# 2022

## ANNUAL REPORT

### OF CENTER FOR SUSTAINABILITY SCIENCE

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# Contents

# Foreword

For the Center for Sustainability Science (CSS), Academia Sinica, 2022 was a dynamic year as the ban on international travel was lifted. Many researches and promotional activities have been thus returning to the natural rhythms. The CSS was able to organize in-person meetings for discussions in more traditional and efficient ways. The inconvenience caused by the pandemic taught society that more knowledge should be gathered before realizing global sustainability goals.

In 2022, the CSS continuously acted as an engine to facilitate sustainability sciences required to meet national and global targets. The Sustainability Science Research Program, the annual funding program of the CSS, invited proposals on five main themes: 1) Novel Technology for 2050 Net-Zero Carbon Emissions in Taiwan, 2) Risk Assessment and Response to Extreme Natural Disasters, 3) Risk Assessment for Human Health under Climate Change, 4) Transformation and Governance for a Sustainable Society, and 5) Ecosystems and Sustainable Agriculture. I am happy to see four excellent proposals were approved and began their three-year project terms in January 2023. Their research findings are thus expected by the end of 2025. Furthermore, the CSS organized four campus seminars and two outcome promotion workshops for the proposals launched before 2022. These events fostered interactions between the projects' principal investigators and stakeholders, which is important for promoting sustainability sciences.

Three of our original CSS international programs, the Future Earth (FE) National Committee, IRDR ICoE Taipei, and the Belmont Forum Program Office (BFPO), maintained their usual momentum to enhance global networking.

The CSS sponsored and organized over 40 events, including webinar series and master forums. Among them, one of our FE working groups, the Early Career Researcher, has made notable strides. It clearly shows that younger generations have become major contributors to the community, indicating a hopeful future. In early 2022, our newly established office, the Global Secretariat Hub Taipei of FE, developed a team capable of working with eight international hubs. In September 2022, the Hub Taipei organized a task force for the first FE Assembly held in Paris. Furthermore, our BFPO acted as the Thematic Program Office for Collaborative Research Action (CRA), namely, the Sustainable System for Consumption and Production (SSCP), for the Belmont Forum headquarters. Almost one year was spent working globally with officers from eight countries to complete the entire process of requesting proposals, reviewing, and awarding. Seven international collaborative proposals submitted by scientists from 12 countries were ultimately awarded, with three-year terms beginning in 2023. Taiwanese scientists were involved in three of these studies, reflecting the strength of well-developed transdisciplinary research in Taiwan.

The ad hoc task for CSS, helping publish the Strategic Recommendations for Science and Technology Actions towards Net Zero Emission in Taiwan of Academia Sinica, was assigned in late 2020 and completed in November 2022. This work made the invitations to over 300 scientists, who were relevant knowledge bearers, to evaluate the potential of all possible technology choices to reduce Taiwan's greenhouse gas emissions.

Five specific technologies were selected, with a priority on stimulating the decarbonization of Taiwan to meet the global goal of net-zero emissions before 2050. Academia Sinica will continuously work with interested colleagues to seek the best energy transition pathways for Taiwan.

This annual report summarizes the highlights of CSS's work during 2022, indicating that Academia Sinica is striving toward its institutional objective of fulfilling social responsibilities in crucial areas. The CSS enthusiastically carries out its assigned jobs and responsibilities, and I believe there will be many more achievements in the coming years.

Mei-Yin Chou

Mei-Yin Chou
Chairperson, Center for Sustainability Science
Academia Sinica

# Center for Sustainability Science

## Introduction

Academia Sinica has three research divisions, namely Mathematics and Physical Sciences, Life Sciences, and Humanities and Social Sciences. Most researchers explore scientific mysteries within their research disciplines. However, contemporary sustainability problems require collaboration across disciplines. The Center for Sustainability Science (CSS) was established in 2012 in Academia Sinica with the core mission of promoting interdisciplinary sustainability science research both domestically and internationally.

The purpose of sustainability science is to use science and other methods to solve problems. Three key tasks of the CSS are：

(1) To plan, organize, and promote the Sustainability Science Research Program (SSRP) through problem solving, interdisciplinary work, and stakeholder participation；

(2) To serve as the project office for three sustainability science-related international cooperation programs (i.e., IRDR-ICoE, Future Earth, Belmont Forum) and to connect Taiwan's researchers to the global sustainability research community；and

(3) To provide evidence-based policy recommendations regarding sustainability issues.

## Organization and Task

Academia Sinica

Center for Sustainability Science (CSS)

Program Panel Committee | Executive Office | Advisory Board

**National Policy Recommendations**

Pathway to Net Zero Committee

**Sustainability Science Research Program**

- Research Project
- Open Symposium
- Regular Seminar
- Outcome Workshop

**International Program**

- Integrated Research on Disaster Risk (IRDR), International Centre of Excellence (ICoE)-Taipei
- Future Earth Taipei and Future Earth Global Secretariat Hub Taipei
- Belmont Forum Program Office

| Program Panel Committee |
|---|
| Dr. Chun-Guey Wu |
| Dr. Jia-Yuh Yu |
| Dr. Faa-Jeng Lin |
| Dr. Teng-Chiu Lin |
| Dr. Yu-Pin Lin |
| Dr. Kuei-Tien Chou |
| Dr. Jin-Li Hu |
| Dr. Mei-Lien Chen |
| Dr. How-Ran Guo |
| Dr. Bing-Joe Hwang |
| Dr. Shin-Cheng Yeh |
| Dr. Fuh-Jyh Jan |

| Advisory Board |
|---|
| Dr. Yuan-Tseh Lee (Chairperson) |
| Dr. Gordon McBean |
| Dr. Hiroshi Matsumoto |
| Dr. Johan Rockström |
| Dr. Leland H. Hartwell |
| Dr. Mark Stafford Smith |
| Dr. Michael Crow |
| Dr. Mohd Nordin Hasan |
| Dr. Olive Shisana |
| Dr. Shaw Chen Liu |

| Members of Executive Office | |
|---|---|
| Chairperson | Vice President Dr. Mei-Yin Chou |
| Executive Secretary | Dr. Yue-Gau Chen |
| Deputy Executive Secretary | Dr. Shih-Chun Lung, Dr. Jian-Cheng Lee |
| Distinguished Visiting Chair | Dr. Yu Wang |
| Visiting Specialist | Dr. Liang-Jung Wei, Revital Shpangental |
| Administration Chief of CSS Office | Dr. Shih-Yun Kuo |
| Science Officers of International Programs | Dr. Yu-Chun Chung, Dr. Han-Yu Chiu,<br>Dr. Hsin-Lin Su, Dr. Chi-Ting Peng,<br>Dr. Ying Liao, Dr. Vladina Presto |
| Program Managers | Yun-Han Chin, Chia-Lun Kuo, Tzu-Hsun Chang, Yen-Yu Chou, En-Yu Chang |

## Highlights in 2022

The CSS had several notable accomplishments in 2022. This annual report presents the key achievements of several SSRP projects (see pages 28–44) and of the CSS's international programs (i.e., IRDR-ICoE, Future Earth, Belmont Forum) (see pages 8–27). The highlights of the policy recommendation mission are as follows.

**Assisting in Publishing "Strategic Recommendations for Science and Technology Actions Toward Net-Zero Emissions in Taiwan"**

Since 2020, the CSS has assisted in preparing policy recommendations for achieving net-zero emissions. During this 2-year project, the CSS organized 23 expert and committee meetings involving 308 participants in which the participants discussed a variety of topics. These topics included energy options (e.g., geothermal energy, bioenergy, hydrogen, energy storage, and fuel cells); decarbonization options in four high-emission industries (i.e., the steel, cement, petrochemical, and electronics industries) and three other sectors (i.e., the transportation, residential and commercial, and agriculture and waste sectors); innovative technology (e.g., carbon capture utilization and storage, next-gen nuclear energy systems); and social and economic driving factors towards Net-Zero transformation.

The Recommendation Report of this project not only provides a comprehensive and systematic analysis of Taiwan's scientific and technological pathways to net-zero emissions but also identifies and prioritizes five crucial net-zero technologies that are likely to reduce greenhouse gas emissions considerably. These technologies are pyrolysis-based hydrogen, geothermal energy, marine energy, high-efficiency solar energy, and biomass carbon sinks.

The report was published and released in November 2022. The full version of the Strategic Recommendations for Science and Technology Actions Toward Net-Zero Emissions in Taiwan can be at https://www.sinica.edu.tw/advice_17.

## Activities in 2022

### January 25

**Pathway to Net Zero Committee 6th Meeting**

Subject: Social-Economic Enabling Factors

### March 16

**SSRP Seminar**

- Project: Governance Transition toward a Sustainable Society: The analysis and practice of the governance transition toward Taiwan 2050 Net-Zero Society (Kuei-tien Chou)
- Project: Global Risks and Local Sustainability under Climate Change in Taiwan (Thung-Hong Lin)

### May 10

**SSRP Seminar**

- Project: Study on Climate Change Risk Assessment of Business (Huang-Hsiung Hsu)
- Project: Integrative Studies of Species Vulnerability to Climate Change (Sheng-Feng Shen)

## May 26

**Pathway to Net Zero Committee 7th Meeting**

Subject: Policy Recommendation

## July 28

**SSRP Outcome Workshop**

Project: Emissions of Reactive Nitrogen Species due to Fertilization and Its Impacts to Air Quality (Charles C.-K. Chou)

## August 4

**SSRP Seminar**

Project: Trans-disciplinary PM2.5 Exposure Research in Urban Areas for Health-oriented Preventive Strategies (II) (Shih-Chun Lung)


## October 27

**SSRP Outcome Workshop**

Project: High Efficiency Solar Fuels: From Materials Development to Device Integration (Yu-Tai Tao)

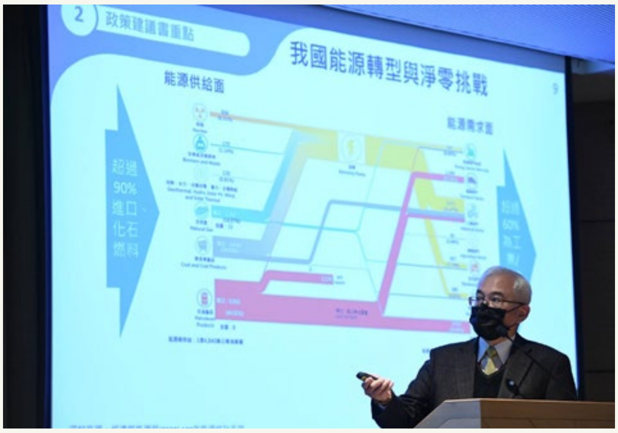
## November 3

**SSRP Seminar**

- Project: Bio-electro opto-controlled conversion of $CO_2$ (Ming-Hsi Chiang)
- Project: Scalable GDE-Based Flow CO2 Electrolyzer with High Energy Efficiency and High Product Selectivity (Chen-Hsiung Hung)

## November 30

**Pathway to Net Zero Committee Policy Recommendation Report Launch Meeting**

# IRDR ICoE Taipei

## Introduction

The emerging global risk landscape has posed new challenges for disaster response and mitigation. To address and respond to changing societal needs, the International Science Council (ISC) and the United Nations Office for Disaster Risk Reduction (UNDRR) jointly established the Integrated Research on Disaster Risk (IRDR) program as a global interdisciplinary program in 2010. In the same year, a chapter of the IRDR program, named the International Centre of Excellence in Taipei (ICoE Taipei), was established in Taiwan with the support of Academia Sinica. Subsequently, ICoE Taipei and the ISC jointly planned and organized international exchange activities to promote disaster-risk-reduction (DRR) events on a global scale. In 2012, the administrative and logistical functions of ICoE Taipei were integrated into the newly established Center for Sustainability Science (CSS) at Academia Sinica.

Taipei ICoE

International Science Council

IRDR ICoE
Integrated Research on Disaster Risk
International Centre of Excellence

The mission of ICoE Taipei is to respond to the international trend toward sustainable disaster reduction and to strengthen Taiwan's role in this area within the Asia-Pacific region. Through its efforts to contribute to scientific research, develop policies, and implement knowledge-based actions, ICoE Taipei is committed to promoting Taiwan's DRR research and experience to the international community.

In alignment with the Sendai Framework for Disaster Reduction (SFDRR), which serves as the United Nations' guiding principle for international DRR for the period from 2015 to 2030 and the core objective of the IRDR program, ICoE Taipei prioritized its tasks and actions to focus on (1) capacity building (i.e., building and enhancing professional disaster reduction capacity), (2) collaborative research (i.e., integration and expansion of cross-national and cross-disciplinary disaster prevention research), and (3) networking (participation in the construction of an international network platform) (Figure 1).

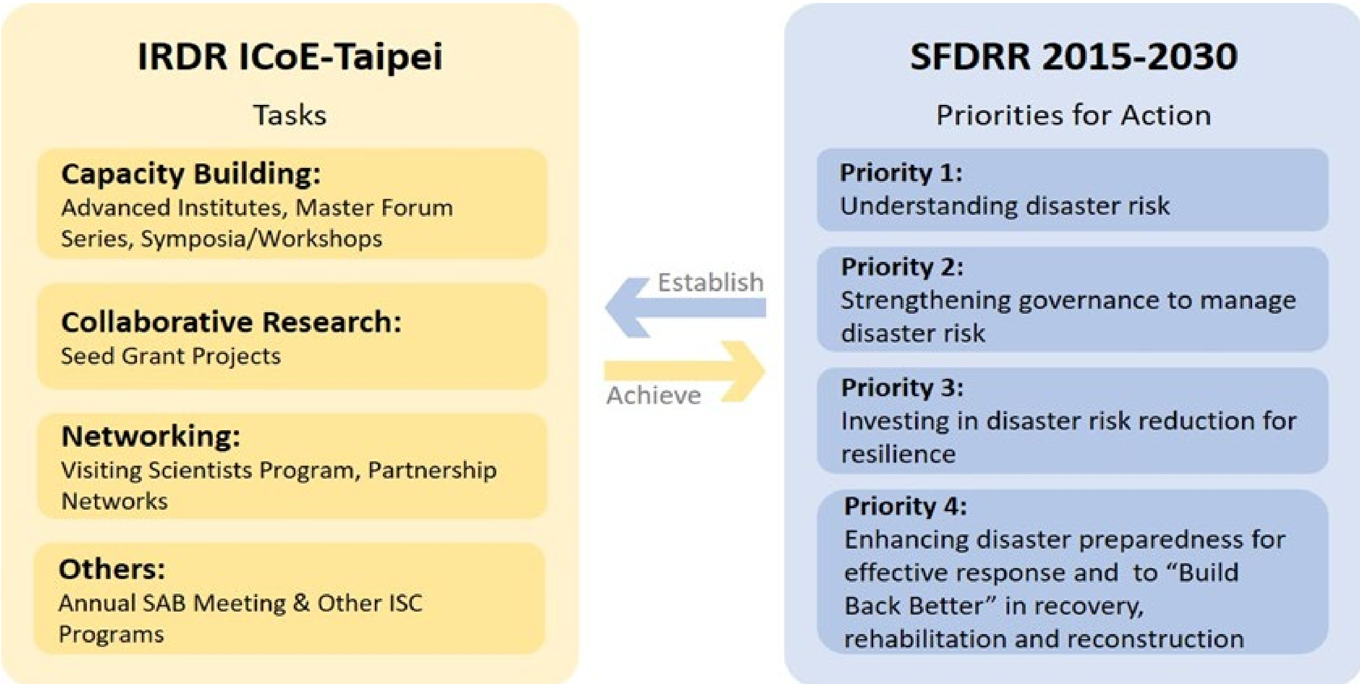



Figure 1. Alignment between main tasks of ICoE Taipei and priorities of SFDRR 2015–2030.


## Highlights in 2022

### 1.Publication of IRDR ICoE Taipei 2010-2021 Ten-Year Report

In 2022, IRDR ICoE Taipei published its 2010–2021 Ten-Year Report (Figure 2). The report comprehensively documents the achievements of ICoE Taipei over the past decade. ICoE Taipei has not only established itself as an international hub for DRR but also as a leading center for organizing capacity-building workshops in the Southeast Asia and Pacific regions. To date, it has successfully conducted 15 international training workshops covering various DRR themes, including environmental change-related disaster management (seven workshops), earthquake risk assessment (two workshops), flood and landslide reduction (two workshops), volcano risk prevention (one workshop), and disaster management strategies (three workshops) (Figure 3). More than 300 experts and young scholars from more than 20 countries attended these training workshops. Additionally, nine key themes were selected for the implementation of follow-up seed grant projects, and 31 multinational and interdisciplinary projects received seed grants as a result. These seed grants are key in providing initial support for young researchers to build international networks and conduct transnational studies.

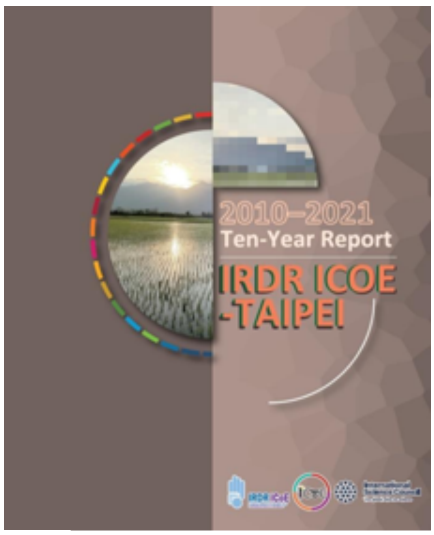



Figure 2. Cover page of IRDR ICoE Taipei Ten-Year Report.

| | | |
|---|---|---|
| 1 | March 2012 | Advanced Institute on Forensic Investigations of Disasters, AI-FORIN |
| 2 | October 2012 | Advanced Institute on Data for Coastal Cities at Risk, AI-DATA |
| 3 | April 2015 | Advanced Institute on Disaster Risk Reduction and Loss Mitigation, AI- DRR & LM |
| 4 | April 2017 | Advanced Institute on Knowledge-based Actions for Disaster Risk Reduction, AI-KBA |
| 5 | July 2017 | Advanced Institute on Disaster Risk Reduction with Systems Approach for Slow-Onset Climate Disasters: Sensors, and Big Data, AI-SOCD on Air Pollution |
| 6 | June 2018 | Advanced Institute on Disaster Risk Reduction with Systems Approach for Slow-Onset Climate Disasters: Heat Stress Sensors, Early Warning, and Information Technology, AI-SOCD-heat stress |
| 7 | August 2018 | Advanced Institute on Landslide Risk Reduction Training School – Landslide hazards: From Site Specific to Regional Assessment, AI-LRRTS |
| 8 | October 2018 | Advanced Institute on Earthquake Hazard and Risk Assessment in East Asia, AI-EHRA |
| 9 | March 2019 | Advanced Institute on Earthquake Early Warning in East Asia, AI-EEW |
| 10 | July 2019 | Advanced Institute – Training Course on Landslide Investigations and Hazards Mitigation, AI-LIHM, Hanoi, Vietnam |
| 11 | September 2019 | Advanced Institute on Health Impacts and Air Sensing in Asian Pollution, AI-Hi-ASAP 2019 |
| 12 | October 2019 | Advanced Institute on Asian Consortium of Volcanology – 4th Field Camp of Asian Consortium of Volcanology, AI-ACV |
| 13 | October 2020 | Advanced Institute on Health Impacts and Air Sensing in Asian Pollution, AI-Hi-ASAP 2020 |
| 14 | October 2021 | Advanced Institute on Health Impacts and Air Sensing in Asian Pollution, AI-Hi-ASAP 2021 |
| 15 | December 2021 | Advanced Institute on Knowledge-based Actions for Disaster Risk Reduction, AI-KBA |

Figure 3. Chronological list of 15 capacity-building workshops organized by ICoE Taipei in the past decade.

**2.Contribution to Transnational DRR Research:**

The call for proposals for the inaugural JDR-ICoE Taipei special issue was announced in May 2022 in collaboration with the Journal of Disaster Research (JDR), which is a leading risk management journal in Japan. Most of the contributing authors have previously participated in the capacity training workshops organized by ICoE Taipei and are from Southeast Asian and South Asian countries. This new initiative highlights the contributions of ICoE Taipei in cultivating talent and sharing research findings in the DRR research community.

## 2022 Activities

### February 17

**ICoE Taipei Master Forum Series 3: Professor John Handmer on "A Framework for Global Risk Science: Priorities, Production, and Debates."**

John Handmer, an honorary professor at the Royal Melbourne Institute of Technology, Australia, gave an online presentation on how he created A Framework for Global Science in Support of Risk-informed Sustainable Development and Planetary Health. This framework was published in 2021 by the ISC, UNDRR, and IRDR program. During the online presentation, Handmer discussed the main research questions proposed in the framework, how these issues were raised, and the substantive and philosophical discussions that were conducted during the development of the framework. Approximately 106 online registrants attended the talk, which was livestreamed on YouTube, where it attracted approximately 141 viewers.


Figure 4. ICoE Taipei 2022 Master Forum flyer.

### June 20–24

**ICoE Taipei and ICoE Japan joint session featured in the Asia Spotlight program at SRI2022**

As part of the Asia Spotlight program at SRI 2022, ICoE Taipei and ICoE Japan co-organized the dialogue-style forum "Online Synthesis Systems (OSS): A Web-Based Knowledge Integration System for Disaster Risk Reduction, Resilience, and Sustainability," which featured risk experts from ICoE Japan and ICoE Taipei.


Figure 5. ICoE Taipei and ICoE Japan joint session flyer.

## November 14 and 15

### ICoE Taipei 2022 Annual Scientific Advisory Board Meeting (SAB meeting) in Taichung

The Scientific Advisory Board (SAB) of IRDR ICoE Taipei comprises both international and local members. Each year, ICoE Taipei holds an SAB meeting to report on the activities of the year, review plans for the coming year, and exchange strategic resources for the Centre's future development. This year's meeting was held on November 14 and 15 at the Lin Hotel in Taichung.

Figure 6. Group photo of 2022 ICoE Taipei SAB meeting attendees (from left to right): Chung-Pai Chang (newly appointed ICoE Taipei director), Wei-Sen Li (SAB member), Anond Snidvongs (SAB member), Yue-Gau Chen (Executive Secretary of CSS), Jian-Cheng Lee (ICoE Taipei director), James Terry (SAB chair), Tony Liu (SAB member), Takashi Okabe (ICoE Japan representative), and Shyh-Jiann Hwang (SAB member).


Figure 7. SAB and guest members attending the online meeting. The individuals in the photo are Kuo-Fong Ma (SAB member, upper middle), Chao-Han Liu (guest member, upper right), Qunli Han (IRDR IPO director, lower left), Gordon McBean (SAB member, lower middle), and Haruo Hayashi (SAB member, lower right).

# Belmont Forum

## Introduction

The Belmont Forum (hereinafter the Forum), formerly known as the Steering Committee of The International Group of Funding Agencies for Global Change Research, was officially established in 2009. The organization aims to promote international transdisciplinary research that helps us to understand, mitigate, and adapt to global environmental changes. A total of 30 funding agencies worldwide, which are also members of the Forum, are authorized to mobilize resources to promote studies aimed at resolving crucial global challenges pertaining to environmental changes. These solution-oriented studies, called collaborative research actions (CRAs), have addressed a wide array of themes since 2012.

The National Science and Technology Council of Taiwan (NSTC; formerly known as the Ministry of Science and Technology) and Academia Sinica (AS) became members of the Forum in 2015 and 2021, respectively. Since then, sustainability science researchers affiliated with 17 Taiwan-based research projects have participated in seven CRAs, namely the food-water-energy nexus (Nexus) CRA; science-driven e-infrastructure innovation (SEI) CRA; the climate, environment, and health (CEH) CRA; the CRA for promoting the sustainability of soil and groundwater for society (Soils); the transdisciplinary research for pathways to sustainability (Pathways) CRA; the Disaster Risk Reduction and Resilience (DR3) CRA; and the Systems of Sustainable Consumption and Production (SSCP) CRA. Notably, the DR3 and SSCP CRAs were supported by two NSTC-coordinated thematic program offices (TPOs), which contributed substantially to the project review and management processes of these CRAs.

## Highlights of Year 2022

### 1.Establishing a TPO for the SSCP CRA

The SSCP-CRA TPO was officially established in Taiwan and approved at the Belmont Forum Plenary Meeting held on October 26, 2021. In February 2022, the SSCP CRA was launched by Belmont Forum, which announced it on its official website (BelmontForum.org). Thereafter, the NSTC, Belmont Forum Program Office (BFPO), and the Taiwan-based research teams affiliated with the SSCP CRA made concerted efforts to collaborate on the SSCP CRA.

In 2022, the TPO worked closely with the Secretariat Coordinator (SEC) and BFgo Provider to establish an application schedule and to collate and update the call documents published on both the BFgo and BelmontForum.org websites. The TPO and the Group of Program Coordinators (GPC) played key roles in the registration review process, and the BFPO held several meetings to coordinate with Forum members, the GPC, and the panel of experts (PoE) involved in the preparation of the multilateral proposal for the SSCP CRA.

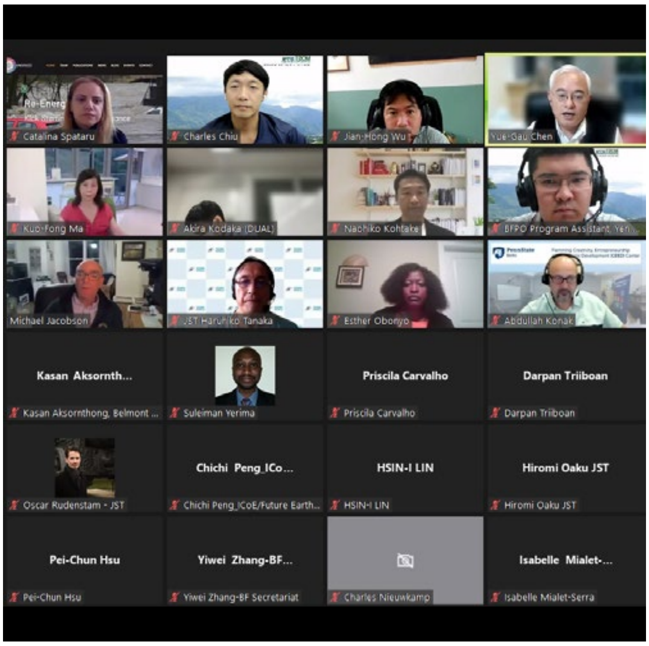



Figure 1. Belmont Forum Midterm DR3 CRA workshop hosted by BFPO.

### 2.Promoting Collaborations Between Taiwanese and International Scholars

The Sustainability Research & Innovation Congress 2022 (SRI2022) was an international conference dedicated to promoting sustainability scholarship and innovation and transdisciplinary and cross-sectoral collaboration and actions. At the SRI2022, the following two sessions related to the Forum were hosted by the BFPO:

#### Midterm DR3 CRA Workshop at the SRI2022

The five Disaster Risk Reduction and Resilience (DR3) project groups involved in the DR3 CRA were invited to conduct a midterm workshop to report the progress of the CRA. During the Q&A segment of the workshop, the principal investigators (PIs) discussed the challenges that they encountered when conducting research and developing solutions.

#### Special event for SRI2022: Scientific and Strategic Experience in Leading Sustainability Science Research in Taiwan

This session brought policymakers and leading AS and NSTC scientists together. At this event, Dr. Minn-Tsong Lin, the Deputy Minister of the NSTC, was the keynote speaker and presented on the topic of science strategy development in a presentation titled "Toward the Sustainable New Age of Taiwan: On a Core-Value-Driven Innovation Policy." Dr. Yue-Gau Chen and Dr. S.C. Candice Lung also discussed the scope of sustainability research in Taiwan and the notable achievements in this field, highlighting Taiwan's major contributions to the Future Earth program and the Forum, which are the world's two most global sustainability science programs.


Figure 2. Special event for SRI2022: Scientific and Strategic Experience in Leading Sustainability Science Research in Taiwan (hosted by BFPO).

## 2022 Activities

### March 14

**2022 Belmont Forum SSCP CRA workshop**

The Belmont Forum Program Office (BFPO) hosted this workshop, which was co-organized with the Research Institute for the Humanities and Social Sciences (RIHSS) to provide a platform for local academic and research exchanges. The workshop was held to promote international scientific research cooperation and increase the participation of local scholars in the SSCP CRA of the Forum. It also provided a platform for exploring SSCP-related research needs, discussing cross-field and interdisciplinary collaborative research structures, and updating local scholars on the latest international research actions.

Figure 3. Belmont Forum SSCP CRA workshop.

### June 9, 14, and 16

**Belmont Forum Scoping Workshops Unlock the Potential of Urban Green and Blue Space**

This 3-day workshop brought together representatives from the international research community and the program officers of interested funding agencies from various Belmont Forum countries. The main goal of the workshop was to identify options for the planned establishment of a Forum CRA themed on unlocking the potential of urban green and blue spaces. The progress of this new CRA was discussed with the 50 Forum members and funding agencies, and feedback was collected to prepare for the new CRA.

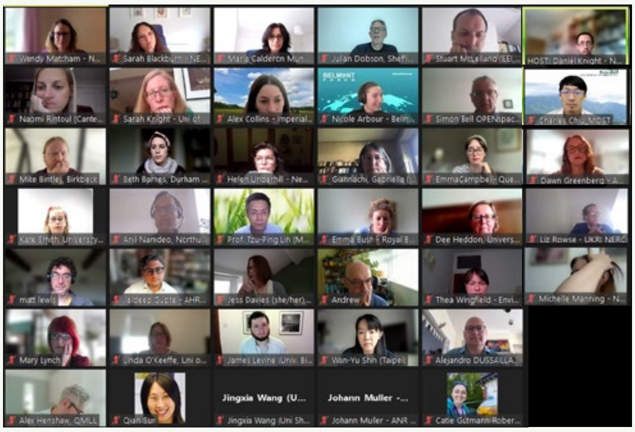


Figure 6. Scoping Workshops for Unlocking Potential of Urban Green and Blue Spaces.

### May 10

**Belmont Forum funder's scoping meeting for Pathways to Sustainability II CRA**

As a TPO, the National Science Foundation (NSF) is working on the second phase of the "Transdisciplinary Research for Pathways to Sustainability" call. This meeting was convened to provide support for networking activities and to establish collaborative projects for supporting transdisciplinary networks. The 36 Forum members and various funding agencies discussed the progress of the Pathways to Sustainability II CRA, and feedback regarding the CRA was collected.


Figure 4. Belmont Forum funder's scoping meeting for Pathways to Sustainability II CRA

### May 25

**Belmont Forum World Rivers Day Conference**

To celebrate 2022 World Rivers Day with worldwide aquatic ecosystem enthusiasts, the Belmont Forum ABRESO Taiwan team organized a conference on the fourth Sunday of September. The conference was attended by both Taiwanese and foreign researchers and stakeholders, and its objective was to redirect the attention of scholars and practitioners toward the ecosystem and human health dimensions related to watershed areas that are being conserved and undergoing transition.

Figure 5. Belmont Forum World Rivers Day Conference

## June 21–25

### Sustainability Research & Innovation Congress 2022

At the SRI2022, the BFPO co-organized the four Forum-related sessions as follows:

(1)Belmont Forum Members Meeting

(2)Midterm DR3 CRA Workshop at the SRI2022

(3)Special Event on SRI 2022 Taiwan at Belmont Forum Workshop on Belmont Forum DR3 CRA

(4)Online Synthesis Systems.

## July 5–7 ; December 1 and 2

### First and second PoE meetings for Belmont Forum SSCP CRA

The NSTC of Taiwan is serving as the TPO for the SSCP CRA. It is responsible for central management, procedure documentation, and the implementation of a streamlined flow of information during the evaluation and selection of proposals. The NSTC hosted a PoE meeting and a post-review meeting (PRM) attended by the GPC and Chair; at these meetings, all relevant information was collected, stored, and provided to the relevant boards, panels, and individuals as required for evaluation and selection purposes.

Figure 7. Belmont Forum SSCP CRA First PoE meeting.

Figure 8. Belmont Forum SSCP CRA Second PoE meeting.

## December 12–16

### American Geophysical Union Fall Meeting

The BFPO attended the American Geophysical Union Fall Meeting 2022. This meeting was held at the McCormick Place Convention Center in Chicago, IL, USA. At this event, the BFPO set up an event booth and shared with interested and qualified attendees information pertaining to the sustainability research conducted in Taiwan and the related exchange opportunities.

Figure 12. AGU Fall Meeting.

## October 25–27

### Belmont Forum 2022 Virtual Plenary Meeting

The Belmont Forum Secretariat organized the plenary meeting, which was a virtual meeting. More than 53 members of the Belmont Forum attended the closed session on the first two days, and more than 69 participants participated in the open session on the final day. The meeting revolved around discussions on the following topics:

- the annual report and coordination practices report
- the presentation of the CRA schedule for upcoming activities (Urban Blue & Green event; Climate, Environment, Health II, and Climate and Cultural Heritage event)
- the presentation of the Belmont Forum portfolio analysis results following the 2022 report.

Figure 9. Opening of SRI 2022.


Figure 10. Dr. Nicole Arbour, Belmont Forum Executive Director, at SRI opening.

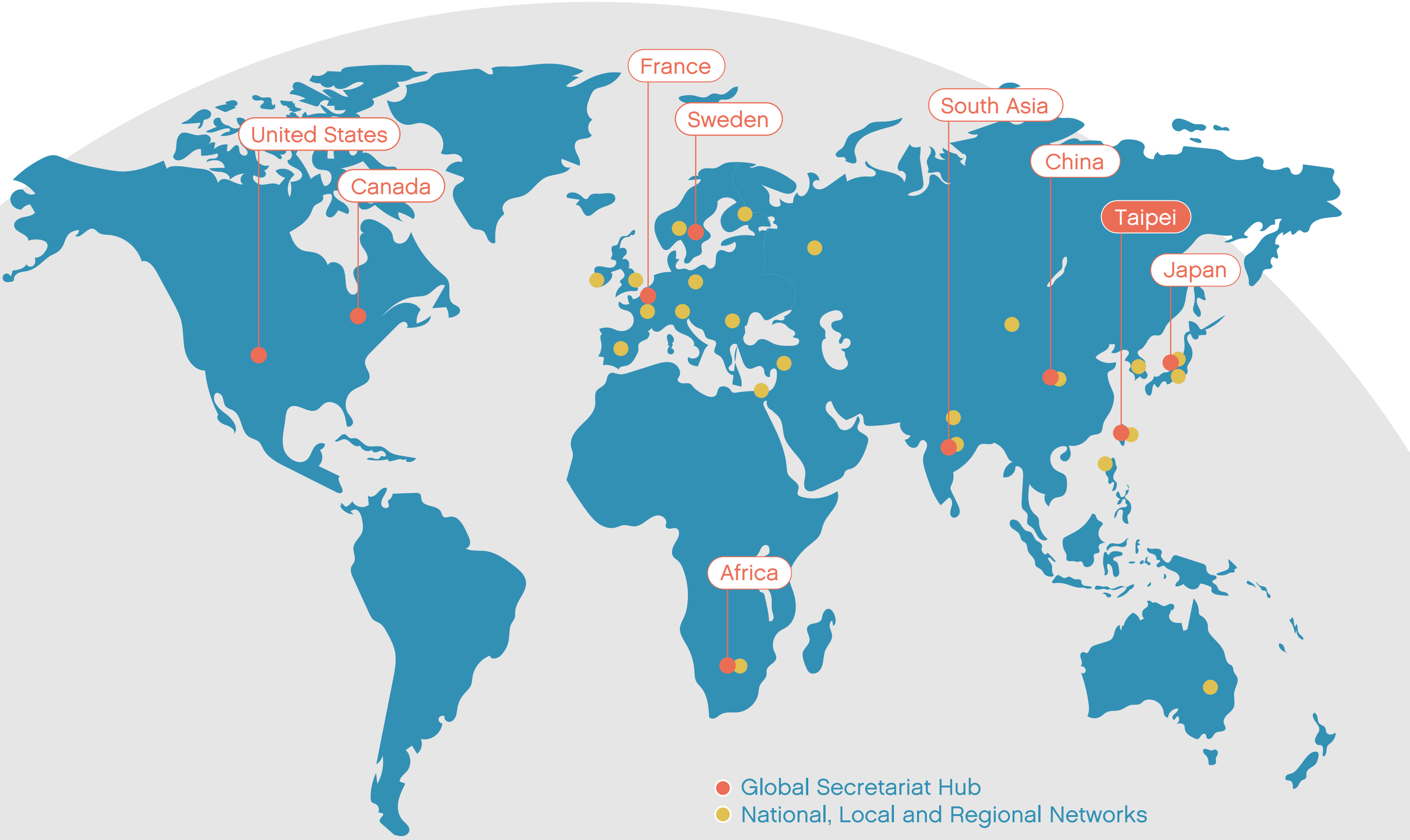
## November 9

### SRI2023 Informative Webinar

SRI2023 will be hosted in the Republic of Panama (SENACYT) by the Inter-American Institute for Global Change Research in June 2023. The organizers of SRI2023 are holding an informational webinar to answer questions about the event and to obtain guidance on making successful contributions during the meeting.


Figure 11. SRI2023 Informative Webinar.

# Future Earth Global Secretariat Hub Taipei




## Introduction

The Future Earth Global Secretariat Hub (GSH) was established in Taipei in 2021 by the Center for Sustainability Studies (CSS) to facilitate Future Earth Taipei's operations and collaborations with the global research community. The Taipei Hub serves four primary functions: promoting research and innovation, capacity and networks, communication and engagement, and finance and operations. The main objective of the Taipei Hub is to connect the local research community with the global research network by organizing events and activities hosted by Future Earth Taipei and CSS.

## Highlights in 2022

### Strengthen Local and Global Research Networks in Sustainability Science

The Taipei Hub is dedicated to enhancing local and global research networks in the field of sustainability science. To achieve this goal, it provides active support to Future Earth Taipei's participation in global events and encourages international collaboration. One such global event is the Sustainability Research & Innovation (SRI) Congress, which the Taipei Hub supported, especially in co-organizing its satellite event, Asia Spotlight Event. The SRI Congress is a platform for local researchers to showcase their research on a global stage. Furthermore, the SRI ASE focuses on regional sustainability topics. These events consist of several online sessions that allow local and international researchers to exchange their ideas and knowledge. In addition, the Taipei Hub has co-organized 13 webinars under the Webinar Series of Global Sustainability that address sustainability issues such as health, risk, urbanization, and oceanography.

### Hub-to-Hub Collaboration through Early Career Researchers (ECRs) Networks

The Taipei Hub has been collaborating with various global hubs, such as Africa, Canada, China, France, Japan, South Asia, Sweden, and the United States, to promote sustainability science. For instance, the Future Earth Taipei Early-Career Researcher (ECR) Working Group has been organizing a Sustainability Science webinar series. Moreover, the hub has been holding bilateral research sessions with the French and Canada Hubs, providing a platform for local researchers to interact with global research networks and share their findings on topics such as net-zero, digital sustainability, energy efficiency, nature-based solutions, and water consumption and management. These webinars have garnered hundreds of participants from local and global research networks, as well as other stakeholders in the sustainability field.

### Capacity Building and Future Earth Global Research Networks (GRNs) Engagement

The first in-person Future Earth Assembly was held in Paris from September 21 to 23, and it was attended by over 100 representatives from Future Earth communities. Dr. Yue-Gau Chen, Dr. Tzu-Ching Meng, Revital Shpangental (the Taipei Hub Director), and the Taipei Hub team represented the Hub at the event. They shared strategic recommendations for Future Earth's development and organized follow-up meetings with other Global Hubs after the Assembly.

As the global liaison for the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS), the Taipei Hub facilitates interactions with other Future Earth Global Research Networks (GRNs). The Taipei Hub Director, Revital Shpangental, visited the iLEAPS International Project Office in October to explore ways of strengthening the Hub's engagement with Future Earth GRNs.

In November, the Taipei Hub was involved in various activities with Future Earth Global Research Network (GRN). The Taipei Hub provided support to the Systems of Sustainable Consumption and Production (SSCP) Knowledge-Action Network (KAN) during their online conference held between November 8 and 17. Professor Anthony Capon, who co-chairs the Health KAN, visited the Taipei Hub and the Future Earth Taipei Health Working Group on November 16th and 17th. In addition, the Taipei Hub collaborated with the Ocean KAN International Project Office and the Future Earth Ocean Working Group to organize the Ocean Action Symposium on November 28th and 29th.

# Major Activities

## February 22

### Webinar Series on Global Sustainability

In 2022, the Future Earth Taipei Health Working Group organized and hosted the first webinar, 'Climate Change and Health,' under the Webinar Series on Global Sustainability. This webinar series aimed to promote global knowledge exchange and collaboration among scholars and stakeholders working in sustainability. The series covered various themes, including digital technology for sustainable finance, science, marine and coastal management.


## June 20–24

### Co-organizing Satellite Event of SRI2022 Asia Spotlight

The aim of the SRI congress is to inspire action and promote sustainability transformation. It brings together international academics, industry stakeholders, and innovators. In addition to the main congress held in Pretoria, South Africa in 2022, the Taipei Hub participated in organizing the SRI Asia Spotlight Event (ASE). This event focused on regional sustainability challenges and opportunities. The Taipei Hub co-organized several sessions for the ASE on the topics of typhoons, environmental open data, blue carbon, online synthesis systems, and smart agriculture.

## September 21–23

### Future Earth Assembly 2022

The Future Earth Assembly 2022 was held in a hybrid format at the Centre International de Conférences Sorbonne Université in Paris. Future Earth aims to advance transdisciplinary research and support transformations that benefit global sustainability. The Assembly provided a crucial and timely opportunity for open discussions, geared towards promoting the mission and vision of Future Earth. Representatives from Future Earth communities attended the Assembly and engaged in strategic discussions. Among them included the Taipei Hub team, led by Dr. Yue-Gau Chen and Dr. Tzu-Ching Meng, who are the Taipei Hub's funder representatives, and the Taipei Hub Director, Revital Shpangental. They participated in discussions with other Future Earth entities, which led to concrete recommendations.

# Future Earth Taipei

## Introduction

Future Earth is a global scientific network that promotes sustainability science and drives the transformation of organizations toward sustainability. Inspired by previously established programs such as the International Geosphere-Biosphere Programme and the International Human Dimensions Programme on Global Environmental Change, the Future Earth network was officially announced in 2012 and finally established in 2015. Future Earth represents the culmination of three decades of effort, and it aims to deepen our knowledge of the connections among environmental, social, and economic systems and apply this knowledge to develop evidence-based policies and actions. A three-pronged approach is currently being employed. It involves (1) supporting 27 Global Research Networks that work together to understand the complex interactions between natural, social, and technological systems, and how those interactions affect the planet's life support systems, socioeconomic development, and human well-being across time and space; (2) building and mobilizing early career networks; and (3) shaping the global narrative by facilitating conversations between scientists and decision-makers. As a member of the International Science Council, which plays a key role in the Governing Council of Future Earth, Academia Sinica has been actively participating in the development of Future Earth and its vision.

In 2015, Future Earth Taipei was officially established, and the Center for Sustainability Science of Academia Sinica assisted in the operation of the Future Earth Taipei Secretariat. The Future Earth Taipei Committee features a diverse composition of members that enhances the link between science and policies/actions. The 4th Committee (2021–2023 term) comprised a total of 33 members, with 23 being affiliated with various research communities and 10 being representatives of industry stakeholders, NGOs, and government agencies (Table 1).To realize Future Earth's strategy for network mobilization, Future Earth Taipei established 11 Working Groups (WGs) comprising more than 125 members by 2020 (Table 2). Among the 11 WGs, eight are affiliated with the Future Earth Knowledge-Action Network (KAN), one is affiliated with Future Earth's emerging Sustainability in the Digital Age initiative, and one is affiliated with Future Earth's Early-Career Network. The NGO WG is an innovative concept developed by Future Earth Taipei, which aims to engage NGOs and leverage their actions and resources to expand scientific knowledge.

**Table 1. Future Earth Taipei Committee Members** [November 2021 – November 2023]

| | | | |
|---|---|---|---|
| Ching-Cheng Chang | Wim Y.C. Chang | Eugene Chien | Wen-Harn Pan |
| Yue-Gau Chen* | Sophia Cheng | Hsin-Huang Michael Hsiao | Huei-min Tsai |
| Yu-Chung Chiang | Chang-Hung Chou | Hsing-juh Lin | Pao-Kuan Wang |
| Tyng-Ruey Chuang | Shu-Li Huang | Teng-Chiu Lin | Ching-Hua Lo |
| Ling-Ling Lee | Jiun-Chuan Lin | Huey-Jen Jenny Su | Shin-Cheng Yeh |
| Neng-Hui Lin | Tze-Luen Lin | Chao-Han Liu | Lin-Yi Tsai |
| Shao-Po Peng | Jough-Tai Wang | Shih-Chun Candice Lung § | Bo-Wen Yan |
| Ming-Dean Cheng | Yu-Pin Lin | Daigee Shaw | Chen-Tung Arthur Chen |
| Meng-Fan Luo | | | |

*: Chair; §: Executive Secretary

**Table 2. Leadership of Future Earth Taipei Working Groups**

| | Working Group | Coordinator | Advisor |
|---|---|---|---|
| 1 | NGOs<br>*Strengthening Stakeholders' R elationships | Young Ku | Eugene Chien |
| 2 | Early Career Researchers | Wan-yu Shih | Jiun-Chuan Lin |
| 3 | Digital Age | Stephen J.H. Yang | Chao-Han Liu |
| 4 | Emergent Risks and Extreme Events | Jian-Hong Wu | Yue-Gau Chen |
| 5 | Finance and Economics | Ching-Cheng Chang | Daigee Shaw |
| 6 | Health | Shih-Chun Candice Lung | Huey-Jen Jenny Su |
| 7 | Ocean | Tung-Yuan Ho | Chen-Tung Arthur Chen |
| 8 | Natural Assets | Yu-Chung Chiang | Chang-Hung Chou |
| 9 | Systems of Sustainable Consumption and Production | Daigee Shaw | Eugene Chien |
| 10 | Urban | Shu-Li Huang | Hsin-Huang Michael Hsiao |
| 11 | Water-Energy-Food Nexus<br>*Corresponding to Future Earth 8 KANs, KAN: Knowledge-Action Network | Yu-Ping Lin | Chao-Han Liu |

## Highlights in 2022

### Expand and Strengthen Global Networks in Sustainability Science Research

After travel bans were lifted in most countries during the post-pandemic period, international onsite events gradually resumed. The year 2022 was a fruitful year for Future Earth Taipei, which was successful in expanding and strengthening international research networks related to sustainability science. In the first half of 2022, Future Earth Taipei hosted mostly virtual events. For the Sustainability Research & Innovation Congress 2022 (SRI2022), Future Earth Taipei WGs organized seven sessions that focused on themes such as ocean resilience, green infrastructure, and environmental open data. Furthermore, Future Earth Taipei and the Ministry of Science and Technology of Taiwan co-organized a session to introduce the scientific research on sustainability in Taiwan. Future Earth Taipei also co-organized or organized several events that were held from November onward, enabling key members of the Future Earth global community to interact with local researchers and organizations in Taiwan. The guests at these events included Dr. Anthony Capon, the Co-chair of the Future Earth Health KAN; Dr. Linwood Pendleton, the Executive Director of the Ocean KAN International Project Office; and Dr. Stella Alexandroff, a science officer. In December, representatives from Future Earth Taipei attended the American Geophysical Union (AGU) Fall Meeting, which is the most influential event in the field of earth and space science research and was held in Chicago, United States. At this event, the representatives set up a booth in the exhibition area to answer questions and promote scientific research on sustainability in Taiwan.

### Promote and Engage in Transdisciplinary Research on Sustainability

Sustainability research and practices have dominated both the public and private sectors. Concepts such as biodiversity, decarbonization, and justice are frequently applied in academic research and as themes to attract the involvement of organizations and individuals. Future Earth Taipei aims to diversify the paths toward a sustainable future by promoting transdisciplinary sustainability research and facilitating dialogues among stakeholders from different backgrounds.

In May, the Future Earth Urban WG and the Center for Sustainability Science co-organized the Taiwan Sustainable City Symposium to discuss Net-Zero roadmaps. Researchers and public sector stakeholders shared their experiences in implementing green policies aimed at reducing urban carbon emissions and increasing the efficiency of green infrastructure development. Additionally, two representatives from Future Earth Taipei participated in the TERRA School workshop, which was held in October and focused on transdisciplinary research. During this workshop, participants learned how to co-design research proposals by working together with researchers from diverse disciplines.

### Early Career Researchers in the Field of Sustainability Science

Connecting early career researchers (ECRs) with both local and global concerns about environmental changes is a key objective of Future Earth Taipei. To this end, Future Earth Taipei encourages its ECR WG to build its networks by collaborating with stakeholders from various organizations (e.g., NGOs or bottom-up initiatives) or inviting them to participate in various initiatives. With the aim of examining the complexity of environmental changes, ECR WG members organized 20 webinars with diverse themes such as health, carbon neutrality, climate justice, coastal management, the green economy, human rights, just transition, and open data. These ECR webinars provided a valuable platform for enhancing the awareness of individuals and researchers about a wide range of topics. The transdisciplinary nature of the ECR webinars and their role in connecting local and global sustainability research highlight their significance. For example, the webinar "Climate Change Mitigation and Justice," which was held on July 15, attracted approximately 100 attendees from 14 countries to learn about the development of just transition and international experiences related to the process of transitioning to a green economy.

# Major Activities

## January 7

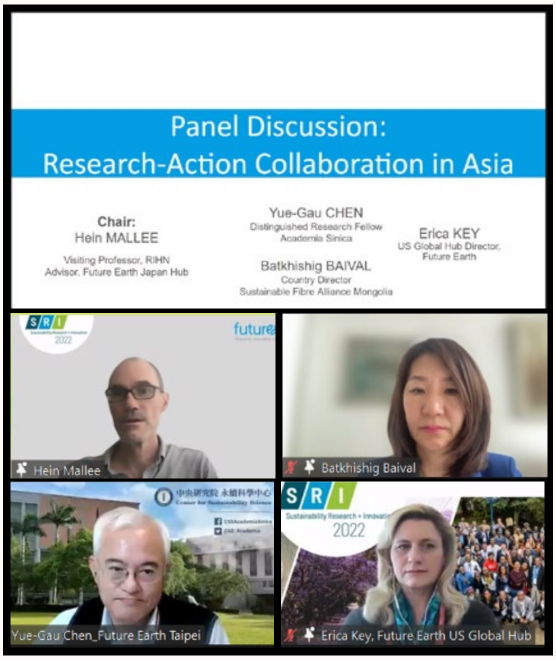
### 2022 Annual Symposium of Future Earth Taipei

The 2nd Annual Symposium of Future Earth Taipei was successfully held with the support of committee and WG members. The symposium welcomed attendees from the scientific, industry, and non-governmental communities. At this symposium, the 11 WGs of Future Earth Taipei presented their annual plans. Several WGs also organized parallel sessions, which included panel discussions and seminars, to discuss topics such as the digital age, systems of sustainable consumption and production, and the water-energy-food nexus. The fruitful discussions at this symposium highlighted the importance of fostering young scientists to contribute to sustainability science and societal transformation.

## June 20–24

### Sustainability Research & Innovation Congress (SRI) 2022

SRI2022, the second global congress on sustainability science jointly organized by Future Earth and the Belmont Forum, was held in Pretoria, South Africa. The conference adopted a hybrid format and brought together international sustainability leaders, experts, industry representatives, and innovators to inspire action and promote sustainability transformation. In addition to the main event, the Asia Spotlight Event was held to highlight various regional sustainability challenges and opportunities. Future Earth Taipei organized or co-organized 10 sessions covering topics such as typhoons, environmental open data, blue carbon, scientific research on sustainability in Taiwan, green infrastructure, online synthesis systems, smart agriculture, and early-career networking. Future Earth Taipei was also a part of the SRI2022 Organizing Team for the Asia Spotlight Event.



## September 21–23

### Future Earth Assembly 2022

Future Earth Assembly 2022 was held from September 21 to 23, 2022, as both an online event and an onsite event at the Centre International de Conférences Sorbonne Université in Paris, France. This annual meeting brought together representatives from all Future Earth–affiliated organizations to share their views and visions and to learn from each other. The Assembly discussed recommendations for the Future Earth Governing Council, which were categorized broadly into the three major themes of (1) collaboration and relationship/network building, (2) capacity building, and (3) funding. Dr. Shih-Chun Candice Lung and Dr. Hsin-Tien Lin (representing Future Earth Taipei) presented at the meeting and shared their strategic recommendations for Future Earth.

## November 16 and 17

### Visit by Health KAN Co-chair Prof. Anthony Capon

On the basis of established friendships and exchanges, we invited Prof. Anthony Capon to visit in November 2022. As an authority on environmental health and health promotion, Prof. Capon's research focuses on urbanization, sustainable development, and human health. During his two-day trip, Prof. Capon visited the Center for Sustainability Science (CSS) of Academia Sinica and held a seminar titled "Future Earth, Future Health: Eco-social approaches to safeguard human health in the Anthropocene." During this seminar, Prof. Capon interacted and discussed with Health WG members and participants. He also communicated with representatives of Future Earth Taipei, Taipei Hub and CSS to discuss current sustainability topics and future collaboration plans.

## Activities

### August 22

**Future Earth Taipei ECR Member Networking**

To expand the Future Earth Taipei ECR network and establish more (transdisciplinary) research collaborations, Future Earth Taipei organized this networking event for ECR WG members. This event featured group discussions that focused on three key themes. Participants were encouraged to brainstorm research ideas and strengthen their research network through these three group discussions. The discussions covered the following topics: (1) the interinfluence between humans and shoreline changes under climate change, (2) the improvements in life quality resulting from sustainable environmental development and its counterpart, and (3) the new technologies that shape sustainable and smart cities/neighborhoods/communities.

### December 12–16

**2022 AGU (American Geophysical Union) Fall Meeting**

Six representatives from Academia Sinica, including the Chair (Dr. Yue-Gau Chen) and Executive Secretary (Dr. Shih-Chun Candice Lung) of Future Earth Taipei, attended the 2022 AGU Fall Meeting, which was held in Chicago, United States. The AGU Fall Meeting attracted more than 25,000 participants from around the world and showcased the most prestigious and advanced Earth and space science research projects. The representatives set up a booth in the exhibition area to answer questions and promote scientific research on sustainability in Taiwan.

Professor Chen-Tung Arthur Chen(Coordinator, Future Earth Taipei Ocean Working Group) is elected to the 2022 Class of American Geophysical Union Fellows.

### November 28 and 29

**2022 Ocean Action Symposium**

To network with the Ocean KAN on topics pertaining to blue carbon and ocean sustainability, Future Earth Taipei Ocean WG and the Center for Sustainability Science organized the 2022 Ocean Action Symposium. This symposium featured a keynote address and three panels. Various stakeholders, including seaweed farmers, fishery companies, and oceanographers discussed their research and exchanged onsite experiences during this symposium. Participants were given opportunities to engage with the keynote speaker (Dr. Linwood Pendleton, Ocean KAN International Project Officer Executive Director) and the panelists through questions regarding transdisciplinary oceanography research and the building of international oceanography networks.

# Sustainability Science Research Program

## Introduction

Academia Sinica aims to promote Sustainability Science Research Program (SSRP) which encourages research fellows to target specific sustainability problems and provides solutions that potentially can be implemented in the real world. Throughout the process, SSRP encourages researchers to collaborate with fellows from different disciplines and broadly involve stakeholders in the projects. The current focal themes include the following six research orientations:

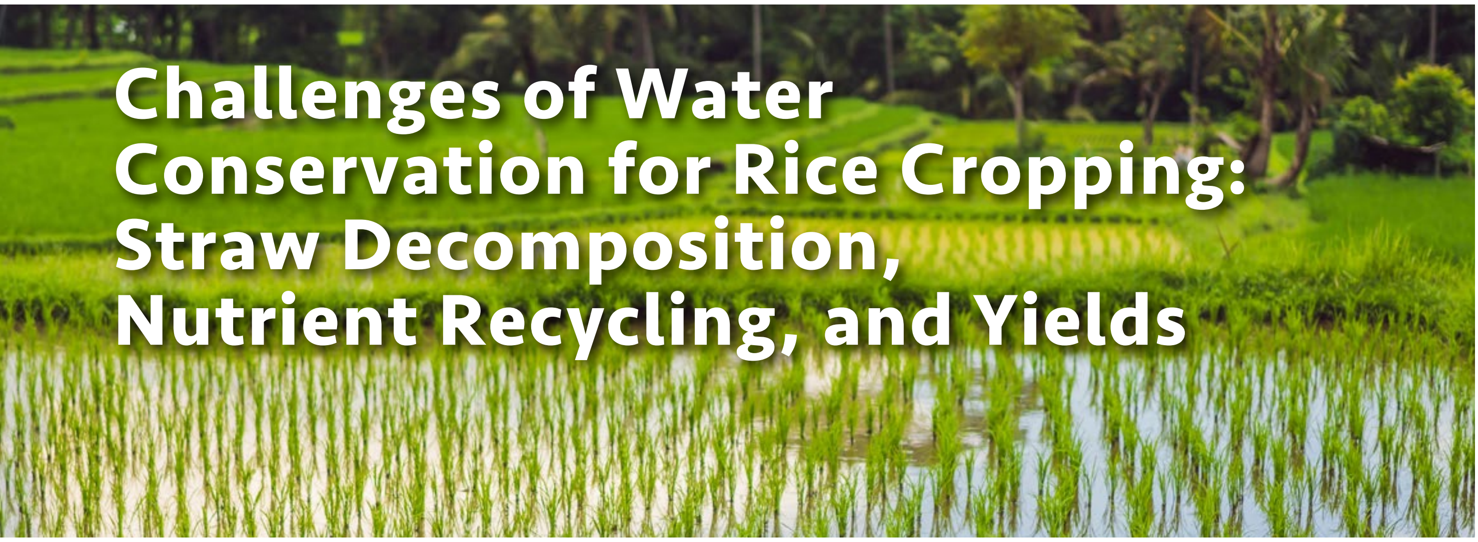
- Energy and Decarbonization Technologies
- Food, Air, and Water Security and Safety
- Transformation towards Sustainable Society
- Health and Environmental Changes
- Earth System under Global Changes
- Disaster Prevention, Reduction and Recovery

The following table lists the main themes that SSRP has called during 2021-2023. These themes are based on aforementioned six research orientations. Each year approximately ten research projects will apply for SSRP and roughly half of them will get the final approval. In 2022, even we had called for 2022 SSRP projects for four main themes which attracted 8 applications, in the end 5 projects covering three main themes have been approved and granted.

| | Main Theme | No. of Project Applications | No. of Project Approval |
|---|---|---|---|
| 2021 SSRP | • Social and Economic Impacts of Climate Change<br>• Risk Investigation and Assessment for Human Health under Environmental Changes<br>• Science and Technology for Energy and Decarbonization<br>• Biodiversity and Sustainable Agriculture<br>• Governance and Transformation toward a Sustainable Society | 14 | 7 |
| 2022 SSRP | • Societal and Economic Transformations under Global Climate Change<br>• Community Health Impact under Environmental Deterioration<br>• Decarbonization Strategies and Technologies in Response to Global Warming<br>• Change and Conservation of Water Resources and Ecosystems | 8 | 5 |
| 2023 SSRP | • Technology of carbon reduction and new energy to help Taiwan meet its goal of net zero emissions by 2050<br>• Risk assessment and response to extreme natural disasters<br>• Risk assessment for human health under climate change<br>• Transformation to and governance of a sustainable society<br>• Ecosystems and sustainable agriculture | 10 | 4 |

### 2022 SSRP Granted Projects

| Main Theme | Granted Projects |
|---|---|
| • Societal and Economic Transformations under Global Climate Change | • Targeting Net Zero in 2050: A Study of Carbon Pricing and Industrial Transformation Strategies in Taiwan |
| • Community Health Impact under Environmental Deterioration | • Investigation of ambient air particulate matter oxidative potential as a critical respiratory health risk parameter<br>• Sustainable Health Strategy for Fine Particulate Matter Control in the Built Environment of Southern Taiwan |
| • Change and Conservation of Water Resources and Ecosystems | • Trend-and-Variation Analyses on the Changes of Water Resources and the Eco-sociology Functions in Taiwan Watershed Ecosystem<br>• Coral Restoration: Construction of the First Coral Farm in North Taiwan and Development of New Techniques for Coral Cultivation |



# Challenges of Water Conservation for Rice Cropping: Straw Decomposition, Nutrient Recycling, and Yields

**Project Duration：2020-2022**

**Project Director**
Kuo-Chen Yeh

**Hosting Institute**
Agricultural Biotechnology Research Center,Academia Sinica

**Sub-Project PI, Co-PI**
Chang-Sheng Wang, National Chung Hsing University
Shan-Li Wang, National Taiwan University

## Research Objectives

Rice (*Oryza sativa L.*) grown in continuous standing water requires a relatively high water input. Because of increasing water scarcity, alternative systems that require less water are urgently needed. Water-saving irrigation regimens are a new concept for rice cultivation. However, shifts in water management from flooded to aerobic conditions are known to influence the accessibility and availability of nutrients, especially for iron (Fe) and might influence rice yield and quality. It is worth noting that in our preliminary study, we found some effects of Fe deficiency on delayed flowering of rice. Incorporation of the remaining straw into the soil has been proposed to counter the negative effects of a water-saving irrigation regimen. However, under Taiwan's intensive rice cropping system, this would be challenging, because the fallow period between rice seasons is often too short to allow sufficient decomposition. In this study, we focused on the isolation of brittle-related cultivars and characterization of their corresponding genes. We hypothesized that brittle straw would enable more rapid decomposition than non-brittle wild-type straw in water-saving irrigation regimens (**Subproject 1**). It would be advantageous for rice straw to decompose quickly enough to facilitate land preparation and cultivation of subsequent crops. Moreover, because straws are characterized by low nutritional value, we expect that engineering rice with a dominant mutation in a conserved bHLH transcription factor could be a strategy for increasing Fe uptake by rice; such manipulation may also enhance tolerance to Fe deficiency (**Subproject 2**). The positive outcome could not only benefit the water conservation rice practice but also shift the paradigm of Fe homeostatic mechanisms in plants. Nutrient release patterns and decomposition rates of rice straw with varying brittleness and high iron accumulation will be investigated to analyze and optimize the effects of incorporating different amounts and types of straw on crop growth (**Subproject 3**). The results will provide information for developing cost-effective and sustainable strategies to recycle and reuse the nutrients in rice straw and enhance the efficiency of managing soil fertility, irrigation water, and agricultural waste (i.e., rice straw) during rice cultivation in a water-saving systemw.

## Main Results to Date

**A novel brittle cultivar with the potential to reduce the yield loss under water saving and increase the yield when applying Fe foliar fertilizer.**

Water supply is a major problem that affects food security. Irrigated rice cultivation accounts for approximately 61% of the total agricultural water consumption in Taiwan. Water conservation is an important consideration in rice culture systems for agricultural sustainability. However, we hypothesized that a lower water supply might affect the yield because of Fe shortage. Moreover, rice straw degradation may also be reduced in low-moisture soils. The brittle mutant and Fe-related mutant lines were planted in a water-saving system (40% water can be saved) and sprayed with foliar Fe fertilizer. The results showed that the grain yield of the wildtype decreased substantially (~29%) under water-saving conditions whereas that of the mutant lines decreased slightly (~14%) or increased (up to 138%). We also found that Fe foliar fertilizer could restore yield loss under water-saving conditions. Interestingly, the results indicate that the brittle mutant line AZ1526 shows potential without loss of yield under water-saving conditions and increases the yield when Fe foliar is applied. The AZ1526 plant showed a higher Fe content than the wild type and the other lines (Figure 1).

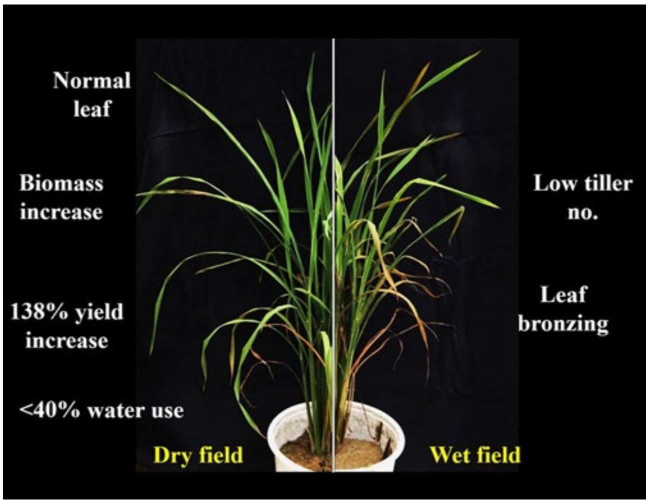
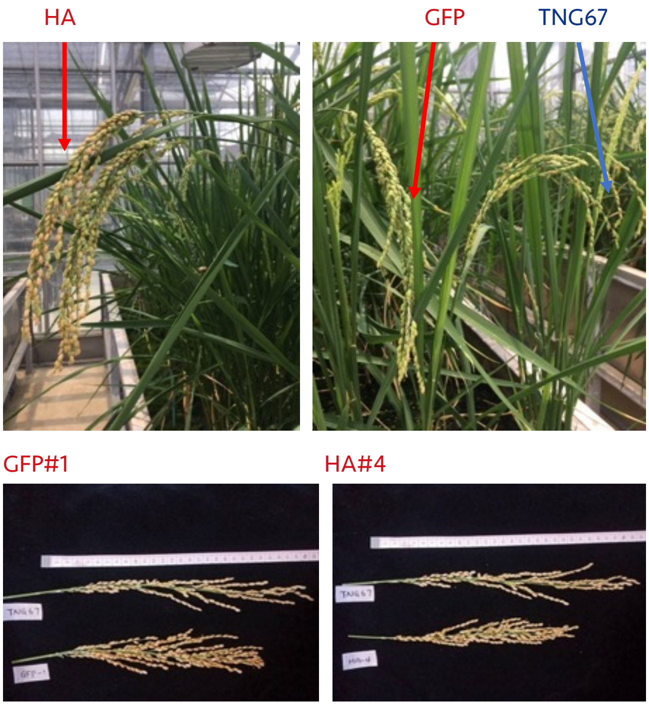



Figure 1. Performance of the unique mutant line, AZ1526, under rice water-saving cultivation.

**Overexpression of *IDT1*$_{A320V}$ in rice results in an improved crop in a water-saving irrigation system**.

The overexpression line of *IDT1*$_{A320V}$ a positive regulator of Fe uptake, was generated using Agrobacterium-mediated callus transformation and regeneration. Transgenic plants overexpressing *IDT*$_{A320V}$ either with GFP or HA-tagged, showed higher biomass, shoot growth with high yield, and more accumulation of Fe than wild-type TNG67 under aerobic water-saving irrigation conditions (Figure 2). In contrast, when grown under waterlogged conditions, these transgenics accumulated much higher levels of toxic Fe, and the *IDT1*$_{A320V}$ overexpression transgenic plants could not survive. Overexpression lines with high yield under water-saving conditions were generated twice with independent transgenics each time, and the results were similar. However, the gene expression was compromised in the T2 generation. Consequently, we lost the growth and high-yield phenotypes of T2. We anticipate that this gene will be silenced in transgenic rice.




| | Panicle Length(cm) | Grain Number | Grain Fertility % |
|---|---|---|---|
| TNG67 | 18-19 | 106 | 72-80 |
| GFP#1 | 26.8 | 258 | 75 |
| HA#4 | 26.6 | 265 | 73 |

Figure 2. Transgenic rice overexpressing *IDT*$_{A320V}$ either with GFP or HA-tagged showed high panicle length and grain number.

**Effects of straw incorporation on the iron availability under business-as-usual (continuous flooding, CF) and water-saving management**

The chemical composition of rice straw substantially influences the straw decomposition rate, which is mainly determined by cellulose, hemicellulose, and lignin contents. Among these, hemicellulose is the most biodegradable species, whereas lignin is the most resistant to microbial decomposition. Compared with the wild type and mutant, the brittle rice straw showed similar contents of cellulose and hemicellulose in biomass but lower lignin content, which was reduced by approximately 34.1%. Moreover, the biomass C/N ratio is critical for microbial decomposition, and a reduced C/N ratio likely accelerates the decomposition rate. The C/N ratio was reduced by approximately 30.0% in brittle rice straw (Table 1).

In addition to the biomass chemical composition evaluation, brittle straw was subjected to fast decomposition under anaerobic conditions (i.e., the CF practice) by producing more methane ($CH_4$) than wild-type mutants. The fast anaerobic decomposition likely accelerated the reduction potential and conversion of Fe(III) to Fe(II) in paddy soils. This study also showed that the incorporation of brittle rice straw increased Fe concentrations in the soil solution, especially under the CF treatment. For instance, compared with wild-type straw incorporation, the incorporation of brittle straw under anaerobic conditions increased the Fe concentration by 72.2% in fine-textured soil (silty clay loam, SiCL) and 46.1% in sandy soil (sandy loam, SL). Under the water-saving (AWD) treatment, brittle straw incorporation increased Fe concentration by 44.5% in fine-textured soil but showed no significant differences between the two rice varieties (Figure 3). Increased Fe concentrations likely improved iron availability for plant uptake.

**Table 1. Chemical composition of rice straw (wild type vs. brittle).**

| | Chemical compositions (%) | | | |
|---|---|---|---|---|
| Variety | Cellulose | Hemicellulose | Lignin | C/N |
| Wild type | 26.2 | 28.8 | 10.5 | 53.6 |
| Brittle | 25.5 | 30.2 | 6.9 | 37.7 |

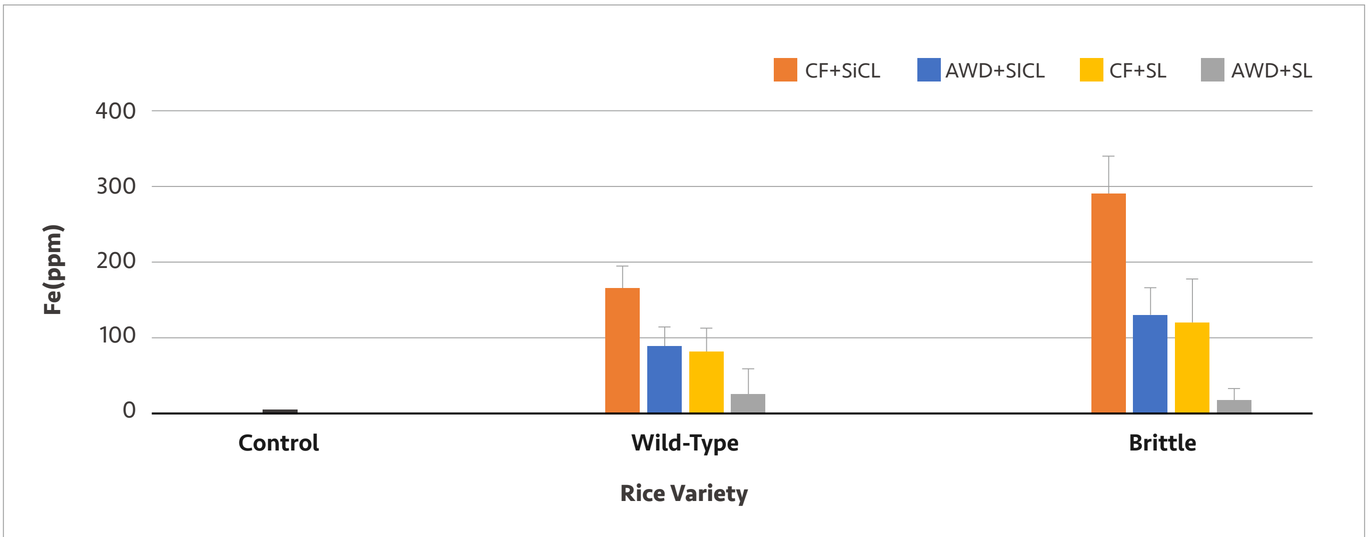
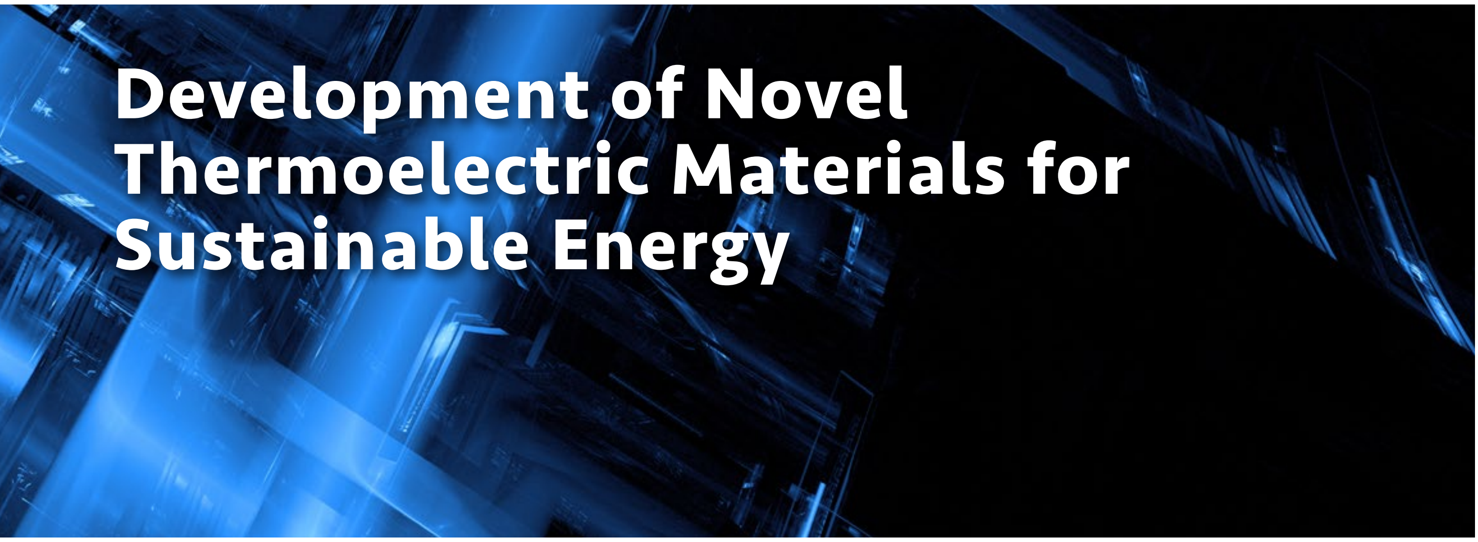



Figure 3. Effects of rice straw incorporation (wild-type vs. brittle) on the Fe concentrations in soil pore water of two soils [silty clay loan (SiCL) vs. sandy loam (SL)] after 14-day incubation under two water regimes, continuous flooding (CF) and water-saving management (AWD).

## Future Research Plan

From project experiments (2020–2022), we found that Fe is an important element for the water-saving cultivation of rice. In future, more field experiments will be employed to create the culturing routine of new cultivars. The *IDT1*$_{A320V}$ transgenics were generated using vectors $P_{UBQ10}$:GFP, which comprises ubiquitin 10 (UBQ10) from Arabidopsis and pEarleyGate 201 that has a CaMV35S promoter. The dicot and 35S viral promoters may be silenced or ineffective in rice. Therefore, the employment of strong native constitutive or drought-induced promoters would be functional throughout generations to produce water-saving cultivars. Additionally, we will continue investigating straw decomposition under different management regimes of water irrigation and rice straw in sequestrating carbon. Potentially stable high-yield cultivars under water-saving conditions could be expected by rational designs and inventions, as needed.

# Development of Novel Thermoelectric Materials for Sustainable Energy



**Project Duration：2020-2022**

**Project Director**
Kuei-Hsien Chen

**Hosting Institute**
Institute of Atomic and Molecular Sciences (IAMS), Academia Sinca

**Sub-Project PI, Co-PI**
- Yang Yuan Chen, Institute of Physics, Academia Sinica
- Sankar Raman, Institute of Physics, Academia Sinica
- Chih-Wei Chang, Center for Condensed Matter Sciences, National Taiwan University
- Chien-Neng Liao, Department of Materials Science and Engineering, National Tsing Hua University
- Ching-Ming Wei, Institute of Atomic and Molecular Sciences, Academia Sinica

## Research Objectives

Thermoelectric technology allows for the direct conversion of heat to electricity. Thus, developing highly efficient thermoelectric materials is being reconsidered as a possible approach to address global energy generation, usage, and management.

This research project aims to develop new strategies for designing thermoelectric materials using innovative material configurations, such as single crystals, nanostructures, and composites, and to comprehend current state-of-the-art thermoelectric materials by investigating their fundamental properties via computational and experimental approaches.

## Main Results to Date

Globally, thermoelectric (TE) research has focused on further improving the efficiency and lowering the cost of TE devices. The relatively low efficiency of thermoelectric energy conversion is a significant impediment to the widespread use of this technology. However, significant progress has been made in high-performance and cost-effective TE materials, owing to their rational thermoelectric designs. Under the leadership of Dr. K.H. Chen, a thermoelectric research team was established with the support of the Center for Sustainability Science, which includes top-tier physicists such as Dr. M. K. Wu, Dr. Y. Y. Chen, Dr. C.M. Wei, Dr. R. Sankar, and Dr. M.Y. Chou. Over the last few years, the team has demonstrated an ultrahigh power factor and TE figure-of-merit (zT) in the n-type TE material $Bi_2Te_{2.7}Se_{0.3}$ for room-temperature applications. Additionally, the team developed strategies to improve the TE performance of mid-temperature GeTe-based materials. Although bismuth telluride ($Bi_2Te_3$)-based alloys remain the most promising material for industrial applications near room temperature, the modulation doping of Cu in $Bi_2Te_{2.7}Se_{0.3}$ crystals demonstrated a record high zT of 1.4 at 300 K (Figure 1). The Cu intercalated samples achieved an ultrahigh power factor of ≈63.5 $\mu Wcm^{-1}K^{-2}$ at room temperature, which is the highest record among single-crystalline and polycrystalline *n*-type $Bi_2Te_3$-based materials.

GeTe-based materials are promising candidates for mid-temperature thermoelectric applications. Controlling the Ge vacancy in GeTe is always challenging because it increases the carrier concentration to approximately $10^{21}$ $cm^{-3}$, which is much higher than the optimal level and degrades the thermoelectric performance. Dr. Raman Sankar developed a solid-state synthesis method for p-type GeTe that can control the Ge vacancy while maintaining the material in the rhombohedral phase up to 773 K without transitioning to the cubic phase. Without additional doping, the Ge vacancy control also increased zT to a maximum of 1.37 at 773 K (Figure 2).

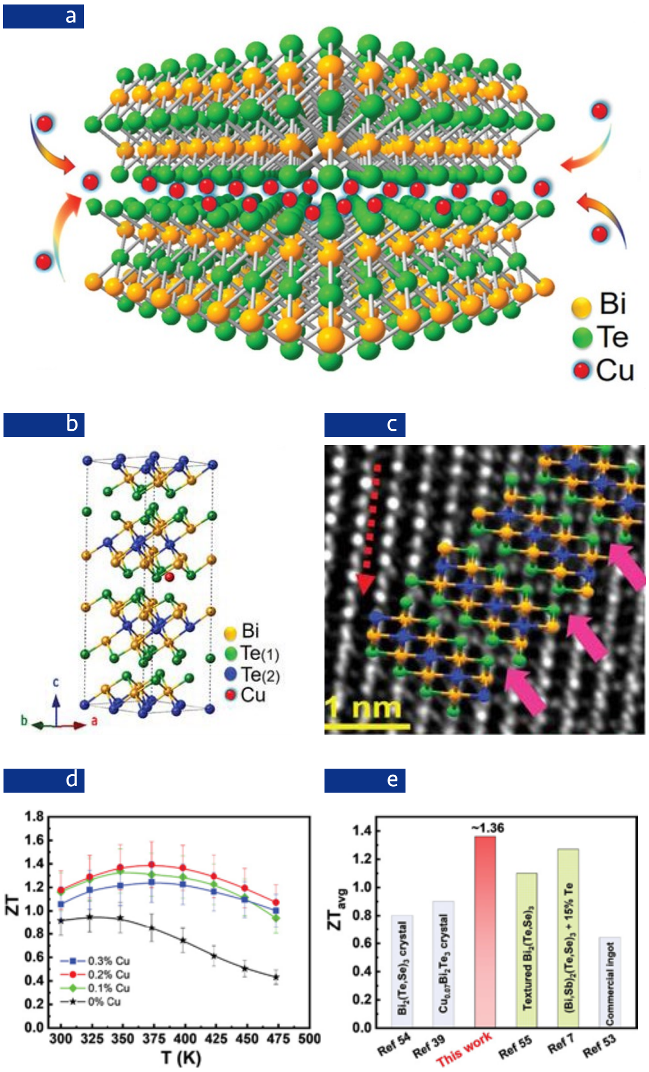



Figure 1. (a) Illustration of the $Bi_2Te_3$ structure with Cu atoms intercalated into the vdWs gap. (b) Cu intercalated within $Bi_2Te_3$ structure. (c) The Cs-HRTEM image of the specimen observed along [100] crystallography zone axis. (d) ZT values of $(CuI)_{0.002}Bi2Te_{2.7}Se_{0.3}$ + y% Cu crystals. (e) Average ZT values for advanced n-type $Bi_2Te_3$-based single crystals and textured alloys.

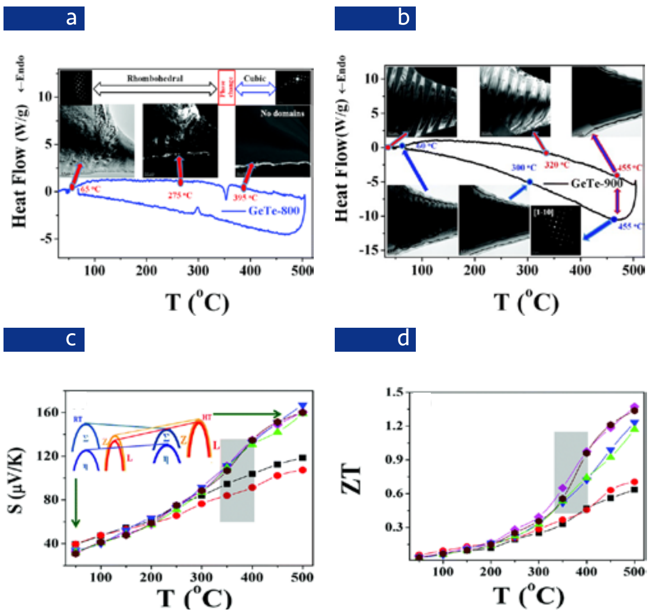



Figure 2. (a) Differential scanning calorimetry (DSC) study and corresponding domain structure images for GeTe-800 with higher Ge vacancies and high-density herringbone micro-domain structures. (b) DSC study and corresponding TEM images for the domain structure of GeTe-900 are nearly free of Ge vacancies and large herringbone-structured domain sizes. (c, d) Temperature dependence of (c) Seebeck coefficient and (d) TE figure-of-merit.

In addition to controlling the Ge vacancies in GeTe, antimony (Sb) substitution in GeTe was explored to optimize the carrier concentration for superior TE performance, and a high zT of 2.35 at 800 K was demonstrated for the $Ge_{0.9}Sb_{0.1}Te$ sample (Figure 3). Inelastic neutron scattering (INS) measurements, combined with density functional theory (DFT), have improved the understanding of the high TE performance and origin of the low thermal conductivity in Ge-Sb-Te. INS measurements revealed significant differences in phonon dispersions and the presence of a new phonon band at a transfer energy E ≈ 5–6 meV in $Ge_{0.92}Sb_{0.08}Te$ (Figure 4).

The performance of a thermoelectric module is determined by the thermoelectric properties of the *n*- and ρ-type materials constituting the module. Recently, *n*-type $CoGe_{1.5}Te_{1.5}$ skutterudite thin-film with zT ~1.3 at 673 K was attained in Dr. K.H. Chen's laboratory, which interests our team because of its excellent compatibility with the ρ-type nature of GeTe-based materials. This skutterudite family of materials, derived from $CoSb_3$, represents the realization of the phonon glass-electron crystal (PGEC) concept. It has been demonstrated that for heavily doped compositions in $CoGe_{1.5}Te_{1.5}$, a secondary conduction band contributed to the carrier transport along with the primary band, significantly improving TE performance.

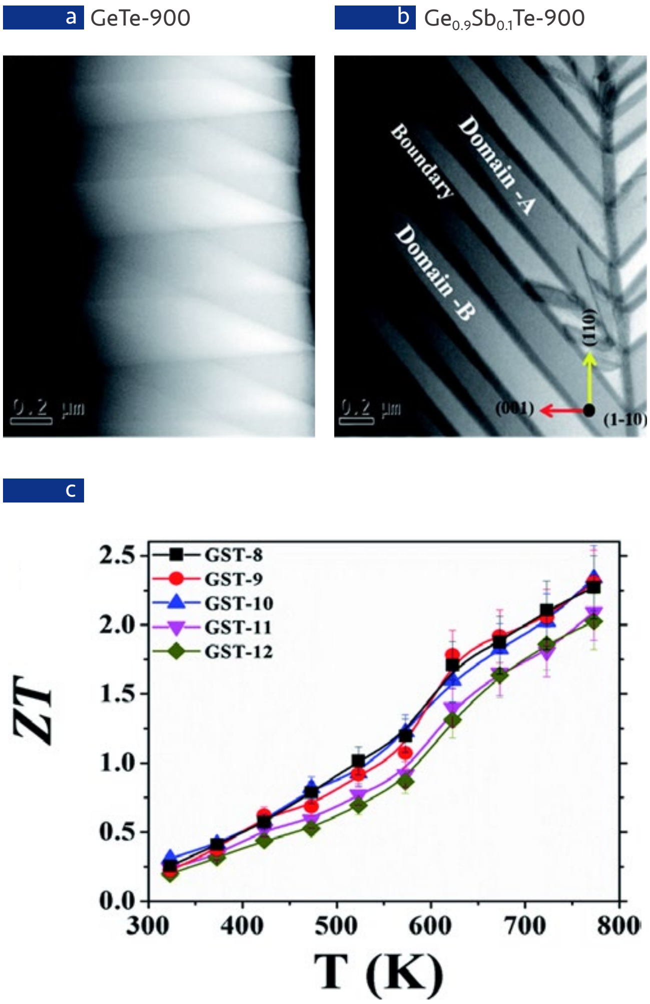



Figure 3.(a) Micro-domain structures of undoped GeTe-900, and (b) herringbone domain structure of $Ge_{0.9}Sb_{0.1}Te_{-900}$ with thickened domain boundaries. (c) Temperature dependence of thermoelectric figure-of-merit ZT for the GST series.

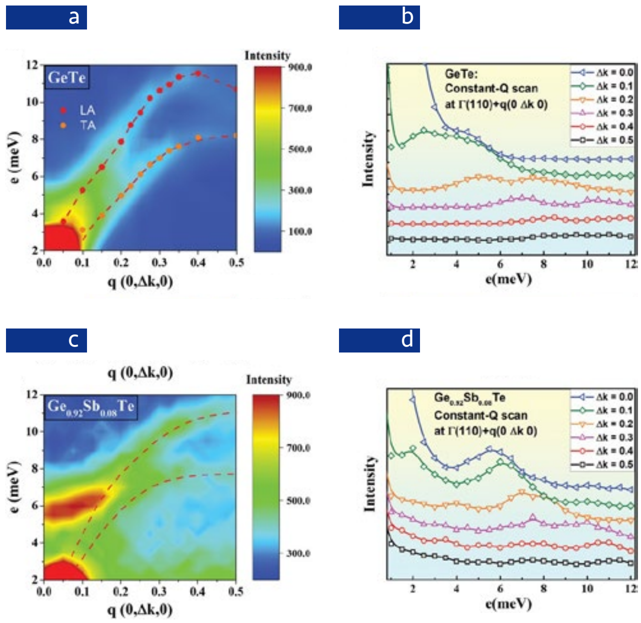



Figure 4. Inelastic neutron scattering studies of GeTe and Sb-doped GeTe. Phonon dispersions relation from *S (Q, E)* with function of energy transfer E and q along [0K0] for a) pristine GeTe and c) $Ge_{0.92}Sb_{0.08}Te$ crystals with TA and LA branches. (b) and (d) show phonon energy spectra for energy scans along [0K0] with a constant Q of k = 1–1.5 for GeTe and $Ge_{0.92}Sb_{0.08}Te$ crystals, respectively.

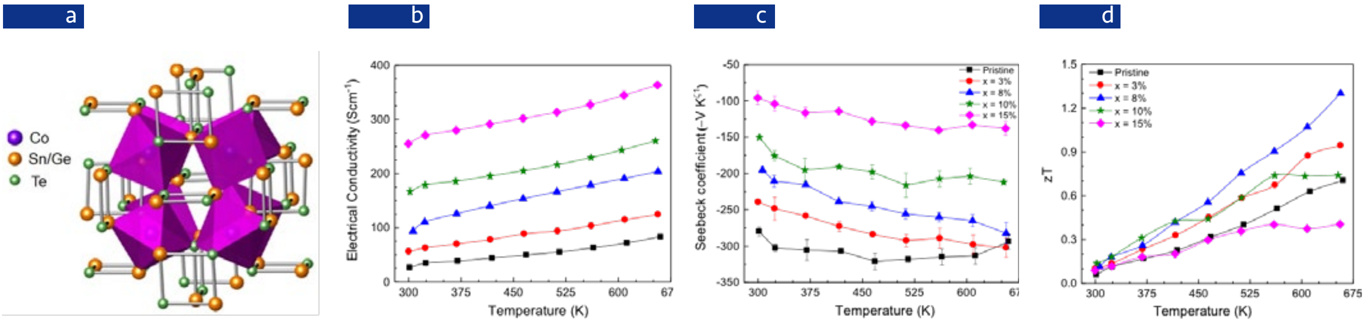
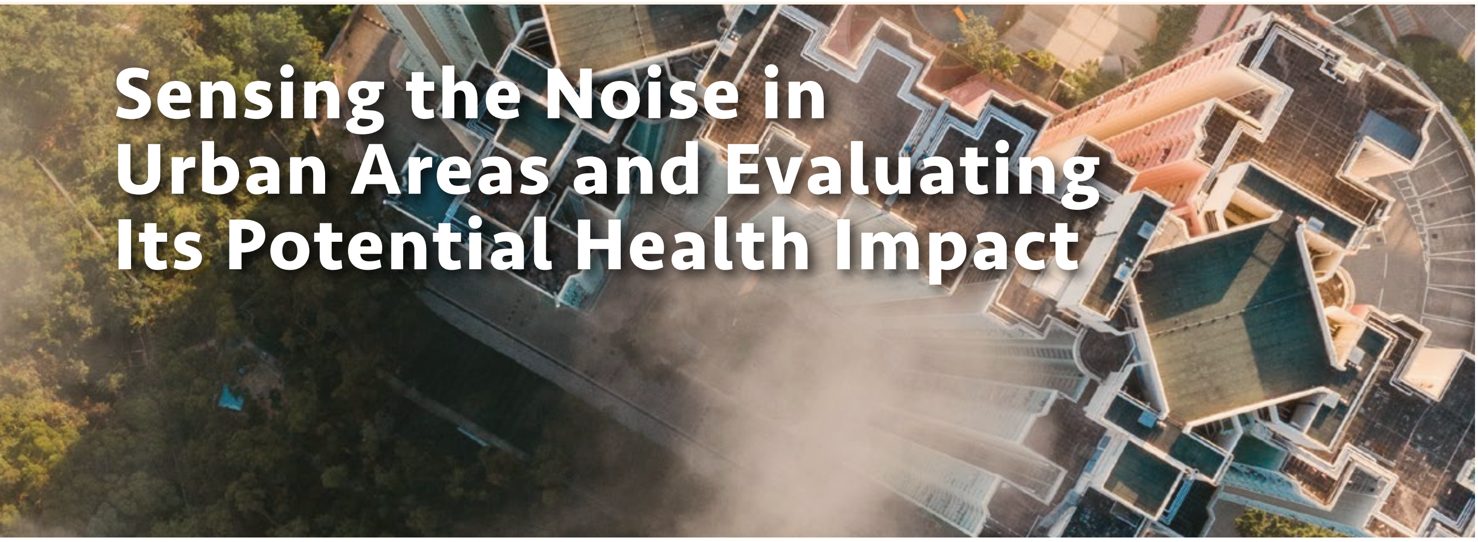



Figure 5.(a) Crystal structure of $CoGe_{1.5}Te_{1.5}$ skutterudite material. Temperature dependence of (b) electrical conductivity, (c) Seebeck coefficient, and (d) TE figure-of-merit.

## Future Research Plan

Herein, we continue the momentum in thermoelectric research to develop novel IV-VI layered chalcogenides in single-crystal and polycrystalline forms. The materials synthesis approach will explore earth-abundant and inexpensive TE materials, such as SnS, which showed potential after preliminary measurements. Further doping, alloying, characterization, and theoretical calculation of SnS are underway to realize civil applications of thermoelectric technology.



# Sensing the Noise in Urban Areas and Evaluating Its Potential Health Impact

**Project Duration：2020-2022**

**Project Director**

Ta-Chien Chan is a research fellow of the Research Center for Humanities and Social Sciences, Academia Sinica. Dr. Chan is an interdisciplinary scholar in both health and spatial science, whose research focuses on spatial epidemiology, infectious disease epidemiology, health informatics on disease surveillance, spatio-temporal statistics, and data visualization. Dr. Chan has conducted a series of research studies on the health risk associated with air pollution, meteorological factors, and noise for the advancement of environmental health and sustainable development.

**Hosting Institute**

Research Center for Humanities and Social Sciences, Academia Sinica

**Sub-Project PI, Co-PI**

- Ling-Jyh Chen, Institute of Information Science, Academia Sinica
- Chin-Chi Kuo, Big Data Center, China Medical University Hospital
- Wen-Chi Pan, Institute of Environmental and Occupational Health Sciences, National Yang Ming Chiao Tung University


## Research Objectives

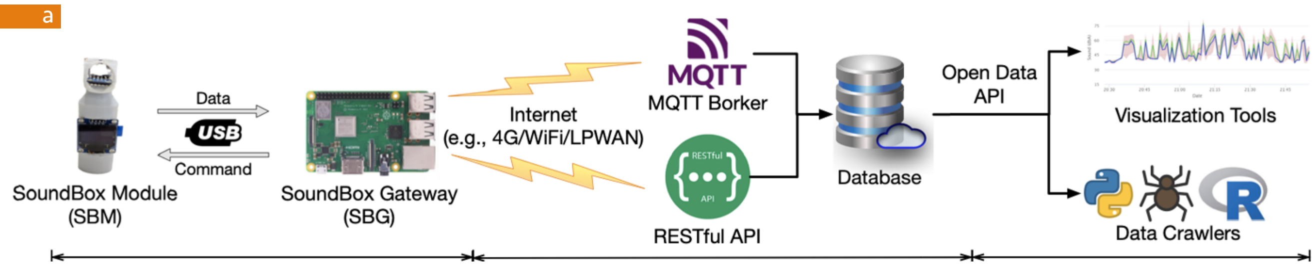
Environmental noise is an emerging public health issue and a major environmental concern in Europe. Similarly, in Taiwan, complaints regarding public nuisances have surged since 1998. Noise complaints rank first among all public nuisances, with more than 80,000 noise complaints being made annually since 2012, accounting for more than 30% of all public nuisance complaints. Although government agencies have established standards for monitoring and controlling noise, the challenge lies in measuring noise accurately in a timely manner. Owing to the limited manpower of local environmental protection departments in Taiwan, inadequate spatial and temporal coverage of noise monitors limits the generation of noise maps or exposure models, which in turn complicates subsequent health impact assessments. Therefore, it is important to elucidate these effects. This situation further highlights the urgent need for residents to achieve a better quality of life. Noise pollution is not merely an annoyance, because it aggravates mental health and chronic diseases. Therefore, systematic noise monitoring is warranted, especially in urban areas. However, comprehensive and longitudinal noise measurements as well as health impact evaluations of noise exposure remain challenging. The proposed integrated project attempts to address these challenges. Good noise management in a city can not only facilitate the achievement of the Sustainable Development Goals (SDG) proposed by the United Nations, including "Goal 3: Good health and well-being" and "Goal 11: Sustainable cities and communities," but can also enhance the quality of life of Taiwanese population.

## Main Results to Date

Sensing and evaluating noise in urban areas produced significant outcomes in four aspects: (i) scientific tool development for noise measurement; (ii) noise mapping in urban environments; (iii) exposure–health relationship evaluation; and (iv) noise assessment at environmental and personal levels. The developed scientific tool is a system called SoundBox, which uses open hardware and is based on commercially available microsound sensors with calibration models established through standard measurement procedures (Figure 1(a)). Unlike existing noise-sensing devices, SoundBox is distinguished by several features: 1) SoundBox is Internet of Things (IoT)-based, thereby facilitating continuous and real-time noise measurement at a finer granularity; 2) it is based on low-cost sound sensors, which are commercially available off-the-shelf (COTS) and more affordable than conventional instruments; 3) it is an open federated system that promotes collaboration, sharing, and contribution to its hardware, software, data, analysis, and calibration models with assured quality; and 4) it also conducts sound classification by incorporating artificial intelligence and edge computing techniques in its design. Co-location experiments were conducted to evaluate the accuracy of the SoundBox Module (SBM) compared to that of professional instruments (Figure 1(b)).

The developed SBM can achieve an R-squared value of 0.98 compared with the Class 2 meter, indicating that the performance of the SBM is nearly identical to that of the Class 2 meter. Finally, linear regression on the measurement results of the SBM and Class 1 meter yielded an R-squared value of 0.95, which was slightly higher than that obtained by the comparison of Class 1 and Class 2 meters (R-squared value: 0.942). Thus, the accuracy of the developed SBM is considered acceptable. Therefore, we decided to use the linear regression results (where the explanatory variable is the raw measurement of SBM and the dependent variable is the calibration result) as the calibration equation for future SBM development and experiments. The SoundBox was not only used to build a noise map to highlight the spatial distribution of noise levels for Sanzhi District but also to measure the traffic noise in the field to validate the results of the 2D and 3D dynamic noise models.

a




b

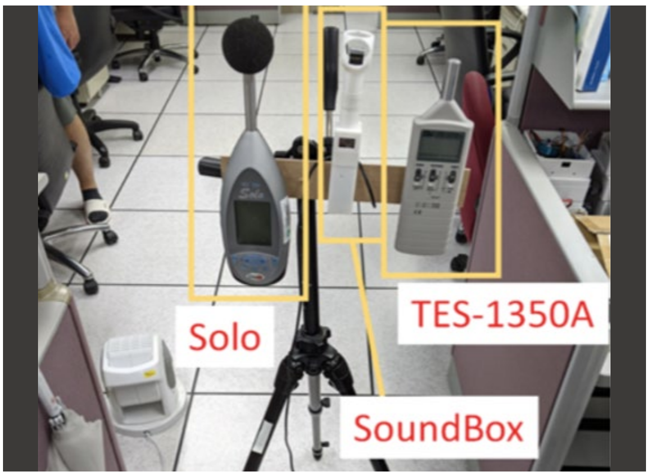



Figure 1. (a) Overall architecture of the SoundBox system. (b) Accuracy evaluation of the developed SBM unit against that of professional instruments (one Class 1 decibel meter (i.e., Solo SLM) and one Class 2 decibel meter (i.e., TES-1350A))

Traffic noise is a prominent feature of the urban environment and is considered the second most prevalent environmental risk after fine particle pollution, especially in densely populated cities. Noise maps can help identify vulnerable communities in which suitable approaches for noise reduction can be adopted and remind residents to take action to improve their quality of life. Owing to the absence of city-scale noise monitoring and traffic information, only a limited number of studies have considered the use of traffic noise maps for an entire city. Currently, with the increase in the use of real-time road traffic monitoring sites equipped with IoT-based sensors, traffic data have gradually become more abundant. Methodologies were developed to build 2D and 3D noise models for Taipei City, which demonstrate the spread of noise pollution. The strength of the proposed noise models lies in the precise and accurate assessment of traffic noise exposure and objective estimation of traffic noise exposure using noise monitoring points.

Figure 2(a) shows the spatial distribution of the hourly mean noise levels for the entire 24-h cycle in Taipei City. The hourly mean difference between the predicted and measured noise levels ranged from -6.25 to -4.46 dBA in the 2D noise model. For the 3D noise map (Figure 2(b)), the hourly mean prediction error was 0.02–1.93 dBA. Based on the WHO benchmark for excessive road traffic noise, we found that at least 30% of the inhabitants of Taipei City are exposed to levels exceeding 53 dBA Lden and more than 25% to noise levels exceeding 45 dBA Lnight. By deploying SoundBox to measure noise levels during September 2021–June 2022, a noise map based on kriging interpolation was produced for Sanzhi District, a rural district in New Taipei City (Figure 2(c)). The noise level predicted by the random forest algorithm ranged from 53.86 to 70.90 dBA. These methods have the potential to improve information compilation for environmental planning and management in urban and rural areas, as they help to clearly indicate pollution hotspots and better implement noise mitigation measures. Furthermore, we developed the LINE chatbot platform to generate soundscape maps based on individuals' perception of the acoustic environment and used them to collect data pertaining to the sound and subjective feeling of the sound recorded by volunteers in May–July, 2022.

Regarding the exposure–health relationship evaluation, indoor noise pollution has recently been gaining much attention, especially concerning healthcare facilities that require a quiet physical environment that helps reduce adverse impacts for both patients and healthcare professionals. Patients in intensive care units (ICUs) who suffer from multiple critical illnesses require a much quieter environment for better quality of sleep and rest. However, previous evidence has shown that the noise level was higher in the ICUs than in the general wards. Therefore, we improved the limitations of short-term noise sampling in previous studies conducted in ICUs by deploying SoundBox to collect long-term, continuous, and real-time noise exposure data (Figure 3(a)). The average sound level ranged from approximately 45 to 80 dBA, and the average maximum sound level ranged from approximately 45 to 90 dBA. Notably, we found a similar average sound level range from Monday to Sunday (Figure 3(b)). Furthermore, we used a case-crossover design to explore the acute health effects of noise exposure to control unmeasured time-invariant confounders and applied a unidirectional approach to select the control periods 5 min, 30 min, and 1 h before the case period.

The results showed that both the average noise level and average maximum noise level were significantly associated with the heart rate and systolic blood pressure (SBP). The association between the average noise level and abnormal heart rate was 1.23 (95% CI: 1.15, 1.29), 1.32 (95% CI: 1.18, 1.44), and 1.18 (95% CI: 1.07, 1.28) at 5-min, 30-min and 1-hour before case period, respectively. Meanwhile, the association between the average noise level and abnormal SBP was 1.14 (95% CI: 1.08, 1.20), 1.20 (95% CI: 1.12, 1.31), and 1.20 (95% CI: 1.09, 1.33) at 5-min, 30-min and 1-hour before case period, respectively.


Figure 2. (a) 2D hourly noise maps for Taipei City, (b) 3D noise maps for Taipei City, and (C) 2D static noise maps for Sanzhi District in New Taipei City

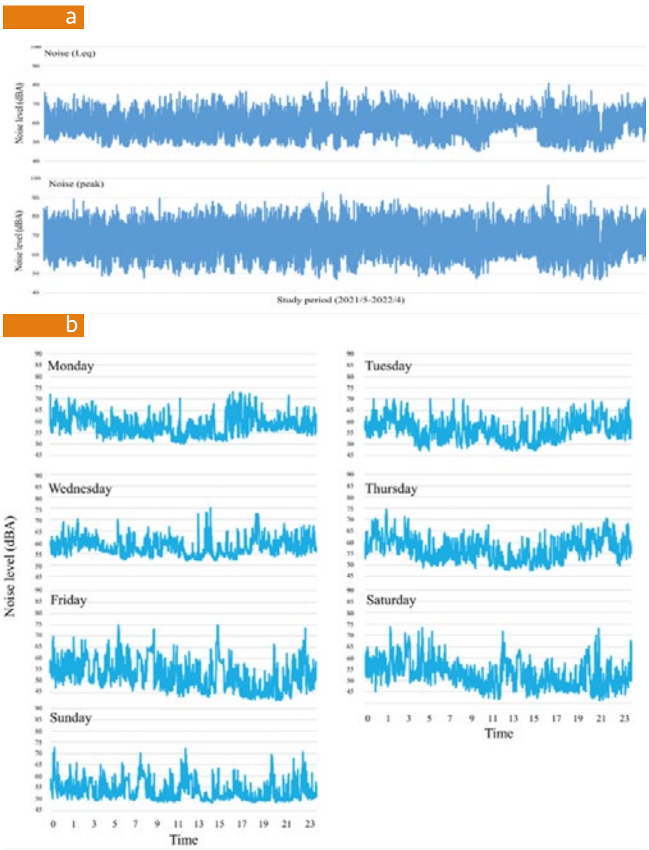



Figure 3. (a) Pattern of intensive care unit (ICU)-noise distribution during study period. (b) Measurements of daily ICU-noise level by week.

We integrated long-term outdoor noise exposure data into a 2.7 million-patient clinical database (2003–2019) to assess the association between noise and multiple health effects based on case-control study designs. The results showed that personal and work-related burnout scores increased by 1.86 ± 0.32 and 1.34 ± 0.26 for each 1 dBA increase in the annual average residential noise level, respectively. Importantly, burnout scores were significantly associated with noise exposure after adjusting for age, sex, BMI, smoking status, working hours, sleeping hours, hypertension, diabetes mellitus, and job type ($P < 0.001$). The scores of individuals exposed to a noise level ≥ 63 dBA were significantly higher, specifically 2.40 ± 0.68 and 2.09 ± 0.55 higher than the personal and work-related burnout scores of individuals exposed to a noise level < 63 dBA, respectively ($P < 0.001$). The odds ratios (ORs) for low versus moderate and high personal and work-related burnout corresponding to each 1 dBA increase in residential noise level were 1.32 (95% CI: 1.21, 1.44) and 1.23 (95% CI: 1.14, 1.33), respectively. Compared with individuals with an annual average residential noise exposure of < 63 dBA, those with an annual average exposure of ≥ 63 dBA had adjusted ORs for personal and work-related burnout (binary scale: low vs. moderate or high) of 1.43 (95% CI: 1.20, 1.70) and 1.37 (95% CI: 1.17, 1.61), respectively. We also examined the effect of annual noise exposure on morbidity and observed elevated risks of gestational diabetes mellitus, glucose intolerance, infantile hemangioma, poor health among children, coronary artery disease, and Parkinson's disease (PD).

Moreover, we developed noise modeling tools at the personal level by building a novel questionnaire-based approach to model personal noise exposure levels. The model, constructed using place, surroundings, activity, awareness of sound, time, and air pollution data to predict personal noise exposure levels, performed satisfactorily (R2 = 0.552).

In summary, using a unique multidisciplinary approach, we provide a competitive edge in the field of environmental noise research, as evidenced by previous studies. Most importantly, the integration of data obtained from these innovative scientific tools and models provides a scientific foundation for policymakers in various agencies to formulate preventive strategies to reduce noise-related health risks in Taiwan. Overall, this transdisciplinary, co-designed, solution-oriented project achieves the aim of advancing science while contributing to society.

## Future Research Plan

In future studies, we aim to expand the application of the SoundBox in environmental health science. In particular, we intend to scale up the scope of research at the personal, community, and urban levels in Taiwan using advanced data analysis methods and modeling approaches to assess noise exposure in cities with high resolution to mitigate noise exposure and health risks in Taiwan. Additionally, to clarify the association between subjective feelings and hearing sounds in daily life, we will continuously collect subjective sound perception and objective soundscape data using our LINE chatbot platform, including the quality of life, medical history, and health behaviors, as well as IoT-embedded devices such as smart watches that can compute heart rate variability and the level of nervousness. Comfort acoustic indicators and profiles of soundscapes are important for creating a sustainable acoustic environment.

## Website

The 2D and 3D dynamic maps: https://soundmap.colife.org.tw/noiseMap/

The soundscape map: https://soundmap.geohealth.tw/survey/

## Publications


[1] Huang, T., Chan, T. C., Huang, Y. J., & Pan, W. C. (2020). The Association between Noise Exposure and Metabolic Syndrome: A Longitudinal Cohort Study in Taiwan. International journal of environmental research and public health, 17(12), 4236. doi:https://doi.org/10.3390/ijerph17124236

[2] Mahajan, S., Luo, C.-H., Wu, D.-Y., & Chen, L.-J. (2021). From Do-It-Yourself (DIY) to Do-It-Together (DIT): Reflections on designing a citizen-driven air quality monitoring framework in Taiwan. Sustainable Cities and Society, 66, 102628. doi:https://doi.org/10.1016/j.scs.2020.102628

[3] Tang, J.-H., Lin, B.-C., Hwang, J.-S., Chen, L.-J., Wu, B.-S., Jian, H.-L., Lee, Y.-T., & Chan, T.-C. (2022). Dynamic modeling for noise mapping in urban areas. Environmental Impact Assessment Review, 97, 106864. doi:https://doi.org/10.1016/j.eiar.2022.106864

# New Strategies for Improving Rice Nitrogen Utilization Efficiency

## Project Duration：2020-2022

**Project Director**

Yi-Fang Tsay, Distinguished Research Fellow at the Institute of Molecular Biology, Academia Sinica, Taiwan; International Member of the National Academy of Sciences, USA. Dr. Tsay was awarded a Ph.D. from the Institute of Biological Sciences, Carnegie-Mellon University in 1990. Her major research interests include nitrate transport, nitrate sensing, and nitrogen utilization efficiency of plants.

**Hosting Institute**

Institute of Molecular Biology, Academia Sinica

**Sub-Project PI, Co-PI**

- Ming-Hsiun Hsieh, Institute of Plant and Microbial Biology, Academia Sinica
- Ching-Shan Tseng, Taiwan Agricultural Research Institute/ Biotechnology Division

## Research Objectives

The production of N fertilizer consumes 2% of the world's energy, and more than 110 teragrams of N fertilizers are required annually to secure crop production. Nevertheless, only 30–50% of the applied fertilizer is taken up and used by crops. N fertilizers that remain in the soil cause severe environmental problems, including their being emitted as the greenhouse gas N2O and leaching into water systems to cause eutrophication. It is estimated that for each dollar that farmers spend on N fertilizers, four are spent trying to deal with the environmental damage caused. Therefore, improving the N utilization efficiency (NUE) of crops is a global priority for ensuring sustainable agriculture. Rice is the most important crop in Taiwan and one of the top three crops worldwide. Therefore, the main objectives of this project were to

1. enhance nitrate remobilization and identify new markers for improving NUE in rice, and

2. target N-responsive genes to enhance NUE in rice.

## Main Results to Date

### A. Enhancing nitrate remobilization

Nitrate is the primary N source for most plants. Nitrate taken up by plants is assimilated immediately, stored in vacuoles for later use, or translocated into different plant parts for subsequent assimilation or storage. Efficient nitrate allocation represents a somewhat unexplored avenue relative to uptake and assimilation for enhancing NUE. Therefore, one major objective of this project is to explore the potential of enhancing nitrate redistribution to improve NUE.

### A-1 NRT1.7 is responsible for source-to-sink remobilization of nitrate

Nitrate can be stored in large quantities in vacuoles. Our study revealed that nitrate stored in vacuoles of Arabidopsis was remobilized by AtNRT1.7. NRT1.7, mainly expressed in the phloem of minor veins in old leaves, remobilizes stored nitrate by loading nitrate into the phloem of source leaves and delivering it to N-demanding tissues such as young leaves and seeds. The growth defects displayed by the nrt1.7 mutant under N starvation indicate that NRT1.7-mediated nitrate remobilization is crucial for plants to sustain vigorous growth when there is no external N supply. Therefore, we developed a new strategy to enhance NRT1.7-mediated nitrate recycling by replacing NRT1.7 with a hyperactive chimeric nitrate transporter, NC4N, in Arabidopsis, tobacco, and rice, improving NUE.

### A-2 Hyperactive chimeric nitrate transporter NC4N

Unlike other members of the NRT1/NPF family that are low-affinity nitrate transporters, CHL1 (AtNRT1.1/AtNPF6.3) is a dual-affinity nitrate transporter involved in both high- and low-affinity nitrate uptake. The high- and low-affinity modes of CHL1 are dependent on the phosphorylation status at threonine 101. To identify the structural determinants of CHL1 that are critical for its dual-affinity activity, we conducted a domain-shuffling analysis between the dual-affinity transporter CHL1 and the low-affinity transporter AtNRT1.2. One of these chimeric transporters, NC4N, in which the second to fifth transmembrane domains of NRT1.2 were replaced by the corresponding region of CHL1 (Figure 1A), exhibited hyperactive low-affinity nitrate uptake.

The uptake activity of NC4N was 3-fold greater than that of CHL1 and 12-fold greater than that of either NRT1.2 or NRT1.7 (Figure 1B). Therefore, NC4N is a powerful tool for manipulating nitrate transport in plants.

### A-3 Transgenic NRT1.7p::NC4N::3' Arabidopsis, tobacco, and rice exhibit enhanced N recycling and improved growth and yield

To promote NRT1.7-mediated nitrate remobilization, we introduced NC4N driven by the AtNRT1.7 promoter into Arabidopsis, tobacco, and rice. A $^{15}$N-labeled nitrate tracing assay revealed considerably enhanced source-to-sink nitrate remobilization in the transgenic AtNRT1.7p::NC4N::3' plants at both the vegetative and reproductive stages (Figure 1C).

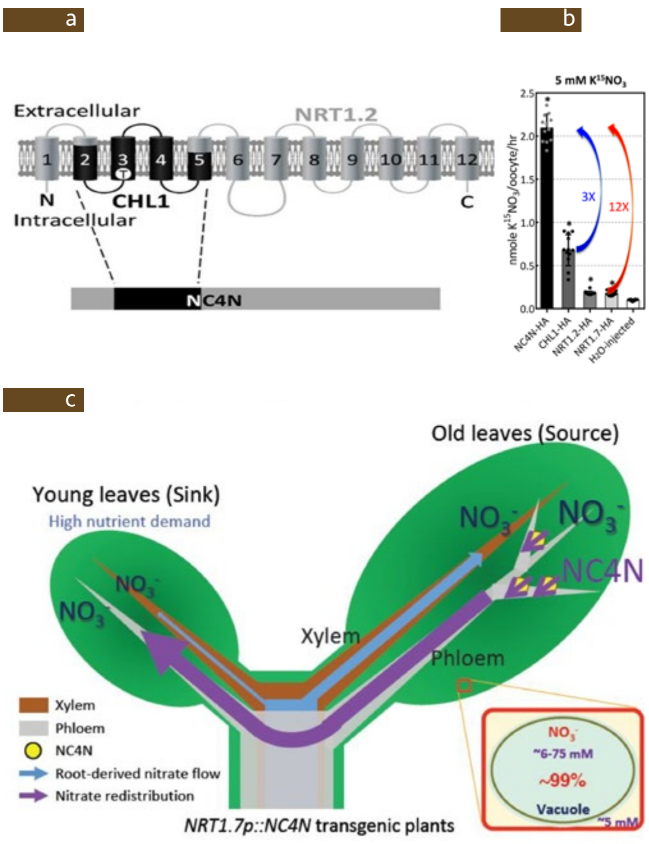



Figure 1. **AtNRT1.7p::NC4N::3' transgenic plants exhibit enhanced N recycling from source-to-sink tissues. a**, Chimeric nitrate transporter NC4N was generated by domain shuffling between the dual-affinity nitrate transporter CHL1 and the low-affinity transporter NRT1.2. **b**, Functional analysis of NC4N in Xenopus oocytes shows that NC4N is a hyperactive nitrate transporter. **c**, Expressing NC4N under the control of the NRT1.7 promoter enhances source-to-sink remobilization of nitrate through phloem transport.

Due to enhanced nitrate remobilization, vegetative growth of both transgenic Arabidopsis and tobacco improved by 19–38% and 25–38%, respectively (Figure 2), and AtNRT1.7p::NC4N::3′ bolstered seed production in Arabidopsis by 14–20% (Figure 2). To extend our strategy to rice grown under agricultural conditions, we performed a field trial on transgenic rice expressing AtNRT1.7p::NC4N::3′. Grain yields of transgenic rice were enhanced by 8–11%, with the increase in panicle number per clump (by 6–18%) and grain number per panicle (by 7–9%) being the major factors contributing to the increased grain yield (Figure 2).

Our results indicate that energizing nitrate recycling using the AtNRT1.7 promoter to drive the expression of the hyperactive chimeric nitrate transporter NC4N is a feasible tool for enhancing NUE in rice. Considering the problems of global food shortages and environmental pollution, our approach provides a novel strategy for enhancing NUE, improving crop production without increasing the demand for land or N fertilizers.

### B. Identifying new markers for improving NUE

To identify novel genes involved in regulating NUE, we also adopted a genetic approach by screening 1300 mutagenized lines grown hydroponically for NUE.  After several rounds of testing, we focused on three particular mutants: increased NUE under low-N conditions, reduced NUE under high N conditions, and improved growth under both high and low N. Identifying the causative genes for these phenotypes in these three mutants improve the understanding of how plants sense internal and external N conditions to use N efficiently.

### C. Targeting N-responsive genes to enhance NUE

As the primary N source for most plants, nitrate in the primary N assimilation pathway is taken up by plants and then reduced to nitrite and ammonium by nitrate and nitrite reductases, respectively. Inorganic NH4+ taken up from the environment or derived from nitrate reduction, photorespiration, protein degradation, and remobilization of N-containing compounds is assimilated into glutamine (Gln) and glutamate (Glu) via the Gln synthetase (GS)/ Gln:2-oxoglutarate (2OG) aminotransferase (GOGAT) pathway (Fig. 1). Gln is the first organic N synthesized in the cell and acts as the primary source for Glu biosynthesis (Liao et al., 2022). We aimed to study whether exogenous Gln represents a nutrient and stress signal in rice.

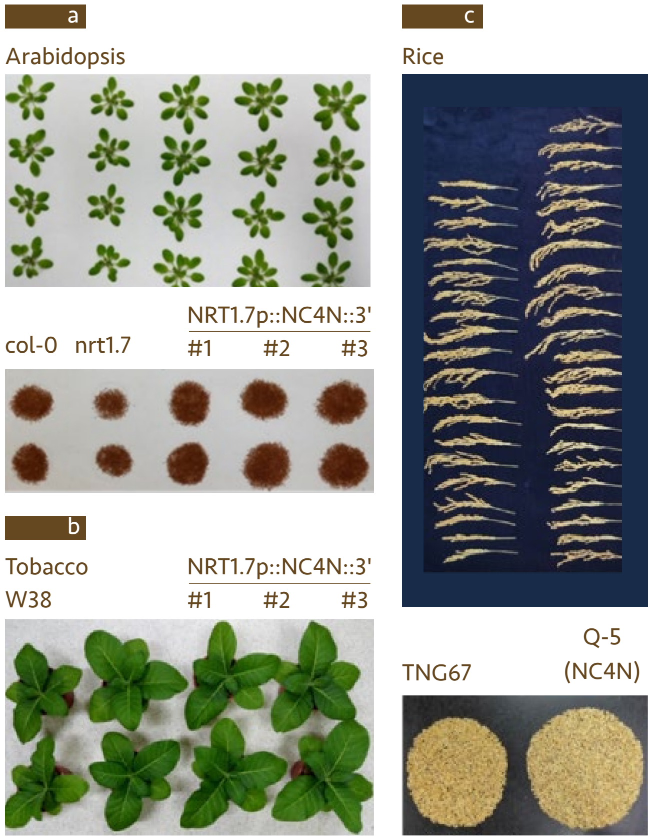



Figure 2. **Transgenic AtNRT1.7p::NC4N::3′ Arabidopsis, tobacco, and rice plants show improved growth or increased yield. a**, Representative 28-day-old plants grown hydroponically under conditions of N fluctuation (top panel), and the seeds produced by the Col-0, nrt1.7 mutant and three transgenic Arabidopsis plants (bottom panel). **b**, Representative 40-day-old plants of transgenic tobacco. **c**, Panicle number (top panel) and grain yield (bottom panel) are increased in transgenic rice.

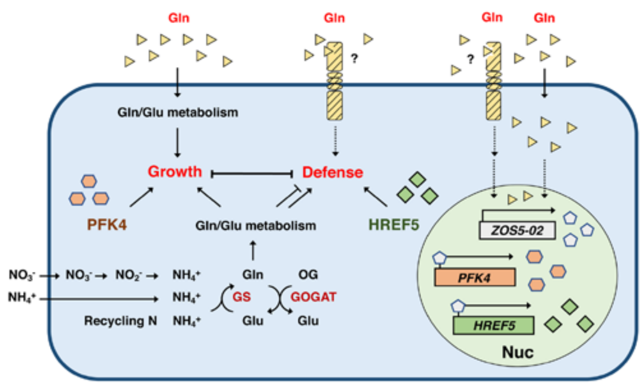



Figure 3. **Working model of Glutamine-induced growth and defense in rice.** Gln-induced ZOS5-02 plays a key role in activating PFK4 and HREF5 to promote rice growth and defense responses. The dashed lines indicate hypothetical responses; hatched shapes represent putative Gln receptors. ZOS, zinc-finger protein of Oryza sativa; PFK4, phosphofructokinase4; HREF5, hypoxia-responsive EF-protein5; GS, Gln synthetase; GOGAT, Gln:2-oxoglutarate aminotransferase.

As the first organic N synthesized in the primary N assimilation pathway and one of the most abundant free amino acids, Gln may play a crucial role in plant nutrition, metabolism, and signaling. We discovered that feeding Gln to N-starved rice seedlings rapidly induces the expression of genes involved in metabolism and stress responses. The induction of stress-responsive genes by Gln raises a notable question as to whether exogenous Gln can serve as a nutrient to support plant growth and a stressor to elicit plant defense responses (Figure 3).

We hypothesize that early Gln-induced transcription factor genes play an important role in regulating Gln responses in rice. ZOS5-02 (Os05g0114400), which encodes a C2H2-type zinc finger protein, is an early Gln responsive gene. To study the function of ZOS5-02, we successfully generated several independent zos5-02 CRISPR mutants. Phenotypic analysis of zos5-02 mutants revealed that zos5-02 seedlings were significantly smaller than wild-type seedlings when grown in hydroponic solutions containing Gln as the N source. These results indicate that ZOS5-02 is critical for the regulation of rice seedling growth in response to Gln.

Notably, Gln-mediated induction of HYPOXIA-RESPONSIVE EF5 (HREF5) and PHOSPHOFRUCTOKINASE4 (PFK4) was compromised in the zos5-02 mutants. Thus, HREF5 and PFK4 are potential targets of ZOS5-02 in Gln signaling. However, the functions of HREF5 remain unclear. Ca2+ is a secondary messenger in many biotic and abiotic stress-signaling pathways. The induction of HERF5 by Gln indicates that the Gln signaling pathway may use HREF5-Ca2+ as a secondary messenger to elicit stress responses in rice. PFK is a key regulatory enzyme in glycolysis that converts fructose-6-phosphate into fructose 1,6-bisphosphate. Thus, the regulation of a carbon (C) metabolic gene by Gln implies that PFK4 may play a key role in coordinating C and N metabolism in rice.

These results advance the knowledge of Gln signaling in rice. We have proposed a working model in which ZOS5-02 mediates Gln signaling to regulate the expression of genes involved in metabolism, stress, and defense responses (Figure 3). N is an essential nutrient for plants, and rice is a staple food for more than half of the world's population. The knowledge and materials generated in this project may have practical applications in enhancing rice production.

## Future Research Plan

We plan to use two approaches to further optimize our strategy to enhance nitrate remobilization. First, we will select and test promoters from rice that can induce a higher expression than the NRT1.7 promoter from Arabidopsis.  Second, we will design and generate a new version of the hyperactive nitrate transporter containing a single point mutation, allowing us to use CRISPR-Cas9 gene editing methodology to improve NUE. Moreover, by identifying causative genes in the three targeted rice NUE mutants, we will obtain new tools for improving the NUE in rice.

The ZOS5-02-HREF5 pathway may represent a signaling module involved in Gln-induced stress and defense responses. By contrast, the ZOS5-02-PFK4 module may be a Gln-elicited nutrient signal responsible for the regulation of metabolic gene expression. We plan to continue to study the molecular mechanisms by which ZOS5-02 regulates Gln-induced gene expression in rice.

## Publications


Chen, K. E., Chen, H. Y., **Tseng, C. S.**, & **Tsay, Y. F.** (2020). Improving nitrogen use efficiency by manipulating nitrate remobilization in plants. Nature Plant, 6(9), 1126-1135

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