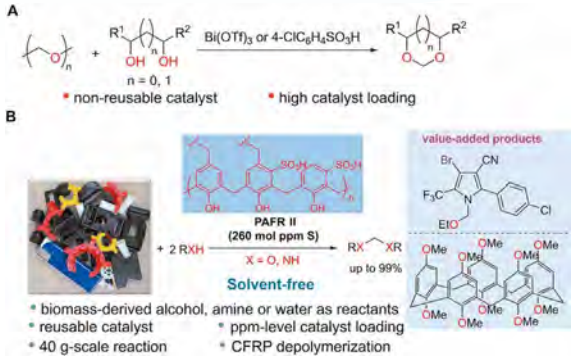


Fig. 7.3.2. Representative examples of POM upcycling using alcohol. (A) Upcycling of POM using homogeneous catalysts. (B) Upcycling of POM using a reusable polymeric acid catalyst (this study).

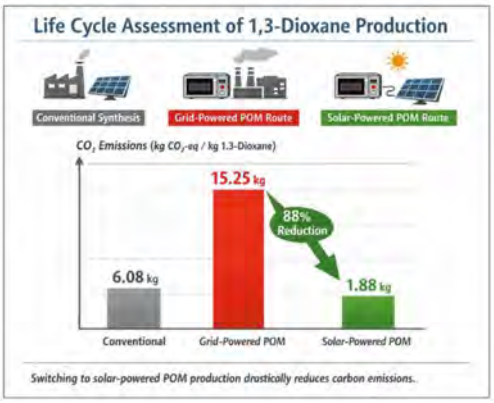


Fig. 7.3.3. Life Cycle Assessment (LCA) results derived comparing multiple routes of POM recycling.

References
Sen A.; Ohno A.; Chapman A.; Xu Y.; Zhang J.; Maeda N.; Carlson J.T.; Yamada Y.M.A. (2026), Upcycling waste polyoxymethylene to value-added chemicals using reusable polymeric acid catalysts at ppm levels, Green Chemistry, 28(6), 2814-2821, DOI: 10.1039/d5gc06065f.

Contrastive self-supervised learning for lightweight and automated fault detection and diagnosis in HVAC systems (Prof. Gao Y.)

This work represents an interdisciplinary fusion of building energy engineering, HVAC fault diagnostics, time-series representation learning, and self-supervised artificial intelligence. The study reformulated HVAC fault detection and diagnosis as a time-series representation learning problem and proposed a lightweight contrastive self-supervised framework that can learn robust diagnostic features under scarce labels and limited computational resources. Compared with conventional supervised baselines, the proposed method achieved substantially higher diagnostic accuracy and macro-F1 while reducing memory demand by 90–97% and shortening training time by 20–25%. This study is considered interdisciplinary because it integrates domain knowledge of HVAC system operation with advanced machine learning theory and deployment-oriented model design, thereby bridging energy systems engineering and modern data-centric AI.

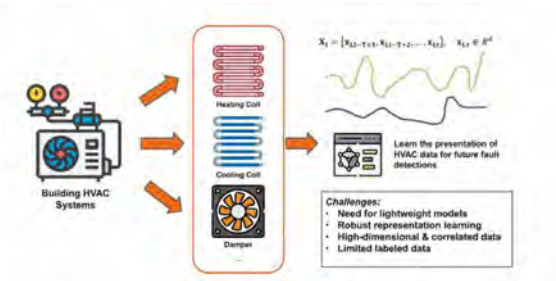


Fig. 7.3.4. Overview of the proposed automated HVAC fault detection and diagnosis setting, where multivariate sensor streams from HVAC subsystems are used to learn transferable time-series representations for robust and lightweight diagnosis.

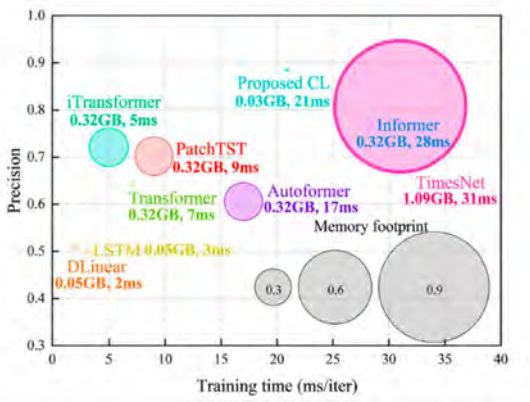


Fig. 7.3.5. Precision–efficiency trade-off comparison showing that the proposed contrastive self-supervised framework achieves strong diagnostic performance while maintaining substantially lower computational cost, highlighting its practical value for deployment in real HVAC systems.

References
Gao Y.; Hu Z.; Otomo J.; Ke Y. (2026), Contrastive self-supervised learning for lightweight and automated fault detection and diagnosis in HVAC systems, Applied Energy, 410, DOI: 10.1016/j.apenergy.2026.127557.

Real-time observation of electrochemically generated nanobubbles and micropancakes with partial contact-line pinning (Prof. Teshima H.)

For optimizing phase-change heat transfer devices and hydrogen energy devices, it is essential to understand the mechanisms underlying the formation of nanometer-sized bubbles (nanobubbles) on electrode surfaces. In this study, we used high-speed atomic force microscopy to visualize the nucleation, growth, and dissolution of nanobubbles, micropancakes, and nanobubble-on-pancake structures during potential sweeps. We found that these gaseous phases exhibit completely different behaviors at

the anode and cathode. We also obtained results that differ markedly from previous experimental observations and theoretical predictions reported on nanobubbles using conventional AFM with limited temporal resolution; however, these discrepancies can be reasonably explained by considering nanoscale wetting and interfacial phenomena. This work was made possible by combining cutting-edge high-speed AFM measurements with electrochemical techniques developed by our collaborators at Hokkaido University and my own deep expertise in nanoscale bubble dynamics and interfacial phenomena. None of these elements alone would have been sufficient to accomplish this study. I believe this work represents an interdisciplinary achievement that bridges electrochemistry and interfacial science through nanoscale measurement technology.

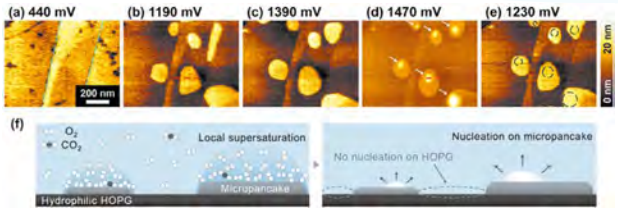


Fig. 7.3.6. (a–e) HS-AFM images of the formation and dissolution processes of nanobubble-on-pancake structures on HOPG at the following potentials: (a) 440 mV, (b) 1190 mV, (c) 1390 mV, (d) 1470 mV, and (e) 1230 mV. (f) Schematic illustration of the formation pathway of the nanobubble-on-pancake structures via local supersaturation during anodic sweep. Structures are not represented to scale for clarity.

References
Ohashi R.; Teshima H.; Naganuma T.; Cheng Y.C.; Ueda M.; Matsushima H. (2026), Real-time observation of electrochemically generated nanobubbles and micropancakes with partial contact-line pinning, Applied Surface Science, 725, DOI: 10.1016/j.apsusc.2025.165746.

Empowering women to combat energy poverty in South Asia (Prof. Karmaker S.C., PI Chapman A.J.)

This research is inherently interdisciplinary as it integrates concepts, theories, and methods from multiple fields to address the complex issue of energy poverty. It combines insights from energy economics and environmental studies to understand access to modern energy services, while incorporating perspectives from gender studies and development economics to examine the role of women's empowerment in shaping household energy decisions. The study also employs advanced econometric techniques from applied statistics and data science to establish causal relationships using large-scale survey data. By linking social, economic, and energy-related dimensions, the research provides a comprehensive framework that bridges disciplinary boundaries and supports more effective, gender-responsive policy design for sustainable development.

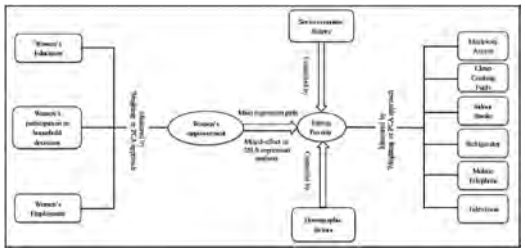


Fig. 7.3.7. The analysis reveals a significant decline in energy poverty over time, closely associated with rising levels of women's empowerment. Despite this progress, a persistent urban–rural gap remains, largely due to limited access to modern energy services and clean cooking fuels in rural areas, highlighting the need for targeted interventions. Importantly, the findings confirm a strong negative relationship between MWE scores and energy poverty, with substantial reductions observed in India, Nepal, and Pakistan among highly empowered households. This underscores the critical role of women's education, employment, and decision-making power in advancing clean energy transitions and reducing household energy poverty.

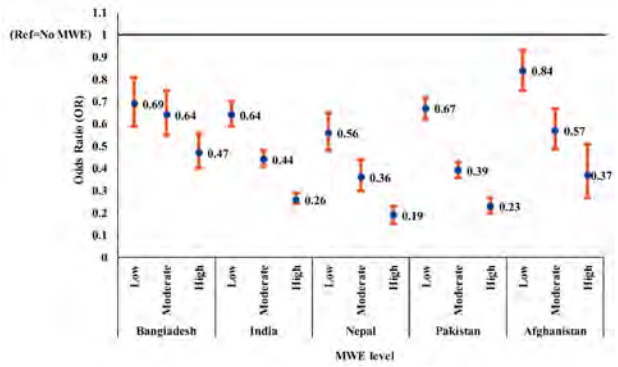


Fig. 7.3.8. The results indicate a strong and consistent negative association between MWE scores and household energy poverty across all countries analyzed. In Bangladesh, households with low, moderate, and high MWE scores were 31%, 36%, and 53% less likely to experience energy poverty, respectively, compared to those with no empowerment. A similar pattern is observed in other countries, where households with high MWE scores experienced substantial reductions in energy poverty, 74% in India, 81% in Nepal, 77% in Pakistan, and 63% in Afghanistan. These findings underscore the significant role of women's empowerment in mitigating household energy poverty across South Asia.

References
Karmaker S.C.; Sen K.K.; Singha B.; Chapman A.J.; Bari W.; Hosan S.; Saha B.B. (2025), Empowering women to combat energy poverty in South Asia, Energy, 338, DOI: 10.1016/j.energy.2025.138765.

Advanced Energy Materials (AEM)

Cooperation of Two Metal Centers in a CO_2 Electroreduction Catalyst: Flexible Electron Manipulation and Adaptive Coordination on a Dinuclear Cobalt Complex (Prof. Donoshita M., PI Yamauchi M.)

Metal complexes with flexible redox and coordination properties possibly act as ingenious electrocatalysts to activate stable molecules such as CO_2. To date, most studies have focused on mononuclear complexes in electrochemical CO_2 reduction (eCO_2R). However, the development of electrocatalysts that operate at low overpotentials while maintaining high selectivity remains a critical challenge. Herein, we clarified that the use of a dinuclear metal complex exhibiting cooperation of two metal centers can be an effective strategy for addressing this issue. The focused catalyst is a Co^{II} dinuclear complex (2) bearing two CoII ions in close proximity, whose coordination environment is similar to that of a typical mononuclear complex, Co^{II} tetraphenylporphyrin (1). Based on experimental and computational studies, it was clarified that **2** exhibits simultaneous two-electron reduction prior to CO_2 activation, which allows bypassing the reaction step that hinders the catalytic cycle on **1**. Furthermore, metal-to-metal electron transfer and a CO_2-derived intermediate bridging over two metal centers are found in the catalytic cycle of **2**, which would contribute to low activation barrier. It is then concluded that the cooperative functions of the two metal centers are the key to the efficient eCO_2R performance.

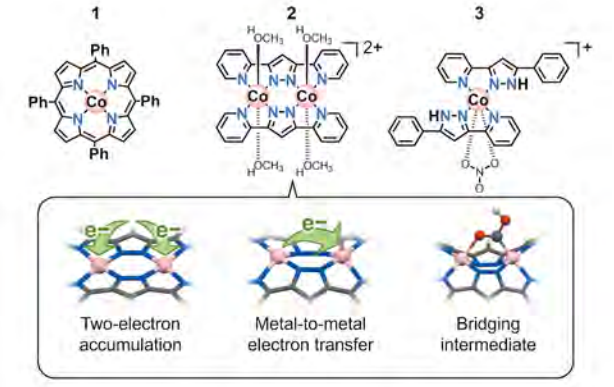


Fig. 8.1.1. Molecular structures of **1** (top left), **2** (top center), and **3** (top right) investigated in this research. The bottom part represents the characteristic properties of **2**.

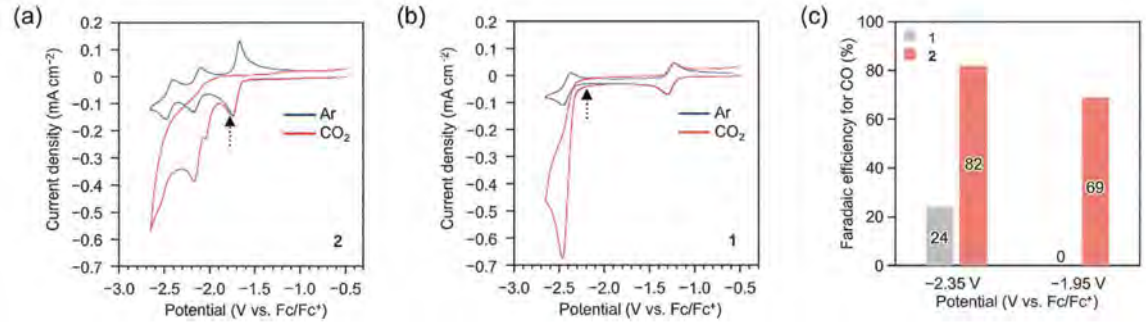


Fig. 8.1.2. Cyclic voltammograms of (a) **2** and (b) **1**, where the data recorded in Ar and CO_2 are shown in red and blue lines, respectively. The difference in the current density in the voltammograms recorded in Ar and CO_2 represents the eCO_2R activity. 2 exhibits eCO_2R at more positive potential compared to **1**, indicating that **2** can promote eCO_2R more energy-efficiently. Figure (c) represents the Faradaic efficiency for CO at −2.35 and −1.95 V vs Fc/Fc^+, which indicates that **2** can produce CO from CO_2 at more positive potential compared to 1 with high product selectivity.

References

Pan Y.; Donoshita M.; Kametani Y.; Shiota Y.; Wu S.-Q.; Sato O.; Yamauchi M. (2025), Cooperation of Two Metal Centers in a CO_2 Electroreduction Catalyst: Flexible Electron Manipulation and Adaptive Coordination on a Dinuclear Cobalt Complex, Advanced Science, 12(46), DOI: 10.1002/advs.202508361.

Advanced Energy Conversion Systems (AECS)

Interfacial dipole engineering by self-assembled molecules in n-i-p and p-i-n perovskite solar cells (Prof. Guo Z., Prof. Matsushima T.)

Self-assembled molecules hold great promise for realizing highly efficient and durable perovskite solar cells. However, their use has been largely limited to the bottom interface of perovskite films, and their application to the top surface remains poorly understood. In this work, we developed two self-assembled molecules and achieved ordered and uniform molecular packing on the perovskite top surface. By demonstrating that these molecules can be applied to both the bottom and top interfaces of perovskite films, we clearly show that their primary function (as well as that of previously reported self-assembled molecules) is dipole-driven interfacial modulation, which facilitates hole transfer and optimizes the surface energetics of perovskites. As a result, we achieved a power conversion efficiency of 26.18%, together with improved operational durability.

This result contributes to the Thrust roadmap (Project 5), in which achieving >26% power conversion efficiency for lead-based perovskite solar cells is set as a milestone for 2025–2030.

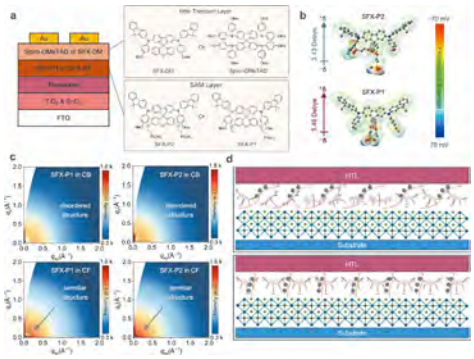


Fig. 8.2.1. Fundamental properties and stacking behavior of Self-assembled molecules (SAMs). (a) Device architecture of the perovskite solar cells. (b) ESP distributions and molecular dipole moments of SFX-P2 and SFX-P1 SAMs calculated by DFT. (c) 2D GIWAXS patterns of SFX-P1 and SFX-P2 films fabricated using CB or CF as the solvent. (d) Schematic illustration of the proposed molecular assembly behavior and hole transport characteristics of SAM layers fabricated with CB (first row) and CF (second row) solvents.

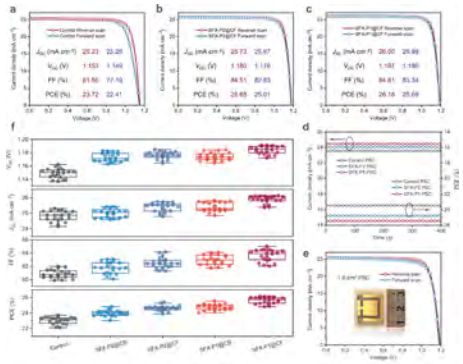


Fig. 8.2.2. Photovoltaic performance. (a) *J-V* curves of champion PSCs using SFX-DM as HTL without SAM modifications. (b) *J-V* curves of champion PSCs using SFX-DM as HTL with SFX-P2 SAM modification. (c) *J-V* curves of champion PSCs using SFX-DM as HTL with SFX-P1 SAM modification. (d) Stabilized PCE and J_{SC} of champion PSCs using SFX-DM as HTL without and with SFX-P2 or SFX-P1 SAM modifications. e *J-V* curves of PSCs using SFX-DM as HTL with SFX-P1 SAM modification, with an active area of 1 cm^2. (f) Statistical photovoltaic parameters of PSCs using SFX-DM as HTL without and with SAM modifications.

References

Zhai M.; Wu T.; Du K.; Chen C.; Shibayama N.; Narmandakh K.; Khan A.H.H.; Wang Y.-C.; Shang J.; Staykov A.; Song J.T.; Ida S.; Wang P.; Yamada S.; Tamada K.; Zhao S.; Wang A.; Guo Z.; Matsushima T.; Miyasaka T.; Cheng M. (2026), Interfacial dipole engineering by self-assembled molecules in n-i-p and p-i-n perovskite solar cells, Nature Communications , 17(1), DOI: 10.1038/s41467-026-69198-2.

Alkaline water electrolysis using iodine redox species (Prof. Tomisaki M., PI Matsumoto H.)

Water electrolysis using iodine redox species aiming to produce hydrogen efficiently without using a membrane was investigated. In order to restrain the oxygen evolution reaction, iodide ions were added to the electrolyte. As the oxidation reaction of iodide ions occurs in lower potential than the oxygen evolution reaction, iodide ions were oxidized with high efficiency suppressing the oxygen evolution. By adding chromate species into the solution, reduction reaction of iodate ions on cathode was restrained, and hydrogen was selectively produced from cathode. Both iodate ions and hydrogen were obtained efficiently and selectively.

References

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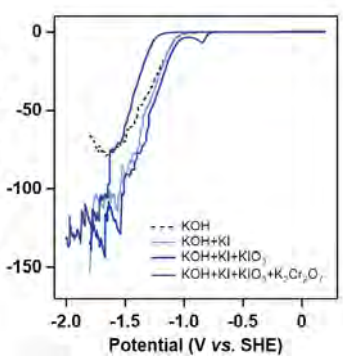


Fig. 8.2.3. Linear sweep voltammograms obtained by using Ni electrodes in aqueous solutions containing KOH, KI, KIO_3, or $K_2Cr_2O_7$.

Acceleration effect of gaseous CO_2 on photobiocatalytic H_2 formation (Prof. Ohsaki Y.)

Enzymes, which are biocatalysts, can carry out chemical reactions that are artificially difficult without high energy consumption at ambient temperature and pressure with high conversion efficiency. However, enzymes are often unstable because they are sensitive to the external environment, and their conversion rates are often slow. Therefore, we focus on the inorganic / whole-cell bio hybrid photocatalyst system. This system uses bacteria to protect enzymes from the external environment and combined photocatalyst to improve the catalytic reaction rate. In this research, we focused on hydrogenase that converts water into hydrogen. Our system that combined *Escherichia coli* (*E. coli*) expressing hydrogenase as a bio catalyst, TiO_2 as a photocatalyst, and methyl viologen (MV^{2+}) as an electron mediator that connects them, was irradiated with light from a Xe lamp under Ar and CO_2 atmospheres. Hydrogen formation was not observed under dark condition, but it was confirmed when the photobiocatalytic system was irradiated the Xe lamp. And under gaseous CO_2 condition, H_2 formation rate increased by 283% compared to under Ar condition. Subsequent investigations revealed that MV^{2+} becomes more easily penetration into bacteria. The penetration of the electron mediator into the bacteria is a bottleneck in the combination of photocatalyst and biocatalyst, and we have obtained results that will lead to an improvement in this bottleneck.

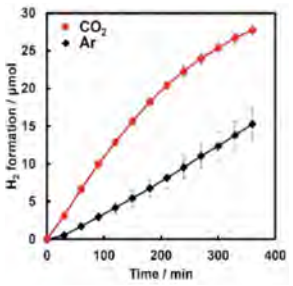


Fig. 8.2.4. This graph shows comparison of the amount of hydrogen formation in our system combining TiO_2 and E. coli expressing hydrogenase under CO_2 atmosphere and under Ar atmosphere. It was found that photobiocatalytic reaction under gaseous CO_2 condition, H_2 formation rate increased by 283%, and the amount of H_2 formation increased by 105% at 300 min compared to under Ar atmosphere.

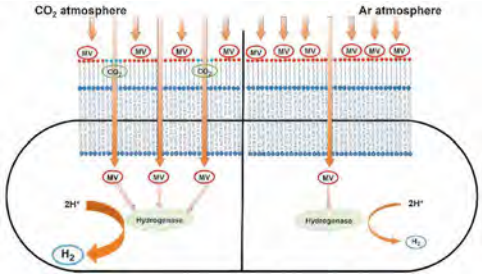


Fig. 8.2.5. This graph shows the image of the CO_2 effect. Result of zeta potential measurement showed the gaseous CO_2 neutralizes the negative potential of the cell membrane surface. Therefore, we propose that the lipopolysaccharide on the surface was neutralized, and as a result, the cell membrane surface became slightly unstable, which promoted the penetration of MV^{2+}.

References

Ohsaki Y.; Kosem N.; Song J.T.; Watanabe M.; Inada M.; Ishihara T. (2026), Acceleration effect of gaseous CO_2 on photobiocatalytic H_2 formation by water splitting, Biocatalysis and Biotransformation, DOI: 10.1080/10242422.2026.2619122.

Unlocking Dual Functionality in Triazine-Based Emitters: Synergistic Enhancement of Two-Photon Absorption and TADF-OLED Performance with Electron-Withdrawing Substituents (Prof. Chitose Y.)

In this study, we established a rational molecular design strategy to overcome the intrinsic trade-off between two-photon absorption (2PA) and thermally activated delayed fluorescence (TADF) by introducing electron-withdrawing substituents into the CzTRZ framework. The EWICT effect enabled precise control of charge-transfer (CT) character in both ground and excited states, allowing the simultaneous realization of high 2PA cross-sections, fast RISC, and efficient TADF emission without sacrificing oscillator strength. Notably, CzTRZCN exhibited a large μ_{01}, a high σ_2 of up to 200 GM, a fast k_{RISC}, and an EQE of 13.5% in OLED devices, along with high two-photon brightness. These findings highlight the effectiveness of electronic modulation via substituents, rather than geometric twisting, as a key design principle for high-performance 2PA–TADF materials. This work provides a versatile platform for advanced optoelectronic and bioimaging applications and opens new directions for the development of multifunctional organic emitters.

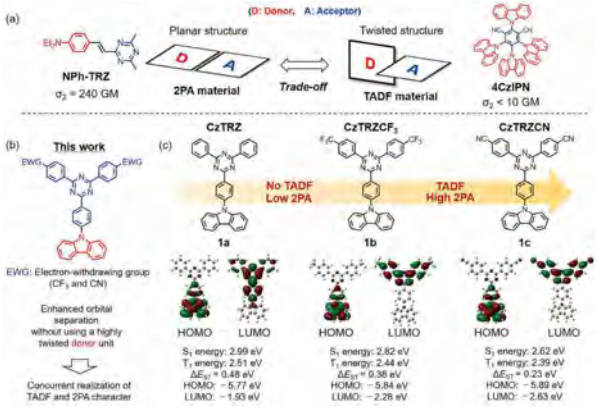


Fig. 8.2.6. a) The trade-off in the molecular design between 2PA and TADF materials. b) Molecular design concept in this work. c) Chemical structures of the designed CzTRZ derivatives, their frontier molecular orbitals, and the corresponding energy levels calculated at the PBE0/6-31G(d,p) level of theory with the polarizable continuum model (PCM) with toluene as the solvent.

References
Chitose Y.; Mageswari G.V.; Zenke R.; Ide T.; Kohata S.; Lin J.-H.; Lin T.-C.; Tsuchiya Y.; Adachi C. (2025), Unlocking Dual Functionality in Triazine-Based Emitters: Synergistic Enhancement of Two-Photon Absorption and TADF-OLED Performance with Electron-Withdrawing Substituents, Advanced Materials, 37(44), DOI: 10.1002/adma.202509857.

Coumarin 343 – modified TiO_2 in Photobiocatalytic Hydrogen Production (Dr. Kosem N.)

The development of efficient and sustainable systems for solar-to-hydrogen (H_2) conversion remains a significant challenge in the transition toward clean energy. In this study, we report the first application of the organic dye coumarin 343 (C343) as a visible-light photosensitizer in a hybrid photobiocatalytic system for H_2 production. Our results demonstrate that C343 exhibits superior photostability under solar irradiation and higher methyl viologen (MV^{2+}) reduction activity compared to eosin Y and carboxyeosin. To improve solar energy utilization, C343 was immobilized onto TiO_2 nanoparticles to form a dye-sensitized photocatalyst (C343–TiO_2). This system efficiently transfers photoexcited electrons to MV^{2+} under visible light. Furthermore, coupling C343–TiO_2 with recombinant *E. coli* as a whole-cell biocatalyst enabled efficient H_2 production under biocompatible conditions (100 mM L-cysteine, pH 8, 2 mg/mL C343–TiO_2, 5 mM MV^{2+}, and 5 mg/mL cells under 100 mW/cm² light). The system achieved a solar-to-H_2 conversion efficiency of 2.69%, significantly higher than that of pristine TiO_2 (1.81%). This work establishes a novel photobiocatalytic platform based on a stable organic dye, offering a promising strategy for solar-to-fuel conversion via integrated inorganic–biological systems.

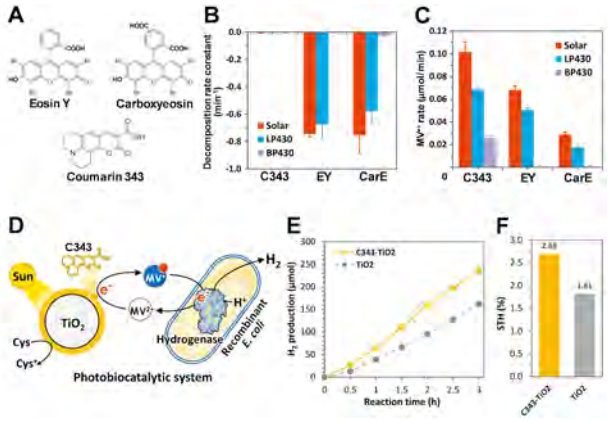


Fig. 8.2.7. The schematic illustrates a hybrid photobiocatalytic system for H_2 production using C343–TiO_2 coupled with hydrogenase-expressing *E. coli*. (A) Chemical structures of eosin Y, carboxyeosin, and coumarin 343 (C343). (B) Decomposition rate constants of each dye under irradiation. (C) Methyl viologen (MV^{2+}) reduction capacity of each dye. (D) Schematic representation of the photobiocatalytic H_2 production system based on C343–TiO_2 coupled with recombinant *E. coli*. (E) Kinetic H_2 production in the hybrid system using C343–TiO_2 compared with pristine TiO_2. (F) Solar-to-H_2 (STH) conversion efficiency of C343–TiO_2 versus pristine TiO_2.

References
[1] Shang J.; Kosem N.; Kayo Y.; Shen X.-F.; Matsuyama S.; Watanabe M.; Inada M.; Ishihara T.; Staykov A. (2025), Improved charge transfer performance of eosin Y-sensitized anatase TiO_2 by anchoring group modification: from theoretical design to experiment, Journal of Materials Chemistry A, DOI: 10.1039/d5ta05712d.
[2] Kosem N.; Ohsaki Y.; Watanabe M.; Song J.T.; Ishihara T. (2026), Coumarin 343 – modified TiO_2 in Photobiocatalytic Hydrogen Production. (Manuscript under preparation.).

Heteroatom engineering of ortho-fluorinated triarylamine based hole transport materials for enhanced performance in perovskite solar cells (Dr. Raju T.B., Prof. Watanabe M., Prof. Guo Z., Prof. Matsushima T.)

The development of cost-effective and high-performance charge transport materials is of paramount importance for advancing the commercialization of perovskite solar cells (PSCs). In this study, we present three cost-effective hole transport materials (HTMs) featuring strategically engineered intramolecular noncovalent interactions, which collectively enhance both the efficiency and stability of PSCs.

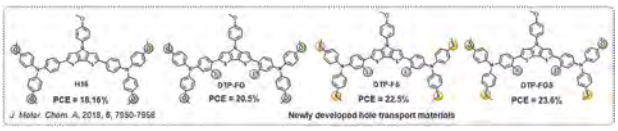


Fig. 8.2.8. Chemical structures of the newly developed HTMs, DTP-FO, DTP-FS, and DTP-FOS.

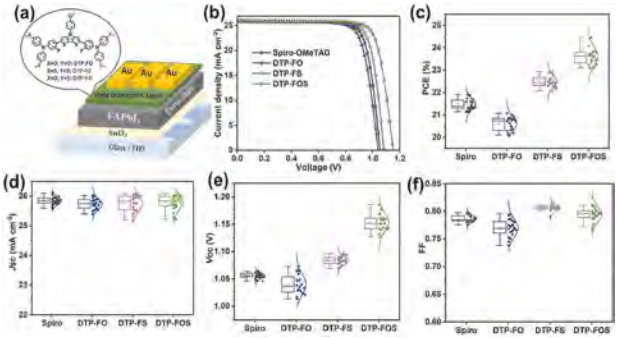
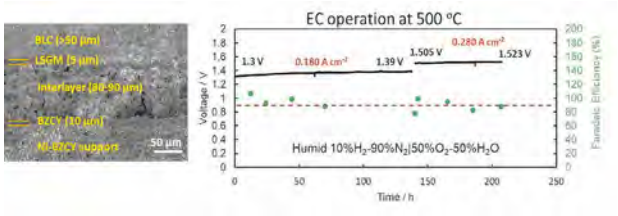


Fig. 8.2.9. (a) Schematic illustration of the PSC architecture incorporating HTMs. (b) Representative *J–V* curves of the devices measured under AM 1.5G illumination at 100 mW cm⁻². (c–f) Statistical distributions of the photovoltaic parameters for the as-fabricated PSCs, based on an average of 20 individual devices.

References
Telugu B.R.; Watanabe M.; Guo Z.; Wang P.; Yamada S.; Zhai M.; Matsushima T. (2026), Heteroatom engineering of ortho-fluorinated triarylamine based hole transport materials for enhanced performance in perovskite solar cells, Journal of Materials Chemistry A, 14(11), 6470-6478, DOI: 10.1039/d5ta07841e.

Fabrication of solid oxide electrolysis cells for hydrogen production (Dr. Khan S.)

The solid oxide cell is one of the key energy conversion devices for achieving a low-carbon society. A single solid-ion conductor such as oxide ion or proton conductor is generally used for the electrolyte sandwiched between positive and negative electrodes. However, because of the low oxide ion conductivity, a high operating temperature is required resulting in low stability and high operational cost. In contrast, a cell using proton-conducting oxide can operate at intermediate or low temperatures, unfortunately, the Faradaic efficiency is low because of the partial electronic conductivity. Here, we propose a double decker design for a solid oxide cell by depositing oxide and proton conducting solid oxide films onto an intermediate porous electrode. A proton-conducting electrolyte, $BaZr_{0.44}Ce_{0.36}Y0.1O_{3-\delta}$ film was deposited on a porous NiO- $SrZr_{0.5}Ce_{0.4}Y_{0.1}O_{3-\delta}$ substrate by the tape-casting and co-sintering method. Onto this half-cell, a porous interlayer electrode of several oxides was deposited, and the upper electrolyte film of $La_{0.9}Sr_{0.1}Ga_{0.8}Mg_{0.2}O_{3-\delta}$ was further deposited by the pulsed laser deposition method. Finally, an air electrode was deposited to assemble a single cell with two electrolyte layers. By using oxide, proton and electron triple conductor for the interlayer electrode, the newly designed cell generated good performance for both fuel cell and steam electrolysis modes at low temperature. More importantly, this cell shows a high and stable Faradaic efficiency despite the $BaZr_{0.44}Ce_{0.36}Y_{0.1}O_{3-\delta}$ proton conductor cell, which makes it more promising for green H_2 production from steam electrolysis.



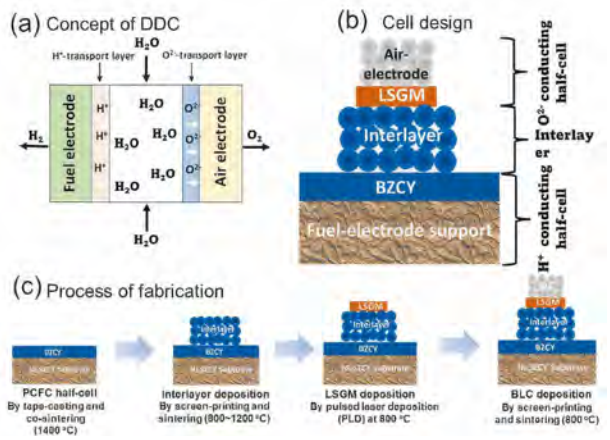


Fig. 8.2.10. (a)-(b) represents the concept of DDC for steam electrolysis. Steam is introduced into DDC at the interconnecting layer (also called interlayer). Electrolysis is expected to occur at the interlayer, with the transport of oxide ions toward oxygen-conducting layer (O^{2-}-transport layer) and protons towards the proton-conducting layer (H_+-transport layer), respectively. The final products of H_2 and O_2 are formed at the fuel electrode and air electrode, respectively. Figure 1(c) shows the process of fabrication of DDCs by using state-of-the-art thin-film deposition techniques such as tape-casting and co-sintering method and pulsed laser deposition (PLD). First, large-size protonic half cells composed of NiO-SZCY/BZCY were fabricated via tape-casting and co-sintering method. An interlayer was, then, deposited onto the PCCs by screen-printing and sintering method. Later, a thin LSGM film was deposited by PLD method and finally air-electrode was deposited on the LSGM to fabricate a completed cell. The original concept of a DDC was restricted to an effective steam-electrolysis cell to produce H_2 and O_2 gas, separately.

Fig. 8.2.11. It shows the cross-sectional view of DDC and its EC performance at 500°C for 240 hours. As expected, the Faradaic efficiency maintained high (~90%) after 200 hours. This result indicates that oxide ions were effectively pumped upwards to LSGM film, which is an oxide-ion conducting film. As a result, hole formation at the BZCY electrolyte was suppressed and enhanced Faradaic efficiency.

References
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Theoretical Modelling of Oxygen Evolution Reaction (OER) on $KTaO_3$ [001] Surface (Dr. Hanindriyo A.T., PI Staykov A., PI Ishihara T.)

Experimental data shows the possibility of oxygen evolution on the surface of perovskite $KTaO_3$. This study aims to investigate, by theoretical means, the reaction coordinates of oxygen evolution reaction (OER) on the $K(Ta,Zr)O_3$ [001] surface. Possible reaction pathways were investigated starting from the adsorption of water molecule on a $(KO)^-$ terminated surface post-surface reconstruction.

Key OER coordinates (Fig. 8.2.12) were successfully calculated with density functional theory (DFT), and the Nudged Elastic Band (NEB) method is applied to perform a search for the lowest reaction barrier in between the key coordinates. The results show 3 prominent energy activation barriers from the initial adsorption of H_2O molecule on the $K(Ta,Zr)O_3$ [001] surface:

1. H^+ dissociation from adsorbed H_2O
2. Lattice oxygen evolution
3. Formation and desorption of H_2 and O_2

From the NEB calculation results, it is shown that apart from the final electrochemical step (requiring external electrochemical energy), the other two reaction barriers are quite easily surmountable under normal conditions, leading to a plausible OER pathway on $KTaO_3$ [001] surface.

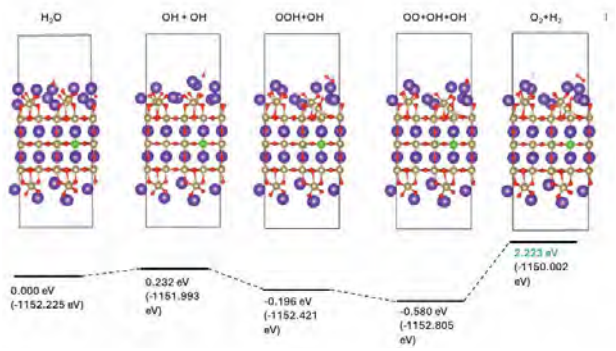


Fig. 8.2.12. Key OER coordinates on $K(Ta,Zr)O_3$ [001] surface starting from H_2O adsorption.

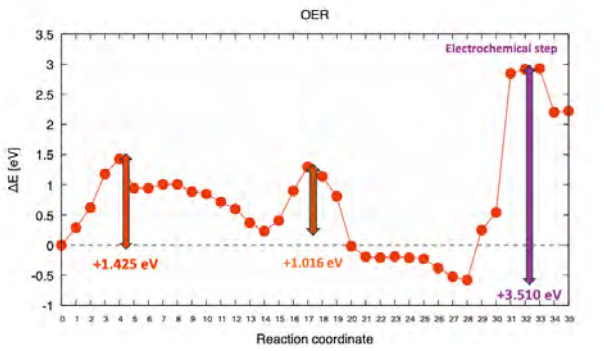


Fig. 8.2.13. OER activation barrier energies on the $K(Ta,Zr)O_3$ [001] surface, calculated by NEB method.

Multiscale Science and Engineering for Energy and the Environment (MSEEE)

Electrification or Hydrogen? A strategic pathway for Japan's energy transition (Prof. Karmaker S.C., PI Chapman A.J.)

This study represents a significant research accomplishment by providing a comprehensive, quantitative assessment of Japan's energy transition pathways toward carbon neutrality by 2050. By systematically comparing Business-as-Usual (BAU), High Electrification (HE), and Hydrogen Economy (H2E) scenarios, the research advances understanding of the cost, emission, and economic trade-offs associated with each pathway. The findings demonstrate that while electrification offers the most cost-effective and energy-efficient route for large-scale decarbonization, hydrogen plays a critical and irreplaceable role in addressing emissions from hard-to-electrify sectors. Importantly, the study moves beyond a binary comparison by identifying a balanced, synergistic approach that integrates both electrification and hydrogen as the most feasible long-term strategy. This work contributes to the field by delivering policy-relevant insights supported by quantitative modeling, thereby informing strategic decision-making for Japan's sustainable and resilient energy future.

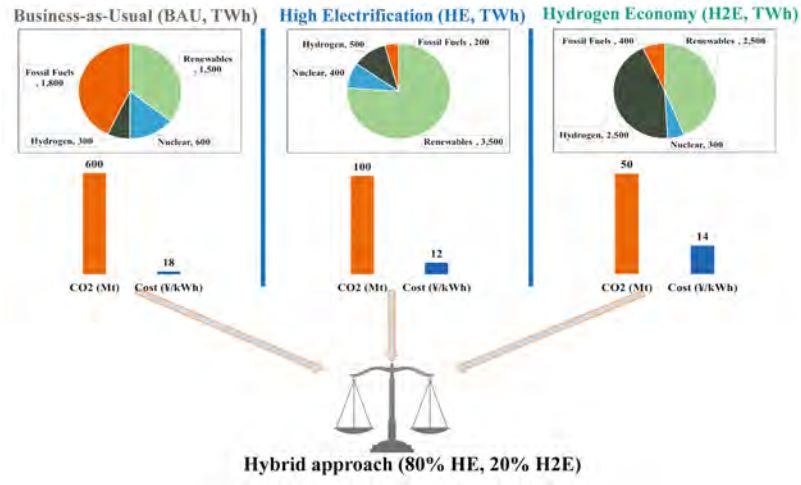


Fig. 8.3.1. The figure shows that the High Electrification (HE) scenario achieves the lowest final delivered energy cost at approximately ¥12/kWh, compared to ¥14/kWh in the Hydrogen Economy (H2E) scenario and ¥18/kWh under Business-as-Usual (BAU). In contrast, the lowest CO_2 emissions are observed in the H2E scenario (50 Mt CO_2), followed by HE (100 Mt CO_2), while BAU remains significantly higher at 600 Mt CO_2. These results highlight a clear trade-off between cost efficiency and emission reduction: electrification minimizes costs, whereas hydrogen maximizes decarbonization, particularly in hard-to-electrify sectors. Consequently, a balanced pathway combining approximately 80% electrification and 20% hydrogen emerges as the most feasible and robust long-term strategy, achieving substantial emission reductions while maintaining economic efficiency and system practicality.

References

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Returning Results to Society

The relevance of I²CNER's research efforts and objectives in FY 2025 toward enabling the green innovation initiative of the government of Japan is evidenced through 21 new collaborative projects with industry as well as some new or continued projects that resulted in technology transfer events.
During FY 2025, I²CNER filed for 28 patents, and was granted 17, bringing the total number of patent applications since inception to 583 and patents awarded to 198.

Long-term operational demonstration of a CO_2 Direct Air Capture and Utilization (DAC-U®) unit based on separation nanomembranes at Expo 2025 Osaka, Kansai, Japan, and the acceleration of its societal implementation (PI Fujikawa S.)

For the direct capture of CO_2 from the atmosphere (DAC), free-standing nanomembranes with only tens of nanometers thickness were created, leading to the development of m-DAC® (membrane-based Direct Air Capture), in which CO_2 is captured and concentrated simply by "filtering" air. In this fiscal year, it was revealed that the interfaces between nanolayers in a composite membrane play a crucial role to determine CO_2 permeation performance, and the target CO_2 permeance on the order of 10,000 GPU was attained together with a practical CO_2/N_2 selectivity (*Adv. Mater. Interfaces*, 2025).
In FY2025, the Direct Air Capture and Utilization (DAC-U®) system developed under the Moonshot Research and Development Program (Project Manager: Shigenori Fujikawa) was demonstrated at "Green Expo," part of the Future Society Showcase of Expo 2025 Osaka, Kansai, Japan (April 13 – October 13, 2025), and was operated for long-term demonstration in the Carbon Recycling Factory. The system, which couples an m-DAC® module with a CO_2 conversion module, was run with almost no interruption throughout the whole period of the Expo (6 months). The exhibit attracted approximately 20,000 visitors and was inspected by dignitaries including the Minister of Economy, Trade and Industry. Coverage by NHK and other media further conveyed the message that "CO_2 is a new resource present in the air" both in Japan and abroad, contributing to improved public acceptance of the technology.
The technology has also been transferred, as an intellectual property package of domestic and international patents, to Carbon Xtract Corporation, a Kyushu University startup (Kyushu University made its first equity investment in business participation with a startup). Fujikawa concurrently serves as CTO of the company, directly linking basic research with product development. As an integral part of the Expo activities, the company, together with West Japan Railway Company and Spice Cube Inc., demonstrated Farmarium™, an urban plant factory equipped with m-DAC®, at JR Bentencho Station. This is the world's first attempt to use captured CO_2 on site to promote photosynthesis in vegetables, and the harvested vegetables were served at shops in JR Osaka Station.



Fig. 9.1. The DAC-U® unit exhibited at "Green Expo" of Expo 2025 Osaka, Kansai, Japan. The unit on the right captures CO_2 from the atmosphere using separation nanomembranes (m-DAC®), and the unit on the left converts the captured CO_2 into methane and other products. Continuous operation was achieved with almost no interruption over the approximately six months of the Expo.



Fig. 9.2. Farmarium™, an urban plant factory equipped with m-DAC® technology. CO_2 is captured from the air inside the station and used on site to promote photosynthesis in vegetables. This is the world's first attempt to utilize CO_2 captured by a small, distributed DAC unit at the point of capture, and it exemplifies how basic research at the university has been extended to business model validation in an urban space.

References
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Related press releases

[1] Kyushu University press release (April 10, 2025), "From "decarbonization" to "DAC-carbonization": a CO_2 recycling unit for the future exhibited at Expo 2025 Osaka, Kansai."

[2] NEDO news release (April 8, 2025), "World's first: CO_2 captured from the atmosphere supplied directly to a facility converting it into city gas."

[3] Carbon Xtract et al. press release (April 7, 2025), "Demonstration of a plant factory using m-DAC® technology to capture CO_2 from the air begins at JR Bentencho Station."

Demonstration of Electrochemical CO_2 Conversion from Atmospheric CO_2 and Water at Expo 2025 Osaka, Kansai, Japan (PI Yamauchi M)

We constructed an electrochemical device to convert CO_2 into chemicals with water and electricity (eU) by combining our device to membrane based direct air capture device (m-DAC®) which was provided by Prof. Fujikawa. We displayed our instruments at Expo 2025 Osaka, Kansai, Japan and achieved electrochemical CO_2 conversion using air as a carbon source.



Fig. 9.3. DAC-U® device demonstrated at Expo 2025 Osaka, Kansai, Japan (from April 13 to October 13, 2025).

Mitigation of Hydrogen Embrittlement by Water Vapor in Hydrogen (PI Kubota M., PI Staykov A., Prof. Shang J.)

This study was conducted as part of Project 3 within the AEM Thrust. It represents a short-term milestone of the project: "*Establish validated physical descriptions of the effects of gas impurities on H_2-assisted cracking.*"

From FY2021 to FY2024, JFE Steel and our group jointly investigated the effects of impurities contained in hydrogen gas. During this collaboration, we published several papers, and in 2025, a new study focused on the mitigation of hydrogen embrittlement by water vapor. The aim of this research was to deepen understanding of the effects of impurities in hydrogen, rather than to develop specific products. Therefore, we cannot provide concrete examples of how the findings have been applied in commercial products. Nevertheless, as JFE Steel is actively engaged in the development of hydrogen equipment, such as high-pressure hydrogen containers for refueling stations, we believe our results substantially contribute to the development of hydrogen-related technologies.

We conducted fatigue crack growth tests on SCM435 low-alloy steel, a typical material for high-pressure hydrogen gas containers, under hydrogen, water-vapor–mixed hydrogen, and air environments. In pure hydrogen, crack growth was significantly accelerated; however, the addition of 991 ppm water vapor effectively suppressed hydrogen-assisted crack growth. The underlying mechanisms were investigated using first-principles calculations. The results revealed that increased water coverage on the Fe surface raised the hydrogen dissociation barrier from 0 to 0.39 eV, reducing the dissociation rate constant by over 10^7. These findings suggest that trace amounts of water vapor can act as a practical inhibitor of gas-induced hydrogen embrittlement, offering new perspectives for enhancing the reliability of structural materials in hydrogen-rich environments.

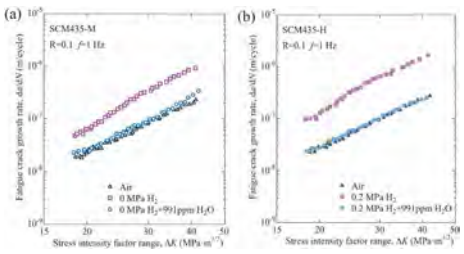


Fig. 9.4. The fatigue crack growth rate versus stress intensity factor range for SCM435-M and SCM435-H in air, H_2, and H_2+H_2O is shown. The suffixes "M" and "H" indicate the strength levels of the steels. For both materials, hydrogen significantly accelerates fatigue crack growth. However, the addition of 991 ppm water vapor completely mitigates this hydrogen-accelerated crack growth.

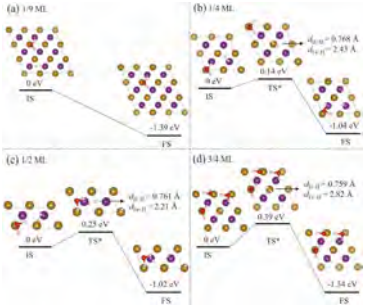


Fig. 9.5. The c-NEB calculation results for hydrogen dissociation on the iron surface with the H_2O coverages of 1/9ML, 1/4ML, 1/2ML, and 3/4ML are shown. it can be found that water had no effect on hydrogen dissociation when the water coverage was 1/9ML as shown in (a). However, an activation energy of 0.14eV appeared at 1/4ML coverage. As a result, the reaction rate constant decreased three magnitudes compared to the hydrogen dissociation on clean iron surface and with 1/9ML water coverage. As the water coverage increased further, (c) for 1/2ML shows that the activation energy rase to 0.25eV, indicating a more significant inhibition of hydrogen dissociation. In (d), at 3/4ML coverage, the activation energy reached 0.39eV, causing the reaction rate constant reduced to 2.74×10^{-7}. These results confirm that as the water coverage increased, hydrogen dissociation was increasingly hindered.

References
Shang J.; Umezaki S.; Masuda T.; Yussalla V.I.; Okano H.; Naho I.; Staykov A.; Kubota M. (2025), Suppressing gaseous hydrogen embrittlement of Cr–Mo steel by introducing water vapor: Insights from experiments and calculations, Corrosion Science, 256, DOI: 10.1016/j.corsci.2025.113252.

Impacts of digital economy on energy inequality and security in developing countries: Insights from econometric and machine learning approaches (PI Saha B.B.)

Energy inequality and security remain major challenges in developing countries, where rural–urban gaps and unreliable systems constrain socio-economic progress. This study examines how the digital economy can help address these problems using econometric and machine learning methods. Results show that a 1% rise in digitalization reduces electricity access inequality by 0.26%, clean cooking inequality by 0.13%, and improves energy security by 0.17%. The effects are strongest in regions with severe disparities. Mediation analysis indicates that lowering income and gender inequality strengthens these benefits. The study concludes that combining digital infrastructure with renewable energy systems can improve equity and security. Policymakers should invest in rural digital technologies, expand digital literacy, and reduce socio-economic barriers.



Fig. 9.6. The figure presents a framework linking the digital economy with energy inequality and energy security. It shows how digital technologies enhance energy access, efficiency, and reliability, thereby reducing disparities in electricity and clean cooking. The framework also highlights the role of income and gender inequality as mediating factors influencing these outcomes.

References
Sen K.K.; Karmaker S.C.; Chapman A.J.; Saha B.B. (2025), Digital economy in reducing energy inequality and enhancing energy security for environmental sustainability, Journal of Cleaner Production, 522, DOI: 10.1016/j.jclepro.2025.146344.

Industrial transfer potential of a low-temperature methanol synthesis reactor concept (Prof. Nakamura J., Dr. Yan M.)

This work has direct industrial relevance because it produced a reactor concept and an experimental dataset that can be transferred to process development. These results from the self-designed reactor supported a patent application by Mitsui Chemicals and provided technical evidence for further reactor and process design. The study contributes new understanding of temperature management in low-temperature methanol synthesis and may support carbon recycling technologies, compact reactor development, and future industrial implementation in Japan and beyond.

Mitigation of hydrogen embrittlement of iron and steels by carbon monoxide in gaseous H_2 (PI Staykov A., PI Kubota M.)

This paper provides a comprehensive review of the authors' recent achievements in mitigating hydrogen embrittlement (HE) in iron (Fe) and steels using carbon monoxide (CO) in gaseous H_2. CO contained in H_2 gas preferentially adsorbs on the Fe surface, and effectively suppresses hydrogen dissolution into the material, resulting in mitigating HE. Fracture toughness test results under various conditions demonstrated the effectiveness of CO in mitigating HE, with its impact influenced by factors such as loading rate, gas pressure, strength, and chemical composition. The CO mitigation effect diminishes with the lower loading rate, higher gas pressure, higher strength, and increased chromium content. The mechanisms underlying the effects of these factors on the susceptibility to HE are theoretically elucidated based on the surface reactions of the H_2 and CO molecules with the Fe surface through density functional theory and molecular dynamics simulations. The project was funded by Air Liquide and actively applied in their technology cycle.

References
Komoda R.; Zhang N.; Kubota M.; Staykov A.; Ginet P.; Furtado J.; Prost L.; Nagao A. (2025), Mitigation of hydrogen embrittlement of iron and steels by carbon monoxide in gaseous H_2, International Journal of Hydrogen Energy, 136, 822-832, DOI: 10.1016/j.ijhydene.2024.04.071.

High-entropy photocatalysts for green ammonia synthesis (Prof. Edalati K.)

Ammonia, a critical chemical fertilizer and a potential hydrogen carrier, can be sustainably synthesized from atmospheric nitrogen and water under ambient conditions through photocatalysis. In this study, high-entropy oxides are introduced as a new group of catalysts for nitrogen fixation and photocatalytic ammonia production. The oxides with d^0 and mixed d^0+d^{10} cationic configurations exhibit impressive efficiency in ammonia production compared to binary oxides, while the efficiency is improved by using a mixed cationic configuration. It was shown that the incorporation of d^{10} elements, such as gallium and zinc, boosts the photocatalytic reactions by improving light absorbance, charge separation and charge lifetime. These findings, which were patented in cooperation with Mitsui Chemicals, Inc., demonstrate the potential of high-entropy oxides as next-generation photocatalysts for green ammonia synthesis, offering an effective alternative to conventional catalytic systems.

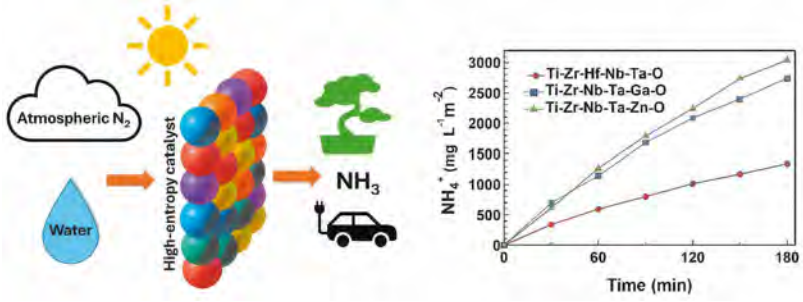


Fig. 9.7. High-entropy catalysts for green ammonia synthesis, where mixed cationic configuration, such as in Ti-Zr-Nb-Ta-Zn/Ga-O, leads to a higher synthesis rate compared to monotonic cationic configuration, such as in Ti-Zr-Hf-Nb-Ta-O.

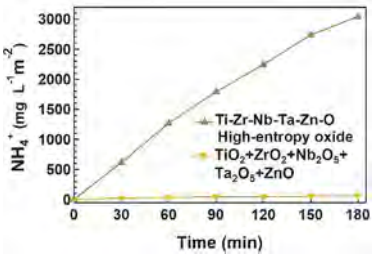


Fig. 9.8. Significantly higher photocatalytic ammonia synthesis using high-entropy oxide compared to a mixture of corresponding binary oxides.

References
Nguyen T.T.; Hidalgo-Jiménez J.; Edalati K. (2025), High-entropy oxide photocatalysts for green ammonia synthesis from nitrogen fixation in water, Scripta Materialia, 269, DOI: 10.1016/j.scriptamat.2025.116931.

Organic compound, photo-assisted water electrolysis catalyst, semiconductor thin film electrode, photo-assisted water electrolysis cell, and method for producing hydrogen (Prof. Watanabe M.)

Organic compound, photo-assisted water electrolysis catalyst, semiconductor thin film electrode, photo-assisted water electrolysis cell, and method for producing hydrogen is investigated. This work can be transferred to halide perovskites based photoanode. Therefore, the halide perovskite based anode with stable carbon hole transporting layer reviewed.

In halide perovskites, the hole transport material determines the high charge transport properties. Therefore, highly efficient hole transport materials have been developed. On the other hand, the hole transport layer is sensitive to environmental conditions such as water and oxygen due to ionic treatments such as cation doping, and the issue of environmental durability has always been raised. Carbon materials are promising as new hole transport layers in halide perovskite materials because they are hydrophobic materials and have hole transport properties. Furthermore, various carbon materials can be used and are expected to be an alternative material for expensive hole transport layers. Leveraging the advantages of carbon materials, their combination with halide perovskites has been applied to fabricate air-stable solar cells. Moreover, the excellent water resistance of carbon materials has enabled the development of photoanodes that use halide perovskites as the photosensitive layer.

References
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Toward Practical Implementation of Perovskite Solar Cells through High-Performance and Durable Organic Materials (Prof. Matsushima T.)

I am working to improve the performance and stability of perovskite solar cells with a strong focus on practical application and technology transfer. In this research, I developed new organic passivation materials and established a clear design strategy that directly contributes to improving device performance and durability. By optimizing molecular structures, I demonstrated that it is possible to simultaneously enhance efficiency and long-term stability, which are critical requirements for commercialization.

The developed materials significantly improved device performance, increasing the energy conversion efficiency from 22.7% to 24.6% and enhancing stability from 61% to 85% after 1000 hours of continuous operation under light at room temperature. These results represent a clear step forward compared

to conventional materials and indicate strong potential for real-world applications. In particular, the ability to maintain high performance over long operation times is essential for deployment in practical energy systems. Furthermore, this research provides concrete design guidelines that can be directly used in industrial material development. By clarifying how molecular structure influences device performance, the results enable more efficient development of next-generation materials. These outcomes can contribute to the development of scalable manufacturing processes and reliable solar cell technologies, supporting the transition toward sustainable energy systems. Through these efforts, I aim to accelerate the implementation of high-performance perovskite solar cells in society and contribute to energy solutions both in Japan and globally.

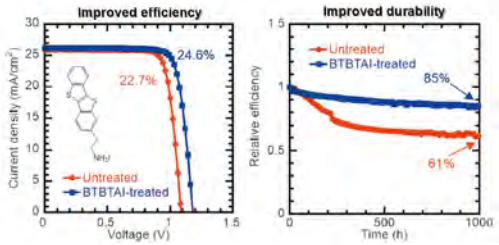


Fig. 9.9. Substantial enhancement of efficiency and durability enabled by newly developed defect passivation.

References
Koseki D.; Senevirathne C.A.M.; Senba D.; Fujita Y.; Lin J.; Zhai M.; Shang J.; Raju T.B.; Ida S.; Watanabe M.; Staykov A.; Segawa H.; Guo Z.; Matsushima T. (2025), Elucidating the mechanism of perovskite surface passivation with organic molecules: the impact of π-conjugation length, Journal of Materials Chemistry A, 13(23), 17783-17798, DOI: 10.1039/d5ta00754b.

Optimizing renewable energy systems with hybrid action space reinforcement learning: A case study on achieving net zero energy in Japan (Prof. Gao Y.)

This study developed a reinforcement-learning-based optimization framework for renewable energy systems integrated with solar photovoltaic, biomass power generation, and battery storage, aiming to support the realization of Net-Zero Energy Buildings in Japan. By introducing a parameterized hybrid action space, the proposed method enables coordinated scheduling of multiple renewable energy components without incurring excessive computational burden. The framework was validated using actual measurement data from an existing energy system and showed improved off-grid operational performance compared with baseline methods. This work has strong potential for returning research results to society because it provides a transferable optimization methodology for low-carbon building operation, renewable integration, and practical energy management, while also involving industrial collaboration and directly addressing real-world decarbonization needs.

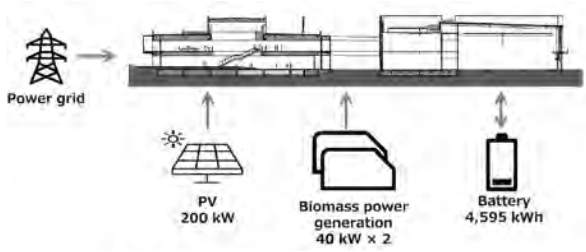


Fig. 9.10. Diagram of the renewable building energy system integrating solar photovoltaic, biomass power generation, battery storage, and building-side energy demand, illustrating the practical energy management setting addressed in this study.

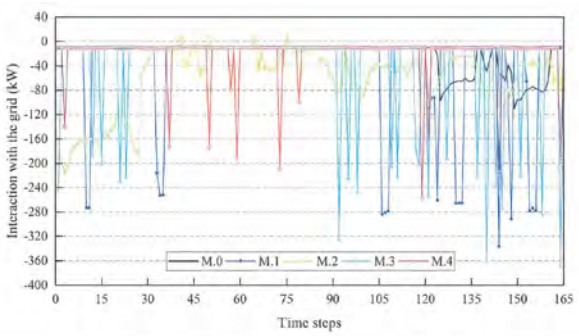


Fig. 9.11. Comparison of optimization target performance across different models, showing that the proposed hybrid-action reinforcement learning method improves system operation toward net-zero energy performance and supports practical low-carbon building energy management.

References
Gao Y.; Hu Z.; Matsunami Y.; Qu M.; Chen W.-A.; Liu M. (2026), Optimizing renewable energy systems with hybrid action space reinforcement learning: A case study on achieving net zero energy in Japan, Renewable Energy, 256, DOI: 10.1016/j.renene.2025.124493.

How does environmental policy shape the impact of energy innovation funding on renewable energy generation? Evidence from econometric and machine learning approaches (Prof. Karmaker S.C., PI Chapman A.J.)

This research advances innovation and technological progress by providing new evidence on how policy design can improve the effectiveness of energy innovation funding in speeding up renewable energy generation. By combining advanced econometric techniques with machine learning methods, the study creates a stronger analytical framework that deepens our understanding of complex interactions between policy tools and technological investments. For Japan, where reaching carbon neutrality by 2050 is a national goal, the findings offer valuable guidance on aligning innovation funding with market-based environmental policies to maximize renewable energy deployment efficiency. Globally, the study contributes to scientific knowledge by showing that financial investments alone are not enough without supportive policy environments, thereby enhancing understanding of policy–technology synergies vital for energy transitions. This interdisciplinary approach not only refines empirical methods but also helps develop more effective, data-driven strategies for sustainable energy innovation worldwide.



Fig. 9.12. This study offers important insights into how environmental policy (EP) shapes the effectiveness of energy innovation funding (EIF) in promoting renewable energy generation (REG). The findings reveal that EIF alone is not sufficient to drive renewable energy expansion unless supported by strong, market-based policies. Both econometric and machine learning results consistently show that instruments such as carbon pricing and renewable energy credits enhance the impact of innovation funding by creating financial incentives and reducing investment risks. In contrast, non-market-based policies are less effective, highlighting the critical role of well-designed policy frameworks in accelerating the transition to renewable energy.

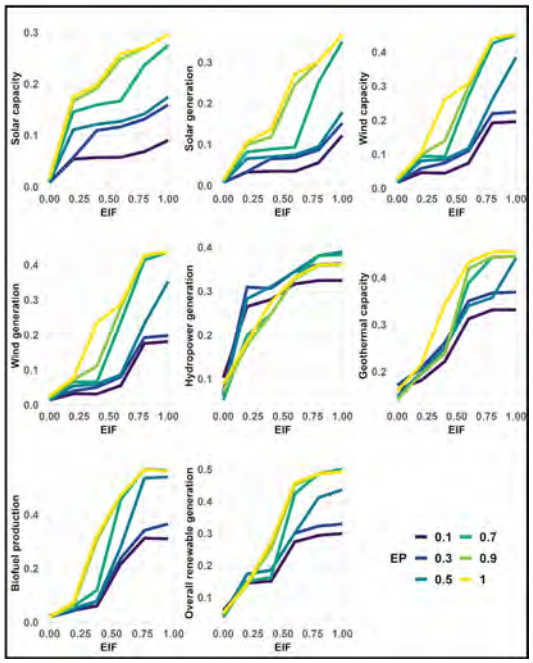


Fig. 9.13. Using the Random Forest (RF) machine learning approach, this study further examined how environmental policy (EP) stringency moderates the relationship between energy innovation funding (EIF) and renewable energy generation (REG) across multiple energy sources, including solar, wind, hydropower, geothermal, and biofuels. The findings consistently show that higher EP stringency significantly strengthens the positive impact of EIF on REG, as evidenced by steeper increases in renewable energy generation under more stringent policy conditions. In contrast, lower levels of EP weaken this relationship, indicating that financial investment alone is insufficient to drive substantial energy transitions. These results, which are consistent across both normalized and non-normalized datasets as well as econometric analyses, highlight the critical role of strong and well-designed environmental policies in maximizing the effectiveness of innovation funding and accelerating the clean energy transition.

References

Sen K.K.; Karmaker S.C.; Chapman A.J.; Saha B.B. (2025), How does environmental policy shape the impact of energy innovation funding on renewable energy generation? Evidence from econometric and machine learning approaches, Energy Economics, 150, DOI: 10.1016/j.eneco.2025.108833.

Network of International Collaborations



Fig. 10.1. This map includes the home institutions of I²CNER's foreign WPI faculty as well as those institutions with which I²CNER has academic agreements.

Globalization by the Numbers

In FY2025, there were a significant number of international activities that enhanced I²CNER's global visibility.

- The Institute's researchers were responsible for organizing, co-organizing, or serving on the scientific committees for 3 international conferences (272 in total since inception); 7 international conference sessions/symposia or workshops (387 since inception); and 7 I²CNER international workshops (111 since inception).
- Our researchers have given 98 keynote, plenary, and invited presentations in international conferences and fora (1078 since inception).
- Our researchers have joint publications with researchers from 85 new institutions (1520 in total since inception).
- Between its inception and March 31, 2026, the Institute has hosted a total of 131 graduate and undergraduate students from various institutions around the world, including Illinois.

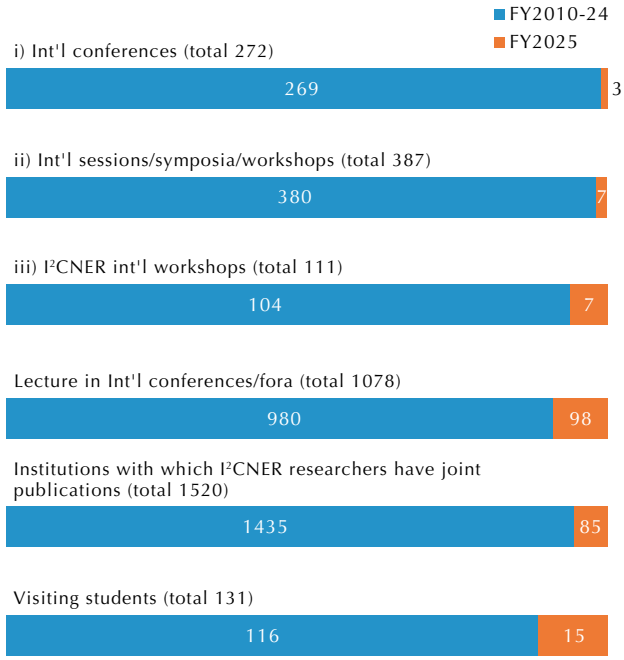


Fig. 10.2. Details of international activities

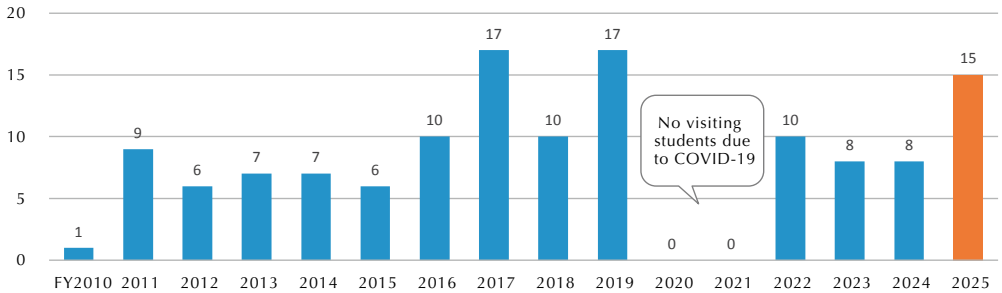


Fig. 10.3. Number of Visiting Students by Year

2025 WPI Symposium Held in Madrid

The Institute of Materials Science of Madrid (ICMM) of the Spanish National Research Council (CSIC), and I²CNER jointly hosted the 2025 WPI Symposium, "Energy Materials for a Sustainable Future," in Madrid from November 11 to 13, 2025.

The symposium was held at the Institute of Ceramics and Glass (ICV), CSIC, and was attended by a total of 180 participants from institutions including Kyushu University, the Spanish National Research Council, Institute of Science Tokyo, Kumamoto University, Forschungszentrum Jülich, the Paul Scherrer Institute, and Imperial College London.

On the first day, leading researchers from each institution delivered presentations. On the second and third days, researchers from Japan and Spain presented a wide range of energy-related research topics. The program also included poster sessions and laboratory tours, providing participants with valuable opportunities for networking and scientific exchange.

Over the three-day event, participants engaged in active discussions and exchanged ideas. The symposium also provided young researchers with an excellent platform to develop ideas with fellow researchers, strengthen international collaborations, and contribute to WPI's missions of "World-Leading Scientific Excellence and Recognition" and "Values for the Future."



Meeting between I²CNER and CSIC



Video message from Tatsuro Ishibashi, President of Kyushu University



Symposium Flyer



Group photo



Symposium Overview

2025 OIST-I²CNER Joint Symposium Held in Okinawa

The Energy Open Center at Okinawa Institute of Science and Technology (OIST) and I²CNER jointly hosted the OIST-I²CNER Joint Symposium on January 21–22, 2026, at OIST in Onna-son, Okinawa, Japan. The theme of the symposium was "Bridging Energy Research for a Sustainable Future."

A total of approximately 100 participants from I²CNER, OIST, and other institutions, including the University of Illinois Urbana-Champaign, Forschungszentrum Jülich, the Paul Scherrer Institute, and Imperial College London, took part in the symposium.

Over the two-day event, the symposium featured 15 research presentations, 16 poster presentations, and three laboratory tours, providing participants with valuable opportunities to learn about a wide range of energy-related research for a sustainable future and to engage in meaningful exchanges of ideas.

Furthermore, participants received insightful explanations of various initiatives at OIST, including its innovation initiatives and academic partnership and visiting programs.

The symposium concluded with a shared hope for further collaboration.



Symposium Flyer



Karin Markides, President of OIST



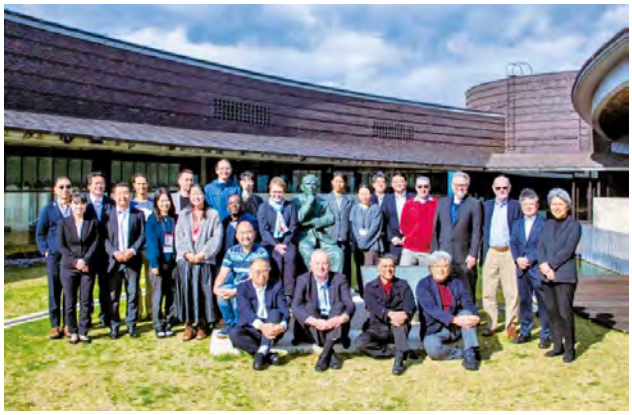
Video message from Tatsuro Ishibashi, President of Kyushu University



Keshav M. Dani, Director of Energy Open Center, OIST



Symposium Overview



Group photo

2026 I²CNER Annual Symposium
Challenge and Innovation For a Carbon-Neutral Society and Beyond



















1. Tatsuro Ishibashi, *President, Kyushu University*
2. Akira Ukawa, *WPI Academy Director*
3. Anita Ho-Baillie, *Professor, The University of Sydney*
4. Tsubasa Otake, *Professor, Hokkaido University*
5. Haiqing Lin, *Professor, University at Buffalo, The State University of New York*
6. Takeshi Tsuji, *Professor, The University of Tokyo*
7. Tom Woo, *Professor, University of Ottawa*
8. Yibin Xu, *Group Leader, National Institute for Materials Science (NIMS)*

Since its inception, I²CNER has held an annual symposium, which has evolved over time from an event that celebrates the current research achievements of its thematic research areas (three thrusts) to an exploratory forum that focuses on a single research topic that is highly relevant to I²CNER's research portfolio and the international community. Additionally, to explore new ways to best represent their thematic research areas, I²CNER's three thrusts jointly hold an international workshop with several researchers and engineers.

This year's I²CNER Annual Symposium, "Challenge and Innovation for a Carbon-Neutral Society and Beyond," was held on January 26, 2026. The symposium featured presentations of the latest research results on three themes related to a carbon-neutral society: materials and electrical conversion, carbon capture technologies, and artificial intelligence. World-class researchers were invited to the symposium and engaged in lively discussions from their respective perspectives.

Program (January 26, 2026)

MC: PI Fujikawa S., *Associate Director, I²CNER, Kyushu University*

Opening Remarks	**Ishibashi T.,** *President, Kyushu University* **Ukawa A.,** *WPI Program Director* **Ishihara T.,** *Director, I²CNER, Kyushu University*
Introduction	**Fujikawa S.,** *Associate Director, I²CNER, Kyushu University*
Session I: Innovation in material and electrical conversion for sustainability	■ **Ho-Baillie A.,** *Professor, School of Physics Faculty of Science, The University of Sydney* "Multijunction Solar Cells" ■ **Otake T.,** *Professor, Faculty of Engineering, Hokkaido University* "What Is Geologic Hydrogen and Its Potential as a New Energy Resource?" ■ **Matsumoto H.,** *Professor, I²CNER, Kyushu University* "Steam Electrolysis by Use of Proton-Conducting Metal Oxides for Energy-Effective Hydrogen Production"
Session II: Carbon capture technologies for sustainability	■ **Lin H.,** *Professor, Department of Chemical and Biological Engineering, University at Buffalo, The State University of New York* "Membrane Solutions for Carbon Capture from Air and Flue Gas Streams" ■ **Selyanchyn R.,** *Associate Professor, I²CNER, Kyushu University* "Development of a Membrane-Based Approach to Direct Air CO_2 Capture: From Materials to Device" ■ **Tsuji T.,** *Professor, School of Engineering, The University of Tokyo* "CCS-Originated Innovations Advancing Supercritical Geothermal, Natural Hydrogen, and Space Exploration"
Session III: Building a carbon-neutral future with intelligence	■ **Woo T.,** *Professor, Department of Chemistry and Biomolecular Science, University of Ottawa* "Data Driven and AI Accelerated Design of Metal Organic Framework Materials for CO_2 Capture" ■ **Xu Y.,** *Group Leader, Data-driven Inorganic Materials Group, National Institute for Materials Science (NISM)* "Data Infrastructure and Machine-Learning-Guided Exploration of Battery Materials" ■ **Staykov A.,** *Associate Professor, I²CNER, Kyushu University* "Theoretical Design of Nanomaterials for CO_2 Gas Separation"
Closing Remarks	**Matsumoto H.,** *Associate Director, I²CNER, Kyushu University*



Director Ishihara delivers an address



Participants discuss during the poster session



Group photo of symposium participants at I²CNER

Distinguished Visitors



May 14, 2025, Deputy Vice Chancellor, Jomo Kenyatta University of Agriculture and Technology; Vice Chancellor, University of Nairobi and others.



October 8, 2025, Executive Dean in the Faculty of Science and International Partnerships Manager, Durham University.



December 19, 2025, Director-General, Kyushu Bureau of Economy, Trade and Industry and others.



March 23, 2026, Langas Group tour participants from Poland.



March 26, 2026, Executive Director, National Energy Technology Center (ENTEC); Deputy Secretary-General, Office of Energy Regulatory Commission of Thailand (OERC) and others

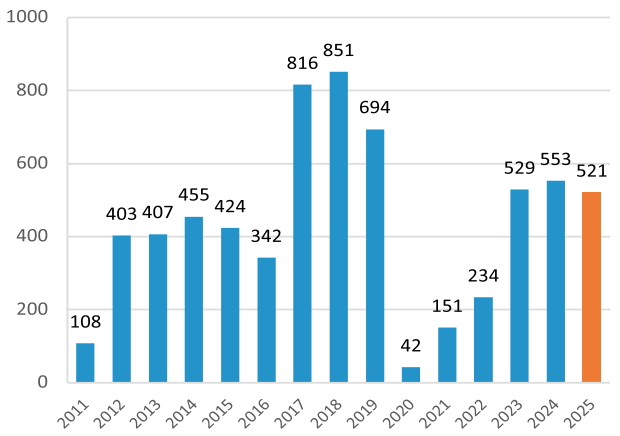


Fig.11. Total number of visitors per year.

Seminars

The I²CNER Seminar Series (ISS)

One of the most important goals of the I²CNER Seminar Series is to engage key members of the international community from academia, national laboratories, industry, and government agencies (policy makers). In FY2025, the Institute hosted 10 speakers (7 non-Japanese) for I²CNER Seminars. Cumulatively, 219 speakers have presented at 216 I²CNER Seminars. The I²CNER Seminar Series was held in either virtual or hybrid form and attracted participants not only from Japan but from around the world.

Selected ISS speakers



Prof. Chih-Jen Shih

Associate Professor,
ETH Zurich, Switzerland

"Miniaturization of Organic Semiconductor Devices"

April 2, 2025



Prof. Kaneaki Tsuzaki

Emeritus Fellow,
National Institute for Materials Science(NIMS), Japan

"P-doping works well for fracture resistance in high strength steel: A case of elongated grain structure"

June 18, 2025



Prof. Sushanta Mitra

Professor,
University of Waterloo, Canada

"Liquid-Liquid Encapsulation: A game-changing Technology"

August 21, 2025



Prof. Shuhuai Yao

Professor,
the Hong Kong University of Science and Technology, China

"Phase Change Dynamics of Supercooled Water Droplets"

March 4, 2026

Institute Interest Seminar Series (IISS)

Since the inception of the Institute, young researchers have been presenting lectures at the Institute Interest Seminar Series (IISS), the goal of which is to initiate interdisciplinary collaborations and train young researchers to present before general scientific audiences outside their areas of expertise. Cumulatively, 424 speakers have presented at 288 seminars. In FY2025, a total of 17 seminars were held, featuring 17 speakers and attracting 714 attendees.

Selected IISS speakers

Dr. Al Abdulghani A.J.

Post-doctoral Research Associate,
Center for Energy Systems Design, I²CNER

"Expanding the Toolbox of Carbon-Neutrality Research with Modulation-Excitation"

May 7, 2025

Prof. Karmaker S.C.

Assistant Professor,
Multiscale Science and Engineering for Energy and the Environment, I²CNER

"Electrification or Hydrogen? A Strategic Pathway for Japan's Energy Transition"

July 16, 2025

Prof. Wang Z.

Associate Professor,
Multiscale Science and Engineering for Energy and the Environment, I²CNER

"Generalizing classical theories of wetting to real liquids"

October 8, 2025

Prof. Donoshita M.

Assistant Professor,
Advanced Energy Materials, I²CNER

"Cooperating Two Metal Centers of a Dinuclear Cobalt Complex in CO_2 Electroreduction"

November 19, 2025

Prof. Song J.

Assistant Professor,
Advanced Energy Conversion Systems, I²CNER

"Electrocatalyst Design for Efficient CO_2 Conversion from Low to High-Temperature Electrochemical Systems"

January 14, 2026

Dr. Yan M.

Post-doctoral Research Associate,
Mitsui Chemicals, Inc.- Carbon Neutral Research Center, I²CNER

"Mixed-Potential-Driven Catalysis: An Electrochemical Framework for Understanding Thermochemistry"

February 18, 2026

Conferences and Symposia

① **The 3rd CEMDI-PAIMS Symposium**, April 23-25, 2025, Fukuoka, Japan
PI Staykov A., Prof. Nguyen L.T.H., Organizer

② **The 25th International Conference on the Science and Applications of Nanotubes and Low-dimensional Materials (NT25)**
June 15-20, 2025, Kyoto, Japan
Prof. Shiraki T., Organizing Chair

③ **Kyushu-Okinawa Open University (KOOU) & University Academic Alliance in Taiwan (UAAT) Japan–Taiwan Exchange and Symposium in Taipei-Tech**, July 17-19, 2025, Taipei, Taiwan
PI Adachi C., Co-organizer

④ **International Symposium on Solar Energy 2025 (ISSE2025)**
July 23-24, 2025, Fukuoka, Japan
Prof. Guo Z., Prof. Matsushima T., Leading Organizer

⑤ **Environmental Engineering and Environmental Economics Conference**
July 30-August 1, 2025, Fukuoka, Japan
PI Chapman A.J., Organizer

⑥ **The 12th International Conference on Power and Energy Systems Engineering (CPESE12)**
September 12-14, 2025, Fukuoka, Japan
Prof. Nguyen D.H., Chair, **PI Chapman A.J.**, Co-chair

⑦ **2025 International Conference on Solid Devices and Materials (SSDM2025)**, September 15-18, 2025, Yokohama, Japan
Prof. Matsushima T., Program Committee

⑧ **The 15th International Conference on Optical Probes of Organic and Hybrid Semiconductors (OP2025)**
September 21-29, 2025, Fukuoka, Japan
PI Adachi C., Organizing Committee

⑨ **International Workshop on Superfunctional Energy/Nano Materials (SENM2025)**, September 24-26, 2025, Fukuoka, Japan
Prof. Edalati K., Chairman

⑩ **The 1st International Symposium on Hydrogen and Energy Storage (iSHES'2025)**, October 27-30, 2025, Shenzhen, China
Prof. Edalati K., Scientific Committee

⑪ **The 15th A3 symposium on Emerging Materials: Nanomaterials for Electronics, Energy, and Environment**
November 13-15, 2025, Kitakyushu, Fukuoka, Japan
Prof. Shiraki T., Organizing Committee

⑫ **The 15th A3 symposium on Emerging Materials: Nanomaterials for Electronics, Energy, and Environment**
November 13-15, 2025, Kitakyushu, Japan
PI Fujigaya T., Symposium Chair

⑬ **The 10th International Workshop on Advanced Nanoscience and Nanomaterials 2025 (10th IWANN2025)**
November 5-7, 2025, Chon Buri, Thailand
Prof. Takahashi Y., Organizing Committee

⑭ **Thai–Japan Green Hydrogen I²CNER Symposium**
March 26-27, 2026, Fukuoka, Japan
Prof. Inada M., Prof. Maeda N., Organizer



① The 3rd CEMDI-PAIMS Symposium



④ ISSE2025



⑥ CPESE12



⑨ SENM2025

Plenary and Keynote Presentations

- **PI Lippert T.,** "Pulsed Laser Deposition for Energy Materials", 10th South African Conference on Photonic Materials 2025, Bloemfontein, South Africa, April 4-9, 2025
- **Prof. Fajar A.T.N.,** "Can AI Truly Revolutionize Molecular Design? Insight from an Experimental Chemist", 3rd CEMDI-PAIMS Symposium, Fukuoka, Japan, April 23, 2025
- **Prof. Hyodo J.,** "Accelerated Discovery of Novel Proton-conducting Ceramics Utilizing Experimental Data and Machine Learning", 3rd CEMDI-PAIMS Symposium, Fukuoka, Japan, April 24, 2025
- **Prof. Kwati L.,** "Processing and challenges in scaling up ceramic protonic membranes for electrochemical energy (PCEC/PCFC) ", 16th Pacific Rim Conference on Ceramic and Glass Technology including Glass & Optical Materials Division Meeting (GOMD 2025), Vancouver, Canada, May 4, 2025
- **Prof. Edalati K.,** "Toward hydrogen storage at room temperature with high-entropy alloys", International Forum on Solid-State Hydrogen Storage, Jiaozuo, China, May 9-10, 2025
- **Prof. Shang J.,** "The effect of carbon dioxide on the hydrogen embrittlement and its pressure dependence", The 12th Youth Forum on Strength of Materials and Structures, Zhengzhou, China, May 17, 2025
- **Prof. Shiraki T.,** "Halogenated Aryl Functionalization in Locally Functionalized Single-Walled Carbon Nanotube Synthesis for Color Center Photoluminescence Modulation", 247th Electrochemical Society (ECS) Meeting, Montréal, Canada, May 20, 2025
- **PI Yamauchi M.,** "Nanoscale electrode design for CO_2 electrolysis and its application to DAC-U system", 2nd World Summit on Environmental Science and Engineering (ENVIRONSUMMIT2025), Paris, France, June 6, 2025
- **PI Adachi C.,** "Holistic Molecular Design Strategies for High-Performance Organic Light Emitting Diodes", International Symposium on Advanced Materials for Photonic Engineering and Optoelectronics Applications (ISAMPEOA-2025), Kénitra, Morocco, June 17, 2025
- **PI Skinner S.J.,** "Ionic Transport in Solid Oxide Electrolytes: Identifying Protons in Oxides Under Reducing Conditions", International Conference on Materials for Advanced Technologies (ICMAT) 2025, Singapore, Singapore, July 1-3, 2025
- **PI Tsuchiyama T.,** "Relation between low elastic limit and mobile dislocation density in as-quenched martensitic steel", Thermec' 2025; International Conference on Processing & Manufacturing of advanced Materials, Tours, France, July 2, 2025
- **PI Chapman A.J.,** "Investigating consumers and their behavior toward sustainability: A machine learning driven approach", 12th International Conference on Industrial Ecology (ISIE2025), Singapore, Singapore, July 4, 2025
- **PI Adachi C.,** "Precise Control of CT States Pioneering Advanced Organic Devices", SPIE Organic Photonics + Electronics 2025, San Diego, US, August 4, 2025
- **PI Ishihara T.,** "Simultaneous Removal of NOx and Particulate Matter (PM) on Cu-CHA/Ag-$ZnAl_2O_4$ Catalysts", 10th Asia-Pacific Congress on Catalysis (APCAT-10), Singapore, Singapore, August 5, 2025
- **PI Staykov A.,** "Gas Inhibition of Hydrogen Embrittlement. Surface Chemistry Approach", National Conference on Pressured Vessels, Hefei, China, September 14-17, 2025
- **PI Matsumoto H.,** "Bilayered and trilayered positrodes towards preventing electronic leakage in protonic ceramic electrolysis cells", 22nd International Conference Solid-State Protonic Conductors (SSPC-22), Copenhagen, Denmark, September 16, 2025
- **Prof. Shang J.,** "Effect of hydrogen on creep properties", 2025 NSFC-CAS-JSPS Joint Symposium on Fatigue-resistant Additive Manufacturing Materials, Chengdu, China, September 19, 2025
- **PI Chapman A.J.,** "Life Cycle and Techno-Economic Assessment of Direct Air Capture and Utilization", 2025 Green Innovation & Engineering International Conference (2025 GREENIE), Taipei, Taiwan, September 23, 2025
- **PI Saha B.B.,** "Multifunctional Adsorbent Materials for CO_2 Capture and Energy Conversion Applications", International Conference on Mathematics, Mechanics, Information Technologies, and Artificial Intelligence (ICMM&IT 2025), Almaty, Kazakhstan, September 24-26, 2025
- **PI Saha B.B.,** "Cutting-Edge Adsorbent Materials for Energy Conversion and Carbon Capture", The 1st International Conference on Thermofluids Engineering (INCOTHERM-2025), Dhanbad, India, October 10-12, 2025
- **PI Somerday B.P.,** "Review and Current Status of Subcritical Cracking Threshold Measurements for Ferritic Steels in H_2 Gas", 5th International Conference on Metals & Hydrogen, Ghent, Belgium, October 15, 2025

- **Prof. Nishihara M.,** "Current Status and Future Perspective of Hydrogen Energy", 18th Asia Pacific Responsible Care Conference (APRCC) 2025, Nusa Dua, Indonesia, October 23, 2025
- **Prof. Watanabe M.,** "Motonori Watanabe, Novel dye-sensitized photoanode for effective water splitting system", The 15th Taiwan-Japan Bilateral Symposium on Architecture of Functional Organic Molecules, Hsinchu, Taiwan, October 27, 2025
- **Prof. Edalati K.,** "High-entropy metal hydrides for hydrogen storage", The First International Symposium on Hydrogen and Energy Storage 2025 (iSHES'25), Shenzhen, China, October 27-30, 2025
- **Dr. Carlson J.T.,** "An extension of old strategies? Japan's move towards a "comprehensive" resource diplomacy in hydrogen supply chains (2020-2024)", Industrial Decarbonization and Hydrogen: The Politics and Economics of Sustainable Structural Transformation, Potsdam, Germany, October 28, 2025
- **Prof. Edalati K.,** "Superfunctional nanoSPD materials: physical nature and applications", 9th International Conference on Nanomaterials by Severe Plastic Deformation (NanoSPD9), Beijing, China, October 31-November 4, 2025
- **Prof. Chitose Y.,** "Balancing CT and LE States toward Dual-Functional Two-Photon Active TADF Emitters", International Symposium on Novel Photoelectric Materials and Their Excited State Dynamics Studies, Guangzhou, China, November 4, 2025
- **Prof. Takahashi Y.,** "Recent Advances in Plasmon-Induced Charge Separation at the Interface between Metal Nanoparticles and p-Type Semiconductors", 10th International Workshop on Advanced Nanoscience and Nanomaterials 2025 (10th IWANN2025), Chon Buri, Thailand, November 5-7, 2025
- **PI Fujigaya T.,** "Gel coating of single-walled carbon nanotubes for in vivo applications", Kyushu-Seibu/Pusan-Gyeongnam Joint Symposium on High Polymers (21st) and Fibers (19th), Busan, Korea, November 27, 2025
- **Prof. Shiraki T.,** "Near-Infrared Nanosensors Using Color Centers Formed in Chemically Functionalized Single-Walled Carbon Nanotubes", 8th International Conference on Advanced Electromaterials (ICAE 2025), Jeju, Korea, November 27, 2025
- **Prof. Guo Z.,** "Constructing Self-assembled Molecules on Perovskite Surfaces for n-i-p Type Solar Cells", 14th International Conference on High-Performance Ceramics (CICC-14), Haikou, China, December 1, 2025
- **Prof. Matsushima T.,** "Improved Durability of Perovskite Solar Cells Based on Organic Materials Chemistry", 5th International Conference on Energy-Earth-Environment-Engineering, Tashkent, Uzbekistan, December 4, 2025
- **Prof. Gao Y.,** "How to address the two major engineering challenges in implementing deep learning for energy consumption prediction: lack of interpretability and scarcity of training data", KOR-JPN Academic Exchange Symposium, Seoul, Korea, December 8, 2025
- **Prof. Matsushima T.,** "Halide Perovskite Solar Cells Towards High Operational Durability: Strategies and Advances", Advanced Materials and Integrated Optoelectronics (AMIO) Symposium, Brisbane, Queensland, Australia, December 8–10, 2025
- **Dr. Raju T.B.,** "Design and development of organic hole transport materials for n-i-p structure perovskite solar cells ", 3rd International Conference on Thin Films and Nanotechnology, Delhi, India, December 11-13, 2025
- **Prof. Watanabe M.,** "TiO_2-ALD protected thiol doped hydrophobic hole transporting layer in solid state dye-synthesized photoanode enhanced photocatalytic water splitting properties", Pacifichem 2025, Honolulu, US, December 18, 2025
- **Prof. Nakamura J.,** "Blueprint for a Methanol Society toward Carbon-Neutrality", Modern Aspects of Green and Sustainable Chemistry (MAGSuC), Delhi, India, January 28, 2026
- **Prof. Teshima H.,** "The Effects of Nanoscale Surface Geometry and Liquid Film on the Three-Phase Contact Line", Korea-Japan Joint Seminar on Heat Transfer IX, Seoul, Korea, February 6, 2026
- **PI Saha B.B.,** "Engineering Advanced Adsorbents for Energy Conversion and Carbon Capture", International Conference on Advances in Mechanical and Aerospace Sciences (ICAMAS-26), Rapum Pare, Arunachal Pradesh, India, March 10-12, 2026
- **Prof. Karmaker S.C.,** "Data-Driven Perspectives on Clean Energy Transition and Sustainability: Integrating Econometrics and Machine Learning", Innovative Concepts of Mathematical Science & Social Sciences in Shaping Sustainable Policies and Addressing Social Challenges (ICMSSC), Tripura, India, March 11-13, 2026

(Only representative ones are listed.)

Selected Awards

Date	Recipient's name	Name of award
May 13, 2025	Chihaya Adachi	Jan Rajchman Prize, the Society for Information Display
May 21, 2025	Toshihiro Tsuchiyama	Academic Achievement Award (Hayashi Award), the Japan Society for Heat Treatment
June 5, 2025	Miki Inada	Award of the Outstanding Papers published in the Journal of the Ceramic Society of Japan
June 24, 2025	Chihaya Adachi	Tokuo Fujii Award, Kyushu University
July 9, 2025	Yasuyuki Takata	Heat Transfer Memorial Award, The American Society of Mechanical Engineers
August 27, 2025	Zhanglin Guo	Innovative PV Encouragement Award, the Japan Photovoltaic Society
September 1, 2025	Kaveh Edalati	Materials Research Letters Impact Award in 2025
September 25, 2025	Yukina Takahashi	2025 Women Analyst Award, the Japan Society for Analytical Chemistry
October 4, 2025	Masamichi Kohno	Thermal Engineering Achievement Award, the Japan Society of Mechanical Engineers
October 28, 2025	Chihaya Adachi	Leo Esaki Prize, the Science and Technology Promotion Foundation of Ibaraki
November 12, 2025	Chihaya Adachi	Highly Cited Researchers 2025, Clarivate
December 3, 2025	Chihaya Adachi	Kobayashi-Uchiike-Mikoshiba Prize, the International Display Workshops General Incorporated Association
December 6, 2025	Juan Shang	Professor Award 2025, the Society of Materials Science, Japan Kyushu Branch
March 18, 2026	Tatsumi Ishihara	Electrochemical Society of Japan Award (Takei Award)



Prof. Takata receiving the Heat Transfer Memorial Award in U.S.



PI Ishihara receiving the Takei Award.

Outreach Activities

Outreach Events

WPI Special Session at the EMBO Fellows' Meeting 2025 (June 28–July 1, 2025)

Thirteen young researchers from WPI participated in the EMBO Fellows' Meeting, held in Heidelberg, Germany, from June 28 to July 1. The meeting was attended by more than 100 EMBO Doctoral Fellows. As part of the meeting, the WPI researchers held a special session titled "Focus on the WPI" to introduce WPI and its institutes. Prof. Ohsaki from I^{2}CNER participated in the session, presenting a poster and interacting with local and WPI researchers.

WPI Science Symposium for High School Students (November 15, 2025)

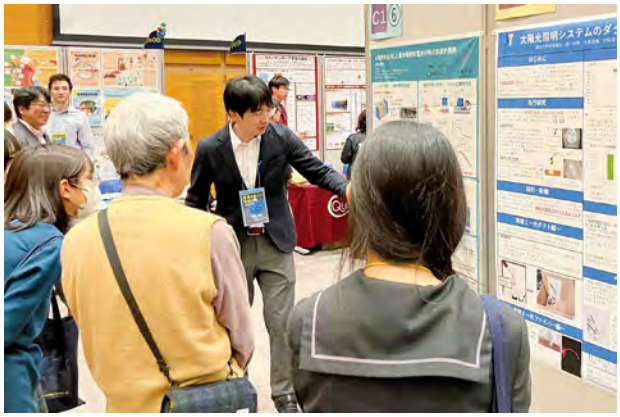
The 14th WPI Science Symposium, "The Eyes of Science Changing the Future," was held in Tsukuba City on November 15, 2025. The symposium was hosted by the International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (WPI-QUP), High Energy Accelerator Research Organization (KEK), and was primarily aimed at high school students and teachers. I^{2}CNER ran a booth together with 17 other WPI centers. During the poster session for high school students, Prof. Hyodo J. from I^{2}CNER presented his research and provided feedback and encouragement to the students.

2025 AGU Annual Meeting (December 15–18, 2025)

The WPI Promotion Center of the Japan Society for the Promotion of Science (JSPS) and WPI institutes, including I^{2}CNER, represented WPI at the 2025 American Geophysical Union (AGU) Annual Meeting, held in New Orleans, Louisiana, U.S., from December 15 to 18, 2025. The WPI Promotion Center, WPI-ELSI, WPI-AIMEC, and I^{2}CNER hosted a booth and carried out promotional activities under the two key messages, "Join World-Leading Research in Japan" and "Build Your Career in Japan."

WPI Young Researchers Forum (March 2, 2026)

The WPI Young Researchers Forum, "Explore Ideas and Expand Networks across WPI Centers," was held in Tokyo on March 2, 2026, with the aim of fostering internal networking among young researchers at WPI centers. Prof. Nicola H. P., a former I^{2}CNER researcher, delivered a special talk on her research experience at I^{2}CNER and her career journey. In addition, two early-career researchers from I^{2}CNER, Prof. Akrami S. and Dr. Wada K., participated in the event. Through group discussions and poster presentations, they interacted with fellow researchers and had an opportunity to reflect on their own career paths.



Prof. Hyodo presents his poster at the WPI Science Symposium.



WPI members staff the booth at AGU Annual Meeting.

Press Releases and Media Coverage

Press Releases

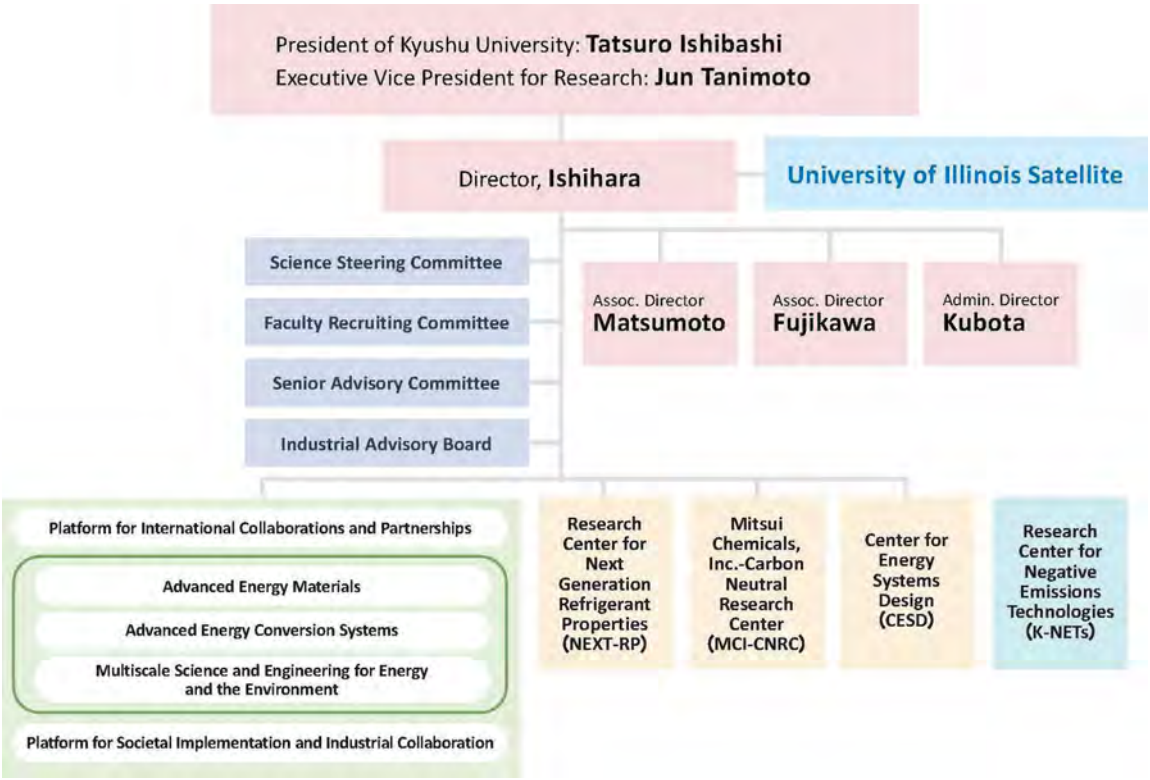
Date	Description
April 10, 2025	**PI Fujikawa S.** Kyushu University showcases carbon neutral research at Expo 2025 ~At Expo 2025's carbon capture demonstration plant, step into a future where household devices can capture and reuse carbon from the air~
May 30, 2025	**PI Adachi C.** A new model to accurately develop better OLEDs
July 10, 2025	**Prof. Nakamura J.** Mixed-Potential-Driven Catalysis: An Electrochemical Mechanism for Room-Temperature CO Oxidation on Gold Catalysts
August 1, 2025	**PI Adachi C.** Developing next-generation organic materials that connect light-emitting technology and medicine
February 10, 2026	**Prof. Edalati K.** Pollutants to Products: A Tailored Multicomponent Photocatalyst for Simultaneous CO_2 and Plastic Waste Conversion
February 24, 2026	**Prof. Edalati K.** High-Pressure Torsion-Induced Transformation of Adenosine Monophosphate: Insights into Prebiotic Chemistry of RNA by Astronomical Impacts

Media Coverage

Date	Media Outlet	Description
April 12, 2025	Yomiuri Shimbun	**PI Fujikawa S.** Exhibition at the Osaka Expo
April 28, 2025	FBS	**PI Fujikawa S.** Exhibition at the Osaka Expo
July 10, 2025	Nishinippon Shimbun	**PI Fujikawa S.** Exhibition at the Osaka Expo
August 18, 2025	NIKKEI Tech Foresight	**PI Adachi C.** New Organic Molecule for Infrared-to-Visible Light Conversion Developed for OLED Applications
August 19, 2025	Yomiuri Shimbun	**PI Fujikawa S.** New Approach to Atmospheric CO_2 Capture: Strategies of Two University Spin-offs Leveraging Proprietary Technologies
September 28, 2025	NHK	**PI Fujikawa S.** The 1.5°C Promise: Act Now to Stop Global Warming
October 29, 2025	Asahi Shimbun, Mainichi Shimbun, Yomiuri Shimbun	**PI Adachi C.** Awarded the Leo Esaki Prize
November 25, 2025	Nishinippon Shimbun	**PI Adachi C.** Profiled in the "Hito" Column Following the Leo Esaki Prize Award
December 5, 2025	Yomiuri Shimbun	**PI Adachi C.** Reflections on Receiving the Leo Esaki Prize
February 13, 2026	Nikkan Kogyo Shimbun	**Prof. Edalati K.** Kyushu University Develops Photocatalytic System to Convert CO_2 and PET into Valuable Resources
February 16, 2026	Asahi Shimbun	**PI Adachi C.** Leo Esaki Prize Winner Adachi Encourages High School Students to Pursue New Research Frontiers

I²CNER Structure (as of April 1, 2026)

Organizational Structure



1) The **Science Steering Committee (SSC)** is chaired by the Director, and its members are the two Associate Directors and the PIs of the thrusts. The SSC is the body that reviews and advises on all matters of the Institute, e.g. planning and operation of research activities, budget implementation, international collaborations, and outreach.

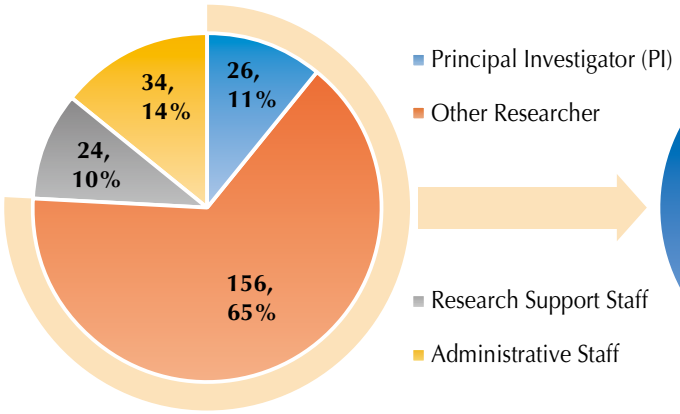
2) The **Senior Advisory Committee (SAC)** makes recommendations on the current status of the Institute and its future directions and provides the Director with a written report detailing their findings and recommendations. The full list of members as of April 1, 2024 is as follows:

- Prof. Petros Sofronis *Chair — University of Illinois at Urbana-Champaign, U.S.
- Prof. Reiner Kirchheim — University of Göttingen, Germany
- Prof. Robert McMeeking — University of California at Santa Barbara, U.S.
- Prof. Michael A. Celia — Princeton University, U.S.
- Prof. Harry L. Tuller — Massachusetts Institute of Technology, U.S.
- Prof. John A. Kilner — Imperial College London, U.K.
- Prof. Ian Robertson — University of Wisconsin-Madison, U.S.
- Prof. Ken Okazaki — Institute of Science Tokyo, Japan
- Dr. John Kopasz — Argonne National Laboratory, U.S.

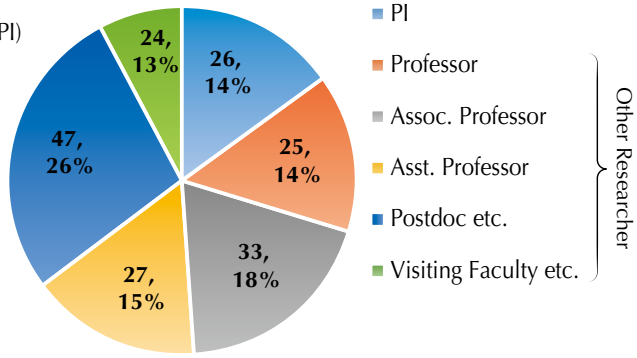
3) In FY2017, I²CNER established **the Industrial Advisory Board (IAB)**, whose members are prominent executives from industry, government agencies, and national laboratories that advise I²CNER on opportunities for interactions with industry and technology transfer. The meeting provides invaluable inputs to I²CNER researchers on areas that industries would have interest for promoting the development of new technologies.

Personnel (as of April 1, 2026)

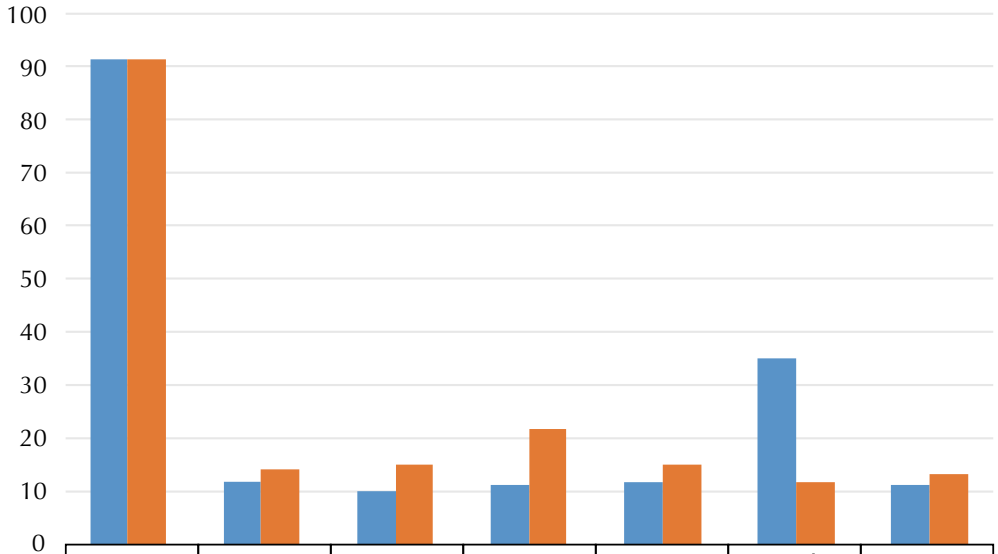
Breakdown of Personnel (Total: 240)



Researchers by Title (Total: 182)



Statistics of Researchers by Title



	Total	PI	Prof.	Assoc. Prof.	Asst. Prof.	Postdoc etc.	Visiting Faculty etc.
Overseas	91	12	10	11	12	35	11
Japanese	91	14	15	22	15	12	13
% Overseas	50%	46%	40%	33%	44%	74%	46%
% Female	14%	15%	0%	15%	11%	26%	8%

Contributed Researchers (as of April 1, 2026)

Administration

Director
Prof. Tatsumi Ishihara

Associate Directors
Prof. Shigenori Fujikawa
Prof. Hiroshige Matsumoto

Administrative Director
Prof. Masanobu Kubota

Principal Investigators

Advanced Energy Materials Thrust
Prof. Masanobu Kubota (Thrust Lead PI)
Prof. Seiji Ogo
Prof. Yoshinori Sawae
Prof. Petros Sofronis, *University of Illinois Urbana-Champaign, U.S.*
Prof. Toshihiro Tsuchiyama
Prof. Cynthia A. Volkert, *University of Göttingen, Germany*
Prof. Miho Yamauchi
Asst. Prof. Brian P. Somerday, *University of Illinois Urbana-Champaign, U.S.*

Advanced Energy Conversion Systems Thrust
Prof. Hiroshige Matsumoto (Thrust Lead PI)
Prof. Chihaya Adachi
Prof. Tsuyohiko Fujigaya
Prof. Tatsumi Ishihara
Prof. Thomas Lippert, *Paul Scherrer Institut, Switzerland*
Prof. Stephen John Skinner, *Imperial College London, U.K.*
Assoc. Prof. Aleksandar Tsekov Staykov
Dr. Ainara Aguadero, *Institute of Materials Science in Madrid (ICMM-CSIC)*

Multiscale Science and Engineering for Energy and the Environment Thrust
Prof. Shigenori Fujikawa (Thrust Lead PI)
Prof. Paul J.A. Kenis, *University of Illinois Urbana-Champaign, U.S.*
Prof. Bidyut Baran Saha
Prof. Yuichi Sugai
Prof. Koji Takahashi
Prof. Shuntaro Tsubaki
Prof. Takeshi Tsuji, *University of Tokyo, Japan*
Assoc. Prof. Anutosh Chakraborty, *Nanyang Technological University, Singapore*
Assoc. Prof. Andrew John Chapman
Dr. Jill Engel-Cox, *University of Colorado Denver*

Full-time Faculty & Postdoctoral Associates

Advanced Energy Materials Thrust
Assoc. Prof. Yukina Takahashi
Assoc. Prof. Ki Seok Yoon

Advanced Energy Conversion Systems Thrust
Assoc. Prof. Kaveh Edalati
Assoc. Prof. Toshinori Matsushima
Assoc. Prof. Motonori Watanabe
Assoc. Prof. Donghyeon Yoo
Asst. Prof. Jose Carlos Madrid Madrid
Asst. Prof. Rupali Ipsita Mohanty
Asst. Prof. Yutaka Ohsaki
Dr. Kevin Mall Haidaraly
Dr. Sovann Khan
Dr. Longtai Li
Dr. Athithya Seenidurai
Dr. Xiaofeng Shen

Multiscale Science and Engineering for Energy and the Environment Thrust
Specially-appointed Prof. Yasuyuki Takata
Dr. Pavlo Baloh
Dr. Kodai Matsumoto
Dr. Adchara Padermshoke

Platform for International Collaborations and Partnerships
Asst. Prof. Saeid Akrami
Asst. Prof. Shamal Chandra Karmaker
Asst. Prof. Juan Shang
Asst. Prof. Mai Tomisaki

Mitsui Chemicals, Inc. -Carbon Neutral Research Center
Prof. Shinya Okazaki
Dr. Obey Gotore
Dr. Adie Tri Hanindriyo
Dr. Nuttavut Kosem
Dr. Besisa Nada Hussien Amin Mohamed
Dr. Jyoti Saroha
Dr. Fang Siman
Dr. Sujesh Subramannian
Dr. Bhim Raju Telugu

Center for Energy Systems Design
Assoc. Prof. Junji Hyodo
Assoc. Prof. Leonard Kwati
Assoc. Prof. Nobutaka Maeda
Asst. Prof. Abbas Beheshti Askari
Asst. Prof. Adroit T.N. Fajar
Asst. Prof. Zhanglin Guo
Dr. Jordan Thomas Carlson
Dr. Daniël René Duijnstee
Dr. Hanbo Jung
Dr. John-In Lee
Dr. Keerti Naik
Dr. Jessie Manopo

Satellite Faculty & Postdoctoral Associates

Advanced Energy Conversion Systems Thrust
Prof. Nenad Miljkovic
Prof. Hong Yang
Assoc. Prof. Elif Ertekin

Multiscale Science and Engineering for Energy and the Environment Thrust
Prof. Caleb S. Brooks
Asst. Prof. Kathryn Huff

Part-time Faculty & Postdoctoral Associates

Advanced Energy Materials Thrust
Prof. Hisao Matsunaga
Prof. Kazuyuki Yagi
Assoc. Prof. Shohei Kawada
Assoc. Prof. Hirokazu Kobayashi

Assoc. Prof. Takuro Masumura
Assoc. Prof. Takahiro Matsumoto
Assoc. Prof. Hironobu Ozawa
Assoc. Prof. Tatsuya Uchida
Assoc. Prof. Kosei Yamauchi
Assoc. Prof. Seido Yarimitsu
Asst. Prof. Masaki Donoshita
Asst. Prof. Taro Koide
Asst. Prof. Tomohiro Noguchi
Asst. Prof. Hironori Shinmori
Asst. Prof. Hiroyoshi Tanaka
Asst. Prof. Takeshi Yatabe
Dr. Sumit Shahajirao Bhosale
Dr. Aparna Kashinath Kharade
Dr. Shailendra Kumar Maurya
Dr. Marvin Kevin Sarango Ramirez
Dr. Hui Zeng

Advanced Energy Conversion Systems Thrust
Prof. Kohei Ito
Prof. Masamichi Nishihara
Prof. Kazunari Sasaki
Assoc. Prof. Miki Inada
Assoc. Prof. Tomohiro Shiraki
Assoc. Prof. Masaki Tanaka
Asst. Prof. Youhei Chitose
Asst. Prof. Shota Fukuma
Asst. Prof. Tharindu Rajakaruna
Asst. Prof. Juntae Song
Asst. Prof. Naoki Tanaka
Asst. Prof. Morits Lukas Weber
Dr. Pablo Paul Castellani
Dr. Maksymilian Pawel Kluczny
Dr. Dengyao Yang

Multiscale Science and Engineering for Energy and the Environment Thrust
Prof. Masamichi Kohno
Prof. Kaname Matsue
Prof. Koji Miyazaki
Prof. Takahiko Miyazaki
Prof. Shoji Mori
Prof. Naoya Sakoda
Prof. Atsuomi Shundo
Prof. Kyaw Thu
Assoc. Prof. Tatsunori Ikeda
Assoc. Prof. Ken Kojio
Assoc. Prof. Qin-Yi Li
Assoc. Prof. Jin Miyawaki
Assoc. Prof. Naoki Ousaka
Assoc. Prof. Roman Selyanchyn
Assoc. Prof. Hideaki Teshima
Assoc. Prof. Zhenying Wang
Asst. Prof. Katsuaki Hashikuni
Asst. Prof. Dawei Li
Asst. Prof. Hikaru Matsumoto
Asst. Prof. Masanori Nagao
Asst. Prof. Yutaro Umehara

Center for Energy System Design
Assoc. Prof. Yuan Gao

Visiting Professors & Scholars

Advanced Energy Materials Thrust
Prof. Nikolaos Aravas, *University of Thessaly, Greece*
Prof. Reiner Kirchheim, *University of Göttingen, Germany*
Prof. Robert O. Ritchie, *University of California, Berkeley, U.S.*
Assoc. Prof. Ryosuke Komoda, *Kyushu Institute of Technology, Japan*
Assoc. Prof. Arnaud Macadre, *Yamaguchi University, Japan*
Asst. Prof. Mohsen Dadfarnia, *Seattle University, U.S.*
Asst. Prof. Nan Zhang, *Nagaoka University of Technology, Japan*
Dr. Akihide Nagao, *EBARA Corporation, Japan*
Dr. Vijay Kshitij Vijayvargia, *University of Illinois Urbana-Champaign, U.S.*

Advanced Energy Conversion Systems Thrust
Prof. Taner Akbay
Prof. Seiichiro Kimura, *Renewable Energy Institute, Japan*
Prof. Limin Guo, *Huazhong University of Science and Technology, China*
Prof. John A. Kilner, *Imperial College London, U.K.*
Prof. Ken Okazaki
Prof. Harry L. Tuller, *Massachusetts Institute of Technology, U.S.*
Dr. Takashi Fujihara, *GCE Institute, Inc., Japan*
Dr. Fabrice Mathevet, *IPCM, Sorbonne University - ENRI, France*
Dr. Masayoshi Yamaguchi, *Mitsui Chemicals, Inc., Japan*
Mr. Takuya Ishikawa, *Mitsui Chemicals, Inc., Japan*
Mr. Kosuke Morikawa, *Mitsui Chemicals, Inc., Japan*

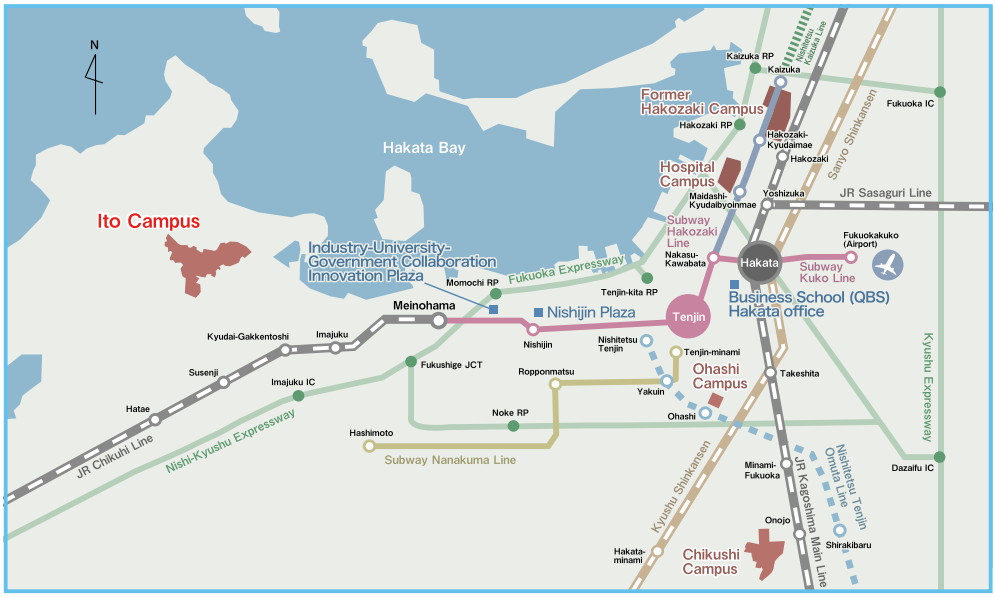
Multiscale Science and Engineering for Energy and the Environment Thrust
Prof. Makoto Akai
Prof. Benny D. Freeman, *University of Texas at Austin, U.S.*
Prof. Yasumasa Fujii, *University of Tokyo, Japan*
Prof. Katsuhiko Hirose, *HyWealth Co., Japan*
Prof. Kuniaki Honda
Prof. Toyoki Kunitake
Prof. Atsushi Kurosawa, *The Institute of Applied Energy, Japan*
Prof. Sushanta Mitra, *University of Waterloo, Canada*
Prof. Khellil Sefiane, *The University of Edinburgh, U.K.*
Assoc. Prof. Jiang Fei, *Yamaguchi University, Japan*
Assoc. Prof. Nguyen Dinh Hoa, *Hanoi University of Science and Technology, Vietnam*
Assoc. Prof. Daniel Orejon, *The University of Edinburgh, U.K.*
Asst. Prof. Jihui Jia, *China University of Petroleum*
Asst. Prof. Yutaku Kita, *King's College London, U.K.*
Asst. Prof. Daniel Orejon, *The University of Edinburgh, U.K.*
Asst. Prof. Biao Shen, *University of Tsukuba, Japan*
Dr. Md. Amirul Islam, *Daishin Co., Ltd., Japan*
Mr. Yukinari Haraguchi, *Carbon Xtract Corporation, Japan*
Ms. Miho Ariyoshi, *NanoMembrane Technologies, Inc., Japan*

Research Center for Next Generation Refrigerant Properties
Prof. Ryo Akasaka, *Kyushu Sangyo University, Japan*
Prof. Yukihiro Higashi
Prof. Chieko Kondo, *Nagasaki University, Japan*
Prof. Akio Miyara, *Saga University, Japan*

*Order by title and alphabetically
*Affiliations for people from Kyushu University are omitted.

Access Map

Map of Fukuoka City



Fukuoka Airport	5min.	Hakata Station	5min.	Tenjin Station	14min.	Meinohama Station	10min.	Kyudai gakkentoshi Station	15min.	Kyudai Big Orange-mae/ Central Library

From Fukuoka Airport,Hakata Station, or Tenjin Station:
Take a train on the Fukuoka City Subway bound for "Meinohama" or "Chikuzen-Maebaru/Karatsu/Nishi-Karatsu."

34min.

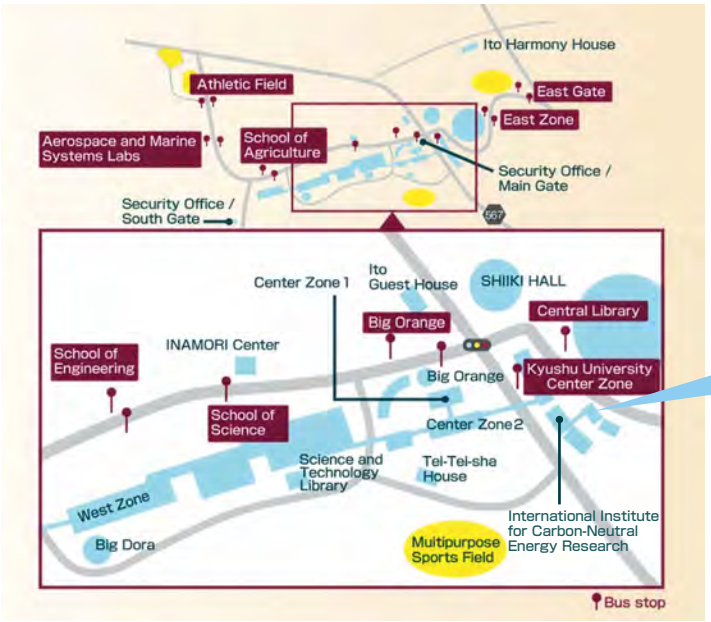
At Meinohama Station:
If your train's destination is "Meinohama," transfer to a JR Kyushu train bound for "Chikuzen-Maebaru/Karatsu/Nishi-Karatsu."

If your train's destination is "Chikuzen-Maebaru/Karatsu/Nishi-Karatsu," no transfer is required at Meinohama Sta.

At Kyudaigakkentoshi Station:
Transfer to Showa bus bound for Kyushu University's Ito Campus.

15min.

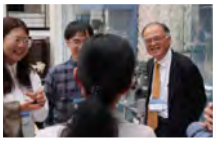
Campus Map (Ito Campus)





International Institute for Carbon-Neutral Energy Research (I^2CNER), Kyushu University
Address: 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
Phone: +81 (0)92-802-6935 Fax: +81 (0)92-802-6939
Website: i2cner.kyushu-u.ac.jp
Facebook: www.facebook.com/I2CNER.news
X: https://x.com/I2CNER

Timeline of I²CNER Activities in FY2025

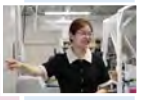










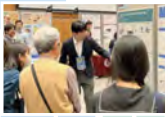












2025

April

- 2 1st I²CNER Seminar Series (ISS)
- 10 **Press release** issued on PI Fujikawa's research
- 12 Media coverage of PI Fujikawa's research
- 14 **Site Visit**
- 16 2nd **ISS**
- 18 **Site Visit**
- 23 122nd **Science Steering Committee (SSC) Meeting**
- 28 **Media coverage** of PI Fujikawa's research

June

- 5 **JCS-Japan Outstanding Paper Award** - Prof. Inada
- 10 **Press release** issued on Prof. Nakamura's research
- 17 **Site Visit**
- 18 3rd **ISS**
- 24 **Tokuo Fujii Award** - PI Adachi
- 25 **Site Visit**
- 28 **WPI Special Session at the EMBO Fellows' Meeting**

August

- 1 **Press release** issued on PI Adachi's research
- 4 125th **SSC Meeting, Site Visit**
- 6 272nd **IISS**
- 18 **Media coverage** of PI Adachi's research
- 19 **Media coverage** of PI Fujikawa's research
- 21 5th **ISS**
- 25 **Site Visit**
- 27 **Innovative PV Encouragement Award** - Prof. Guo

October

- 1 274th **IISS**
- 4 **Thermal Engineering Achievement Award** - Prof. Kohno
- 8 275th **IISS, Site Visit**
- 20 **Site Visit**
- 22 127th **SSC Meeting**
- 28 **Leo Esaki Prize** - PI Adachi
- 29 **Media coverage** of PI Adachi's research

December

- 3 **Kobayashi-Uchiike-Mikoshiba Prize** - PI Adachi, 278th **IISS**
- 5 6th **ISS, Media coverage** of PI Adachi's research
- 6 **JSMS Kyushu Professor Award** - Prof. Shang
- 10 279th **IISS**
- 15 **WPI Booth Exhibition at AGU Annual Meeting** (15-18)
- 16 **Site Visit**
- 17 129th **SSC Meeting**
- 19 **Site Visit**
- 24 280th **IISS**
- 25 **Site Visit**

February

- 4 283rd **IISS**
- 6 7th **ISS**
- 10 **Press release** issued on Prof. Edalati's research
- 13 **Media coverage** of Prof Edalati's research
- 16 **Media coverage** of PI Adachi's research
- 18 284th **IISS**
- 24 **Press release** issued on Prof. Edalati's research
- 25 131st **SSC Meeting**



















2025 May

- 7 268th **Institute Interest Seminar Series (IISS)**
- 13 **Jan Rajchman Prize** - PI Adachi
- 14 269th **IISS, Site Visit**
- 21 **Hayashi Award** - PI Tsuchiyama
- 23 **I²CNER Meeting**
- 28 123rd **SSC Meeting**
- 30 **Press release** issued on PI Adachi's research

July

- 2 270th **IISS, Site Visit**
- 9 **ASME Heat Transfer Memorial Award** - Prof. Takata, 4th **ISS, Site Visit**
- 10 **Media coverage** of PI Fujikawa's research
- 15 124th **SSC Meeting, Site Visit**
- 16 271st **IISS**
- 18 **Site Visit**

September

- 1 **Materials Research Letters Impact Award** - Prof. Edalati
- 3 273rd **IISS**
- 9 **Site Visit**
- 10 **Site Visit**
- 12 **Site Visit**
- 24 126th **SSC Meeting**
- 25 **2025 Women Analyst Award** - Prof. Takahashi Y.
- 28 **Media coverage** of PI Fujikawa's research

November

- 4 **Site Visit**
- 5 276th **IISS**
- 11 **2025 WPI Symposium in Madrid** (11-13)
- 12 **Highly Cited Researchers 2025, Clarivate** - PI Adachi
- 15 **WPI Science Symposium for high school students**
- 19 277th **IISS**
- 20 128th **SSC Meeting**
- 25 **Media coverage** of PI Adachi's research

2026

January

- 7 281st **IISS**
- 14 282nd **IISS, Site Visit**
- 15 **I²CNER Meeting**
- 21 **OIST-I²CNER Joint Symposium** (21-22)
- 23 130th **SSC Meeting**
- 26 **2026 I²CNER Annual Symposium**
- 27 **I²CNER Thrust Workshops**
- 28 **CESD Workshop**

March

- 2 **WPI Young Researchers Forum**
- 4 8th **ISS**, 9th **ISS**, 285th **IISS**
- 9 286th **IISS**
- 11 10th **ISS**, 287th **IISS**, **Site Visit**
- 16 **Site Visit**
- 18 288th **IISS**, **Takei Award** - PI Ishihara
- 23 **Site Visit**
- 27 132nd **SSC Meeting**

I²CNER Annual Report 2025

International Institute for Carbon-Neutral Energy Research (I²CNER)
744 Motooka, Nishi-ku, Fukuoka 819-0395 JAPAN
Phone +81 (0)92-802-6935
Fax +81 (0)92-802-6939
Website : i2cner.kyushu-u.ac.jp

Research Seeds Collection

Support Us



The overhead view of the I²CNER building portrays the *Keeling Curve, which rises over time, to indicate that I²CNER's research will eventually contribute to the downward turn of this curve.
*In 1958, Charles David Keeling began making daily measurements of the concentration of atmospheric carbon dioxide (CO_2) at the Mauna Loa Observatory on the Big Island of Hawaii. Keeling's measurements are the first significant evidence of rapidly increasing carbon dioxide in the atmosphere.

International Institute for Carbon-Neutral Energy Research (I²CNER)
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Website : i2cner.kyushu-u.ac.jp