Research and Development 20 for Clean Energy Technologies

AIST
Create the Future, Collaborate Together

# Now & Future 2026

## Research and Development 20 for Clean Energy Technologies

Oct. 19 – Oct. 23, 2026

# PREFACE

## What is RD20?

Climate change is an issue that the whole world must urgently confront together. We must realize worldwide carbon neutrality as soon as possible to achieve the targets laid out in the Paris Agreement. However, the economic and geographical circumstances are different from country to country. In order to promote effective emissions mitigation, it is then essential to accelerate the transitions of each country based on their diverse circumstances, by utilizing a wide range of technologies and energy sources, rather than adopting a uniform approach. In addition to transitioning through various pathways, we must create innovations that are not simple extensions of conventional technologies and engage with developing countries to realize decarbonization.

G20 members, which account for a major portion of the global CO2 emissions, are expected to lead the innovative research for promoting energy transitions. In particular, leading R&D institutes of G20 members, which carry out cutting-edge research on clean energy, could play a significant role in maximizing global potential of innovation by developing research alliances among the members, thereby accelerating international collaborations including joint R&D activities.

In these circumstances, launched in 2019, Research and Development 20 for Clean Energy Technologies (RD20) is an international initiative aimed at accelerating innovation by strengthening collaboration among leading research institutes from G20 countries and regions that pursue world-leading technological development toward achieving carbon neutrality. RD20 offers participants opportunities to share the research and development efforts, experiences, best practices, and ideas relating to clean energy technologies in their respective countries and regions, as well as to explore possibilities for international collaboration among leading research institutes. It has also helped to deepen and evolve new partnerships among industry, academia, and government stakeholders.

## What is Now & Future?

The National Institute of Advanced Industrial Science and Technology (AIST) compiled the activity summary and project information of each RD20 members, as well as the presentation materials of Leaders Session and Technical Session, as “Now & Future”.

We hope that it will be utilized for creating and promoting new international collaboration based on the framework of RD20.

## “Leaders Statement” and “Leaders Recommendations”

At the 3rd RD20 in 2021, the leaders of RD20 member institutes shared the urgency to significantlyincrease international collaboration of Research and Development to mitigate climate change.“Leaders Statement” summarizes such common understandings of the necessity to develop futuretechnologies

In order to actionize the Leaders Statement, the leaders discussed specific actions for furthercollaboration and adopted recommendations:Leaders Recommendations at the 4th RD20 in 2022Leaders Recommendation 2023 Fukushima at the 5th RD20 in 2023The “Leaders Recommendations” contains general information such as the role and venue of RD20as well as specific collaboration areas like summer schools.

## Leaders Statement

TBD

## Leaders Recommendations

TBD

# 1

# Schedule

Research and Development 20 for Clean Energy Technologies

# The 8th RD20 Conference

## Accelerating Clean Energy Innovation: From Africa to the World

Date: Monday, October 19 - Friday, October 23, 2026
Venue: CSIR International Convention Center (ICC), Pretoria, South Africa
Organizer: Council for Scientific and Industrial Research (CSIR)
Co-organizers: National Institute of Advanced Industrial Science and Technology (AIST), Japan

Launched in 2019, the RD20 is a global research and development initiative designed to strengthen international collaboration and drive innovation among leading research institutes in G20 countries and regions. These institutions are at the forefront of developing advanced technologies that support the transition to carbon neutrality. The RD20 platform enables participants to share research activities, experiences, and best practices in clean energy technologies across countries and regions, while also exploring opportunities for international joint research. In addition, the initiative fosters stronger partnerships and encourages new collaborations among key stakeholders from industry, academia, and government.

The 8th RD20 Conference will be held on October 19- 23 October 2026 in Pretoria, South Africa and online. Leaders and experts of the institutes from G20 members will gather to accelerate collaboration and release the outcomes all over the world.

| Session | Date | Time (SAST) | Attendance |
|---|---|---|---|
| Workshop #1 (WS#1) | Mon. afternoon, Oct. 19 | 13:00 – 16:00 | Invited members only |
| Technical Session (TS) | Tue. morning & afternoon, Oct. 20<br>Wed. morning, Oct. 21 | 09:00 – 17:30<br>09:00 – 11:40 | Open to the public |
| Workshop #2 (WS#2) | Wed. afternoon, Oct. 21 | 13:30 – 16:40 | Invited members only |
| Women in Green Hydrogen Networking Cocktail Event | Wed. evening, Oct. 21 | 17:30 – 21:00 | Invited members only |
| Leaders Session | Thu. morning, Oct. 22<br>Thu. afternoon, Oct. 22 | 09:00 – 12:30<br>14:00 – 17:30 | Open to the public<br>Invited members only |
| The CSIR Facility Tour | Thu. afternoon, Oct. 22 | 13:30 – 17:30 | Invited members only |
| Site Visit Tour | Fri. Oct. 23 | 09:00 – 14:30 | Invited members only |

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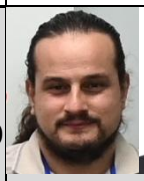
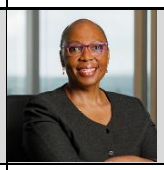
| Exhibition | Tue. Oct. 20 – Thu. Oct. 22 (noon) | 09:00 – 17:00 | Open to the public |

# Day 1: Workshop (Mon. afternoon, Oct. 19, 2026)

| Time | Session (Invited members only) |
|---|---|
| 12:00 - 12:55 | Arrival and Registration (International Convention Center) |
| 12:55 - 13:00 | Safety briefing |
| 13:00 - 16:00 |  **Workshop #1: AI for Energy:** ***Follow-up to the meeting held at KIER, Korea, in April 2026, with the aim of initiating concrete steps for cooperation among RD20 member institutions.*** **Moderator: Dr. Taha Selim Ustun (AIST, Japan)** **Dr. Woonho Baek (KIER, Korea)** **Venue: Crystal / Garnet / Onyx meeting room, First Floor** |
| 13:00 - 16:00 | (The order of presenters and presentation titles are subject to change)<br><br>Dr. Woonho Baek (KIER, Korea)<br>*2026 AI for Energy Workshop*<br><br>Dr. Cho Mincheol (AIST, Japan)<br>*AI Applications in Japanese Home Energy Big Data and Development of External Control Technology for Home Demand-Side Resources*<br><br>Dr. Aidan Rhodes (Imperial College London/UKERC, UK)<br>*Risks and Regulation for AI in Energy Systems*<br><br>**Coffee break (approximately 14:10-14:30)**<br><br>Dr. Amedeo Buonanno (ENEA, Italy) *-online*<br>*Human-AI Interaction in Operational Optimization*<br><br>Dr. Taha Selim Ustun (AIST, Japan)<br>*AI Assisted Predictive Maintenance in Hydroelectric Power Plants*<br><br>Dr. Xiwei (Sherry) Xu (CSIRO, Australia) - *online*<br>*AI Infrastructure × Energy Infrastructure: An Architecture Perspective*<br><br>Dr. Joungho Park (KIER, Korea) - *online*<br>*Reliable Surrogate-Assisted Multi-Objective Optimization for Complex Chemical Processes*<br><br>Discussion and wrap-up |

# Day 2: Technical Session (Tue., Oct. 20, 2026)

| Time | Session (Open to the public) |
|---|---|
| 08:00 - 08:55 | Arrival and Registration (International Convention Center) |
| 08:55 - 09:00 | Safety briefing |
| 9:00 - 10:50 |  **TS plenary: High Level Talks on Clean Energy Technologies**<br>**Moderator: Dr. Thembakazi Mali (CSIR, South Africa)**<br>**Venue: Diamond auditorium, Ground Floor** |
| 09:00 - 09:20 | Welcome address: Dr. Kaven Naidoo (CSIR) |
| 09:20 - 09:40 | Ms. Mandy Mlilo (DSTI, South Africa)<br>*DSTI Hydrogen & Energy Research, Development and Innovation Initiatives* |
| 09:40 - 10:00 | Prof. Dr. Christopher Hebling (Fraunhofer-ISE, Germany)<br>*Pathways to Climate Neutrality Through Renewables and Decarbonized Fossil Energy* |
| 10:00 - 10:20 | Dr. Pierre Serre-Combe (CEA, France)<br>*Low Carbon Energy mix challenge and balance with RE for countries operating or considering Low-Carbon Energy Technologies* |
| 10:20 - 10:40 | Prof. Philippe POGGI (University of Corsica/CNRS, France)<br>*Research, Businesses and Innovation in Overseas Territories: Smart Grids and Energy Transition* |
| 10:40 – 11:00 | Discussion and wrap-up |
| 11:00 - 11:10 | **Coffee Break** |

| Time | Session (Open to the public) |
|---|---|
| 11:10 - 14:50 | **TS #1: Energy Access – Innovative Solutions for Africa**<br>**Moderator: Dr. Kittessa Roro (CSIR, South Africa)**<br>**Venue: Diamond auditorium, Ground Floor** |
| 11:10 - 11:30 | Mr. Jay Bhagwan (Water Research Commission, South Africa)<br>*Conduit hydropower – the invisible opportunity* |
| 11:30 - 11:50 | Dr. Tetra Yanuariadi (ITTO/BRIN, Indonesia)<br>*Energy Access through Sustainable Forest Management: ITTO Projects and Lessons from Tropical Forest Landscapes* |

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| 11:50 - 12:10 | Prof. Nico Fischer (University of Cape Town, South Africa)<br>*Accelerating energy access through clean cooking - GreenQUEST Project* |
| 12:10 - 13:30 | **Lunch** |
| 13:30 - 13:50 | Dr. Sandor Szabo (JRC, EU) - *online*<br>*JRC studies and tools related to Africa* |
| 13:50 - 14:10 | Mr. Alekhya Datta (TERI, India) - *online*<br>*Decentralized Solar Applications - Lessons learned from India and replicability potential in Global South* |
| 14:10 - 14:30 | Prof. Mark Howells (UKERC, UK)<br>*Accelerating Clean Energy Access in Africa from Data-to-Deal: Insights and Tools from Climate Compatible Growth (CCG)* |
| 14:30 - 14:50 | Discussion and wrap-up |
| 14:50 - 15:10 | **Coffee Break** |

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|---|---|---|
| 15:10-17:30 | | **TS #2: Synthetic Fuels**<br>**Moderator:**<br>**Prof. Dr. Christopher Hebling (Fraunhofer-ISE, Germany)**<br>**Dr. Abdelilah Slaoui (CNRS, France)**<br>**Venue: Diamond auditorium, Ground Floor** |
| 15:10 - 15:30 | Dr. Lucero Cobos-Becerra (Helmholtz Zentrum Berlin, Germany)<br>*Industrial Collaboration Meets Synchrotron Science: Catalysis for Sustainable Fuels* | |
| 15:30 - 15:50 | Dr. Prima Zuldian (BRIN, Indonesia) - *online*<br>*RD20 institution latest research on synthetic fuels* | |
| 15:50 - 16:10 | Dr. Denzil Moodley (Sasol, South Africa)<br>*From Science to Scale: How Strategic Partnerships Accelerate Sustainable Fuel Technologies* | |
| 16:10 - 16:30 | Dr. Yuichi Manaka (AIST, Japan)<br>*International Collaborative Research on Ammonia Storage/Release under Severe Conditions* | |
| 16:30 - 16:50 | Dr. Sanjukta Subudhi (TERI, India) - *online*<br>*Sustainable Aviation Fuel through Alcohol to Jet pathway* | |
| 16:50 - 17:10 | Discussion and wrap-up | |

# Day 3: Technical Session (Wed., Oct. 21, 2026)

| Time | Session (Open to the public) |
|---|---|
| 08:00 - 09:00 | Arrival and Registration (International Convention Center) |
| 08:55 - 09:00 | Safety briefing |
| 09:00 - 11:40 | **TS #3: Critical Minerals for Energy**<br>**Moderator: Dr. Aidan Rhodes (Imperial College London/UKERC, UK)**<br>**Venue: Diamond auditorium, Ground Floor** |
| 09:00 - 09:20 | Dr. Angelique Janse van Rensburg (BMW, Germany)<br>*Innovating for Impact: Collaborative R&D for Sustainable, Competitive and Resilient Battery Value Chains* |
| 09:20 - 09:40 | Mr. Shaun Pershad (Eskom)<br>*Critical minerals: Eskom Green hydrogen research: Perspectives from an electricity utility* |
| 09:40 - 10:00 | Ms. Stéphanie Riché (CEA, France) - *online*<br>*Resilient Value Chains for the Energy Transition: A Circular Economy approach on Critical Battery Materials* |
| 10:00 - 10:20 | **Coffee Break** |
| 10:20 - 10:40 | Mr. Souvik Bhattacharjya (TERI, India) - *online*<br>*Bridging India's Critical Mineral demand supply Gap: Challenges and Opportunities* |
| 10:40 - 11:00 | Dr. Fathan Bahfie (BRIN, Indonesia) - *online*<br>*New Developing Green Extraction of Critical Mineral for Energy Security* |
| 11:00 - 11:20 | Dr. Emilie Janots (Université Grenoble Alpes/CNRS, France) - *online*<br>*Rare Earth Elements: Rethinking Extraction — State of Knowledge and Perspectives* |
| 11:20 - 11:40 | Discussion and wrap-up |
| 11:40 - 13:30 | **Lunch** |

| Time | Session (Invited members only) |
|---|---|
| 13:30 - 16:40 | **Workshop #2: Clean Hydrogen and its Derivatives**<br>**Moderator: Dr. Michio Kondo (AIST, Japan)**<br>**Dr. Thabo Hlalele (CSIR, South Africa)**<br>**Venue: Diamond auditorium, Ground Floor** |
| 13:35 - 14:15 | Dr. Hirokazu Kojima (AIST, Japan)<br>*Evaluation Technologies for Large Scale Hydrogen Production by Water Electrolysis*<br><br>Dr. Sibimol Luke (UCL/UK-HyRES/UKERC, UK)<br>*Hydrogen reality check: Hard truths and real pathways*<br><br>Dr. Abdelilah Slaoui (CNRS, France)<br>*Water use & quality for sustainable Hydrogen*<br><br>Dr. Hunmin Park (KIER, Korea)<br>*Recent Progress in Next-Generation SOEC Technology toward Scalable Clean Hydrogen Production* |
| 14:15 - 14:30 | Discussion |
| 14:30 - 15:20 | Prof. Dmitri Bessarabov (NWU/DSTI HySA Infrastructure Center of Competence)<br>*HySA Green Hydrogen Innovation and Value Chain Development Hub at NWU*<br><br>Dr. Abdul Hamid Budiman (BRIN, Indonesia) - *online*<br>*Status and implementation of clean hydrogen in Indonesia*<br><br>Dr. Joungho Park (KIER, Korea) - *online*<br>*Impact of model fidelity and data resolution on green hydrogen economics*<br><br>Dr. Liezl Schoeman (CSIRO, Australia)<br>*Clean Hydrogen and derivatives: industrial applications* |
| 15:20 - 15:35 | Discussion |
| 15:35 - 15:50 | **Coffee Break** |
| 15:50 - 16:20 | Breakout Session |
| 16:20 - 16:40 | Discussion and wrap-up |

| Time | **Women in Green Hydrogen (WiGH) Networking Cocktail Event**<br>**(Invited members only)**<br>**Venue: Amber banquet room** |
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| 17: 30 - 21:00 | Women in research and development, industry professionals, developers, entrepreneurs, policymakers, funding partners and allies will exchange perspectives through a moderated panel and audience discussion, followed by a networking cocktail reception. |

# Day 4: Leaders Session (Thu., Oct. 22, 2026)

| Time | Morning session (Open to the public)<br>Venue: Diamond auditorium, Ground Floor |
|---|---|
| 08:00 - 08:55 | Arrival and Registration (International Convention Center) |
| 09:00 - 09:15 | Safety briefing |
| 09:15 - 10:20 | **Opening Ceremony**<br>Welcome address: Dr. Kaven Naidoo (CSIR)<br><br>Opening remarks:<br>Ms. ISHII Mitsuko (METI, Japan) - *Video Message*<br>Mr. NISHIJO Masaaki (MEXT, Japan) - *Video Message*<br>Mr. SEKIYA Takeshi (MOE, Japan) - *Video Message*<br>Mr. YOSHIDA Takeshi (NEDO, Japan)<br><br>Voices of Leadership: Strengthening Global Cooperation through RD20:<br>Mr. Kazuhiko Ishimura (AIST)<br>Dr. Christopher Hebling (Fh-ISE) |
| 10:20 - 10:50 | **Coffee Break** |
| 10:50 - 11:20 | **RD20 status and activities (moderated by Action Committee members**<br>Report of Summer School 2026: Dr. Abdelilah Slaoui (CNRS)<br>Report of TF activities: Dr. Masahiro Yoshita (AIST), Dr. Thomas Roos (CSIR) |
| 11:20 - 12:10 | **Open Discussion**<br>Leading presentations:<br>Dr. Rebecca Maserumle (Industrial Development Corporation of South Africa)<br>*The role of Green Hydrogen in Africa and Developments in South Africa*<br>Ms. Jetane Charsley (National Intellectual Property Management Office, DSTI)<br><br>Discussion:<br>Leaders of RD20 institutions exchange views on opportunities for collaboration and future partnerships. |
| 12:10 - 12:20 | **Announcement**<br>Announcement of the RD20 Summer School 2027: Dr. Jamie Speirs (UKERC)<br>Announcement of the 9th RD20 2027: Dr. Koichi Matsuoka (AIST) |

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| 12:20 - 12:25 | **Adjournment of morning session**<br>Closing Remarks: Dr. Thembakazi Mali (CSIR) |
| 12:30 - 12:40 | **Group Photo (Entrance of the International Convention Center)** |
| 12:40 - 13:00 | **Visit to the Exhibition Booths** |
| 13:00 - 14:00 | **Lunch** |

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| 13:30 - 17:30 | **The CSIR Facility Tour**<br>For participants who ***cannot attend*** the afternoon part of the Leaders Session, which is exclusively for members of RD20 institutions, a CSIR facility tour will be available until the Conference Closing Dinner. |

| Time | Afternoon session (Members of RD20 Institution only)<br>Venue: Crystal/Garnet/Onyx meeting room, First Floor) |
|---|---|
| 14:00 - 14:05 | Introductory remarks from chairs:<br>Dr. Thulani Dlamini (CSIR, provisional), Mr. Kazuhiko Ishimura (AIST),<br>Dr. Christopher Hebling (Fh-ISE), as a presiding chair |
| 14:05 - 14:20 | Overview of the LS afternoon session in the 8th RD20<br>Reviewing Leaders Recommendation 2025 |
| 14:20 - 15:00 | Moderated Discussion Theme 1<br>Engagement - Exploring ways to support active participation in RD20 activities |
| 15:00 - 15:30 | Moderated Discussion Theme 2<br>Resources for Collaboration Opportunity |
| 15:30 - 15:50 | **Coffee Break** |
| 15:50 - 16:30 | Moderated Discussion Theme 3<br>Membership - Considering future principles related to RD20 membership |
| 16:30 - 17:00 | Moderated Discussion Theme 4<br>Visibility - Improving RD20's visibility and outreach |
| 17:00 - 17:15 | Reviewing discussion for Leaders Recommendation 2026 |
| 17:15 - 17:25 | Future conference approval of hosting institutes<br>・The 10th RD20 Conference in 2028<br>・RD20 Summer School 2028 |
| 17:25 -17:30 | Closing remarks: Dr. Rachel Chikwamba (CSIR) |
| 17:30 | **Adjournment of afternoon session** |

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| **18:00- 21:00** | **Conference Closing Dinner**<br>**Venue: Amber banquet room** |

# Day 5: Site Visit Tour (Fri., Oct. 23, 2026)

**Stakeholder Site Visit to Sasol Research & Technology (Invited members only)**

As part of the conference program, delegates will have the opportunity to participate in exclusive technical site tours hosted by Eskom and Sasol on Friday, 23 October 2026. These visits will provide firsthand exposure to world-class research, innovation and technology development facilities, offering valuable insights into cutting-edge solutions shaping the future of clean energy, sustainability and industrial decarbonization. Participants will engage with experts, explore advanced technologies in action, and gain a deeper understanding of the innovations driving the global energy transition.

The visit to Sasol Research & Technology (R&T) in Sasolburg will showcase Sasol's sustainable aviation fuel (SAF) development journey based on Fischer-Tropsch technology. Delegates will gain insight into the end-to-end technology development pathway, spanning laboratory research, pilot plant testing, and semi-commercial scale demonstration. The visit will include a comprehensive tour of Sasol's R&T facilities, highlighting innovation, scale-up capabilities, and the role of advanced research in enabling sustainable fuels. Subject to time availability, delegates will also participate in a bus tour of the Sasolburg Operations site.

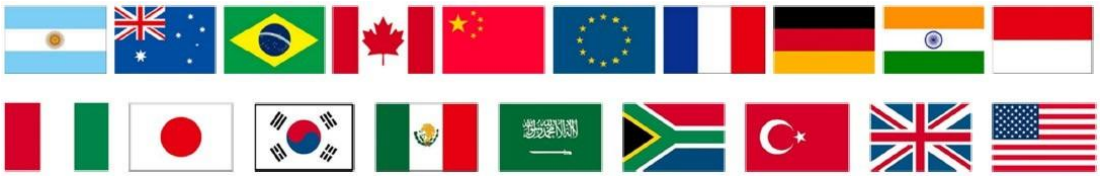
**Stakeholder Site Visit to Eskom RT&D (Invited members only)**

Eskom's Research, Testing & Development (RT&D) business unit plays a critical role in supporting the organization with scientific and technical expertise. It is based at the Eskom Research & Innovation Centre (ERIC) in Rosherville, Johannesburg. The business unit provides research, testing, consulting and strategic technical planning services that help guide Eskom's technological direction. The unit's key function is to open new technological opportunities by offering RT&D support for emerging and cutting-edge technologies, creating partnerships with universities, Universities of Technology (UoTs), Further Education and Training colleges (FETs), and research institutions to address technological and skills challenges faced by Eskom plants.

RT&D's research agenda is primarily driven by the needs of Eskom's line divisions, which represent the company's core business and are the primary beneficiaries of its work. As such, the business unit focuses on applied research that delivers practical, operational solutions aligned with Eskom's strategic objectives. However, the unit also dedicates resources to exploring technology innovation and emerging technologies to ensure Eskom remains competitive and sustainable.

RT&D's work contributes to Eskom's sustainability, balancing financial, social and environmental factors while strengthening Eskom's internal competencies and ensuring the company remains at the forefront of energy technology advancements.

Expected participating countries and regions



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# Summaries of RD20 member institutes:

## Activity Summary, Project Information, and photo and profile of the leaders.

# Australia

CSIRO

Commonwealth Scientific and Industrial Research Organisation

**The 8th RD20 conference, Oct. 19-23, 2026**

**Dr Dietmar Tourbier**
**Director, Energy**
**Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia**

## 1. Introduction

Common features across various scenarios of the global energy future form a set of expectations over the coming decades including: 1) renewable energy and storage will be increasingly important; 2) fossil fuels are needed in the interim, however, emissions must decrease, and; 3) societies will redefine many transport and other energy uses. These expectations imply that the energy system will become more complex requiring greater integration to enable localised implementation as electrification proceeds, energy storage, hydrogen vectors, and low-carbon fuels industries emerge at scale, and deployment of decarbonised energy in the heavy industry and mobility sectors increases.

Concurrently, recent geopolitical events have shifted the focus towards energy and supply chain security. The trajectory of Australia's transition will need to align with these global trends and be responsive to changes in the current global geopolitical landscape and global policy action on energy, emissions, and climate change. Reducing greenhouse emissions from electricity generation and use, while maintaining the affordability of energy and ensuring the security of supply, continues to present complex, inter-related and systems-oriented challenges that can only be resolved through significant and sustained transition of the Australian, and international, energy and industry sectors.

Australia has substantial opportunities to expand the clean energy sector, however, these opportunities will require national strategic alignment, innovation and regulation.[1] The transition must be underpinned by coordinated, evidence-based technical and social solutions and strategies that respond dynamically to the changing energy environment. As Australia's national science agency, CSIRO is well positioned to support Australia's energy transition towards net zero emissions in alignment with national strategies and guidelines illustrated as follows:

- In the electricity sector, the Australian Energy Market Operator (AEMO) Integrated System Plan (ISP), updated in 2026, provides a whole-of-system actionable roadmap to guide the efficient development of Australia's NEM over the next 20 years. Its objective is to facilitate development of an electricity system that is affordable, secure and reliable, and incorporates Australia's ongoing emissions trajectory within an acceptable level of risk. It serves the regulatory purpose of identifying actionable and future ISP projects, as well as informing market participants, investors, policy decision makers and consumers. https://www.aemo.com.au/energy-systems/major-publications/integrated-system-plan-isp/2026-integrated-system-plan-isp
- In 2024, the Australian Government released the revitalised National Science and Research Priorities, which will guide Australian science and research efforts. They

[1] Clarke, D., Baldwin, K., Baum, F., Godfrey, B., Richardson, S., and Robin, L. (2021). *Australian Energy Transition Research Plan*. Report for the Australian Council of Learned Academies (ACOLA), www.acola.org. https://acola.org/sites/default/files/2026-03/acola-2021-australian-energy-transition-plan.pdf

recognise matters that are important to Australians, and how Australia can uniquely, and effectively, contribute to global research. They are challenge-based, overlapping, and cut across discipline, sector and knowledge system boundaries. The first of the five identified priorities is: "Transitioning to a Net Zero Future": https://www.industry.gov.au/publications/national-science-and-research-priorities-2024

- In 2025, the Australian Government announced new emission reduction targets for 2035 accompanied with six sectoral pathways putting Australia on track to reduce emissions by 62–70% below 2005 levels by 2035. This target is ambitious, achievable, and in Australia's national interests. https://www.dcceew.gov.au/about/news/setting-2035-target-path-net-zero
- In late 2025, the Australian Government also announced a $1.1B Cleaner Fuels program to stimulate private investment in Australian onshore production of low carbon liquid fuels, including renewable diesel and sustainable aviation fuel, with first production of drop-in cleaner fuels estimated by 2029. https://www.dcceew.gov.au/about/news/new-prod-incentive-low-carbon-liquid-fuels

CSIRO considers science and innovation is critical in supporting the transition and contributing to securing a resilient and prosperous future for us all, globally. CSIRO is collaborating internationally and within Australia to address the challenges associated with the transition of energy, industry, manufacturing, agricultural and transport sectors through assessment, co-development, and demonstration of priority low emission technologies, systems and solutions.

## 2. R&D activities related to clean energy technology for carbon neutrality

CSIRO contributes to solutions from applied science and research to address the challenges of transitioning energy, transport, industrial technologies, and infrastructure systems. The goal is to support large scale integration of renewable and low emissions energy pathways at a state, national and international scale.

CSIRO is leveraging capabilities across multiple Research Units utilising an Enterprise-level CSIRO Research Portfolio Approach addressing key technology needs in six research areas: Energy and Minerals, Food and Fibre, From Wonder to Discovery, Nature, One Health and Tech Economy. In 2025, CSIRO released the CSIRO book, highlighting the research topics in these six areas. https://www.csiro.au/en/about/corporate-governance/csiro-book

The specific topics addressing challenges in clean energy and carbon neutrality are structured into multiple research topics, including Electricity Transition, Decarbonised Industry and Transport, Carbon Management Technologies, Critical Minerals Supply, and Green Metals.

## 3. Specific research activities

CSIRO seeks to connect industry with the research community to deliver expert advice, technology innovation, engineering, and prototyping. CSIRO is supporting the energy transition and communities by integrating science for social acceptance, policy and development of new skills, while also facilitating environmental sustainability. Our key research projects are illustrated herein by selected examples.

### Electricity transition

CSIRO's research is focussing on enabling generation, use and storage of electricity and emission reduction towards government emissions targets. We anticipate achieving this through the adoption of CSIRO's innovative power generation technology systems and supply networks, new energy storage solutions and systems driving energy efficiency in built environments. Another goal is to improve utilisation of existing infrastructure to enhance Australia's national economic performance.

One of CSIRO's key deliverables is the annual GenCost[2] report, which is a collaboration between CSIRO and the Australian Energy Market Operator (AEMO). GenCost provides an annual update of electricity generation and storage costs, with a strong emphasis on stakeholder engagement. It considers a range of future scenarios to understand the mix of technologies that may be adopted and projects likely costs for these possible pathways.

Another example of electricity network transformation, from the user end, includes simulating building energy use to inform investments in electricity grid systems[3]. CSIRO's energy efficiency software is utilised under the energy efficiency provisions of the National Construction Code (NCC), including its trajectory to future low-energy buildings. We support the development of the software and curate a national repository of housing stock data that underpins national housing policy research.

CSIRO is also leading national and international efforts to source flexible-demand resources from buildings. This work aims at unlocking capacity reserves in the wholesale electricity market worth around $450 million/year. We have developed a building-services digital platform (the Data Clearing House) for hosting machine learning algorithms, and we lead an international collaboration of more than 50 research teams across 19 countries, developing software tools for managing energy flows in buildings[4].

**Industry and transport transition**

CSIRO's research on Advanced Solar Photovoltaics (PV) and Concentrated Solar Thermal (CST) technologies aims to accelerate renewable energy collection and storage at scale to support industry adoption and support industry transition. The aspirations are to improve utilisation of solar energy using low-cost, environmentally-friendly technologies, production methods, flexible materials and systems. CSIRO's research is supporting commercialisation of solar technologies ranging from printable solar cells to perovskite solar cell production. CSIRO in partnership with ARENA, led the Australian Solar Thermal Research Institute (ASTRI) program to facilitate commercial uptake of concentrated solar thermal technologies and systems. The ASTRI program explored and demonstrated pathways to integrate solar thermal energy collection, storage, and utilisation at scale, in a range of applications including power generation, manufacturing, and process industries, where process heat is a key energy requirement.

CSIRO is a core partner of the Collaborative Research Centre for Heavy Industry Low-Carbon Transition (HILT CRC). HILT CRC supports the Australian heavy industry sector to decarbonise their processes for production of materials such as 'green' iron, alumina, cement and other processed minerals. HILT CRC focuses on developing technologies and methods supporting the low-carbon transition, and to reduce production, equipment and safety risks. The industry

[2] https://www.csiro.au/en/research/technology-space/energy/electricity-transition/gencost
[3] https://www.csiro.au/en/about/corporate-governance/ensuring-our-impact/impact-case-studies/environment-energy-resources/residential-energy-efficiency
[4] https://research.csiro.au/dch/

transformation will be progressed through regional hubs that have good local synergies and opportunities.

CSIRO's research encompasses a broad spectrum of Thermal & Electrochemical Technologies to increase efficiency, scale and uptake of low emission technologies and hydrogen energy systems. These include:

- The Victorian Hydrogen Hub, led by Swinburne University of Technology, working in partnership with CSIRO, and Germany's ARENA 2036, brings together researchers, industry partners and businesses to test, trial and demonstrate new and emerging hydrogen technologies to support sustainable manufacturing practices and clean energy storage.
- Endua – an Australian company, backed by Main Sequence Ventures, Ampol and CSIRO - is building the next generation of clean energy storage solutions to power communities, remote industries and off-grid infrastructure. Endua's power banks are standalone on-site units that store energy created from 100% renewables. Renewable energy is stored as hydrogen and then converted back to electricity by fuel cells to deliver sustainable, reliable and affordable electricity on demand.
- Hadean Energy – an Australian company, backed by RFC Ambrian and CSIRO – is targeting the development of hydrogen production technology based on solid oxide electrolysis for industrial processes where low-cost waste heat can be used to support electrolysis to produce hydrogen for use in industrial processes.
- FPR Energy – an Australian company, backed by RFC Ambrian, CSIRO and Osaka Gas - is targeting the development of commercial scale concentrated solar thermal systems for high temperature heat industry application using Falling Particle Receiver (FPR) technology.

**Carbon Management Technologies**

CSIRO leads the Gas Industry Social and Environmental Research Alliance (GISERA) which is focussed on the impacts of onshore gas developments across Australia, with a significant portfolio of research on the social and environmental impacts of onshore gas development. This research is publicly available to support development decisions in regions where natural gas development is occurring or being proposed. After 15 years, the GISERA program is coming to an end in 2026. Ongoing related research will continue.[5]

CSIRO is also developing a portfolio of Sustainable Carbon Utilisation Technologies to support industry transition to net zero emissions, to reduce the cost and improve the efficiency of carbon capture, storage and utilisation. For example, carbon capture research is focused on deploying large-scale demonstration projects that enable substantial reductions in emissions, and provide a pathway for industry to adopt the technologies at industrial scale.

CSIRO has been involved for many years in the development, commissioning and operation of Post-combustion Carbon Capture (PCC) and Direct Air Capture (DAC) pilot plants in Australia and overseas. In collaboration with industry, CSIRO has developed a highly efficient amine solvent that is well-suited for $CO_2$ capture from cement plants, aluminium refining and smelting and steam methane reforming. The PCC technology has also been extended to DAC. Collected $CO_2$ can be placed to geological storage or used for carbon neutral products. CSIRO is also developing solid sorbent technology, CarbonAssist™ which is a proprietary technology that

[5] https://gisera.csiro.au/

allows $CO_2$ capture from different sources at low cost. The capture units are designed to be modular which supports versatility and scalability.

## 4. International collaboration

CSIRO aims to connect Australia to global science, technology, and innovation frontiers as well as supporting access new markets for Australian innovation. CSIRO has extensive international activities and collaborations. These collaborations are conducted under a variety of arrangements, which are not always reflected in formal Memoranda of Understanding (MoU).

CSIRO has concluded MoUs in the field of energy and environment with National Laboratory of the Rockies (NLR, USA – former NREL, USA), the National Institute of Advanced Industrial Science and Technology (AIST Japan), United Kingdom Research and Innovation (UKRI), and more specific collaboration agreements with Argonne National Laboratory (ANL USA).

CSIRO collaborates with many G20 country institutions. Topics include innovations in clean energy technologies, research exchanges, and workshops under a variety of arrangements.

Recent international collaboration examples include:

- The Australian Government is working closely with international partners to advance practical action on climate change and build new clean energy industries[6]. Australia is cooperating to:
  - deepen collaboration to tackle the global climate challenge
  - support regional and global energy transformation
  - build new clean energy trade opportunities for Australia
  - increase and diversify clean energy supply chains.

  Australia has partnerships in place with: Canada, China, Germany, India, Japan, The Republic of Korea, Singapore, The United Kingdom, The United States, The Netherlands, Indonesia and Pacific Island countries
- CSIRO is engaged with the Global Power Systems Transformation Consortium (G-PST), which is a collaborative initiative set by the founding system operators: National Grid Electricity System Operator UK, California Independent System Operator (CAISO), Australia Energy Market Operator (AEMO), Ireland's System Operator (EirGrid), and Denmark's System Operator (Energinet). This Consortium is partnering with several emerging economy and developing country system operators from Africa, Asia, Latin America and Eastern Europe who will also guide the G-PST vision and contribute to advancing power system transformation with a focus on technical collaboration, peer learning and exchange, and workforce development to support local power system transformation priorities[7].

We believe such international activities, together with strategic partnerships, alliances joint projects, researcher exchanges, joint workshops and seminars, are an effective way to facilitate international cooperation.

## 5. Future perspectives (towards carbon neutrality)

CSIRO is focused on supporting the energy transition and drive towards net zero emissions, increasing capability in renewables and digital energy technologies, investing in more clean

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[6] https://www.dcceew.gov.au/climate-change/international-climate-action/international-partnerships

[7] https://globalpst.org/wp-content/uploads/042921G-PST-Research-Agenda-Master-Document-FINAL_updated.pdf

energy growth areas, and taking on major projects with strategic partners, both in Australia and internationally.

**Electricity grid**

CSIRO and the Australian Energy Market Operator (AEMO) are Australian representatives in the Global Power System Transformation (G-PST) Consortium. Working together, we have been aligning Australian research, together with international research institutes, to address the most pressing challenges in decarbonisation of electricity systems. In 2022, CSIRO and AEMO produced the G-PST Research Roadmap that incorporates research plans for the most pressing research topics. This Roadmap considered how Australia could lead the way in solving the global challenge of integrating renewable energy into electricity networks and accelerating the decarbonisation of the energy sector. In 2026 CSIRO released updated progress reports for stage 5 of this Research Roadmap[8].

**Decarbonising industry through renewable heat, low-carbon liquid fuels, including hydrogen and its appropriate storage and utilisation vectors**

One of CSIRO's growth initiatives in energy research is accelerating the decarbonisation of industry and transport through low-cost renewable energy pathways. This includes reducing the cost of hydrogen as a clean energy storage mechanism and exploring opportunities around emerging natural hydrogen discovery, exploration and extraction.

CSIRO's focus on hydrogen as an energy storage vector, is aimed at supporting technology and systems to address production, storage and transport cost competitiveness. Success in this area will support initiatives to facilitate development of an Australian clean hydrogen energy industry.

One key component of decarbonising industry in Australia is the need for clean heat in industrial processes. Recently, CSIRO established a new program on Renewable Heat Industrial Decarbonisation (RHID). The program has been established to assist companies to navigate the initial 'discovery' phase of their thermal decarbonisation opportunities.

[8] https://www.csiro.au/en/research/technology-space/energy/electricity-transition/ar-pst/stage-1

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| | | | <Example> ●●●● ProjectDescribe the summary of the project.[period of the project]<br>Current<br>20XX - 20XX (R&D span) | Describe the target and/or goals of the project.<br>Note the numerical purpose (if possible).<br>e.g. Cost reduction of ■■ to ● | Dr. ******, ●● | (Domestic) ●● Research Institute, ▲▲ University, etc.<br>(International) ●●<br>(Desired collaboration) ●● field test, ▲▲ modeling, ■■ standard, etc. | https://www.●●● |
| CSIRO/Australia | Clean H2 derivatives | Production | Development of PEM electrolysis technology and kW class systems for distributed and off-grid applica<br>2021 - 2026 | Development of low cost electrolysis cells, stacks, BOP and control & safety system for building >20 kW PEM electrolysers. | Dr Sarb Giddey / CSIRO | Endua (CSIRO, Ampol, Main Sequence Ventures) Australia. | This technology is currently being commercialised through Endua (CEO Paul Sernia). https://www.endua.com/ |
| | | | Development of solid oxide electrolysis for steam / CO2 electrolysis for production of hydrogen, synga<br>2016 - 2026 | Demonstration of kW scale SOEC unit at industrial site | Dr Gurpreet Kaur / CSIRO | Hadean Energy | This technology is currently being commercialised through Hadean Energy (www.hadeanenergy.com.au) |
| | | | Basic R&D for novel pathways for electrochemical ammonia synthesis using renewable sources of ele<br>2019 - 2025 | Develop various options for efficient modular design ammonia synthesis. | Dr Gurpreet Kaur / CSIRO | CSIRO Hydrogen FSP / strategic areas of research, | Project complete. Relates to the development of new pathways for modular ammonia synthesis technology. |
| | | | Basic R&D for subsurface hydrogen exploration, including geogenic (natural) hydrogen.<br>2019 - 2026 | Understand geoscience to identify best locations for geogenic hydrogen exploration and potential for subsurface hydrogen production | Dr Ema Frery, Dr Valeria Shulakova/ | CSIRO Hydrogen FSP, ECU, Qld Govt | Geogenic hydrogen exploration attract interest from some Australian exploration companies. Qld State Govt engagement.<br>Initial project complete. Geogenic hydrogen project being progressed through Decarbonisation Pathways Program |
| | | | Exploring the potential for ammonia recovery from wastewater with bipolar membrane electrodialysis.<br>2022 - 2026 | Develop processfor ammonia recovery from waste water. | Dr Sebastien Allard/ CSIRO | CSIRO Hydrogen FSP, Western Australia Water corporation | Relates to ammonia recovery from wastewater. Project Complete |
| | | | Development and demonstration of direct thermochemical solar reactors for production of hydrogen, s<br>2019 - 2025 | Development of catalysts, materials, cell designs for direct steam / H2 reaction, to build a prototype reactor for 250kWth solar field with liquid fuels synthesis reactor | Jin-Soo Kim / CSIRO | ARENA, | https://arena.gov.au/projects/solar-thermochemical-hydrogen-research-and-development/<br>Project Complete |
| | | | basic R&D work on elecrolysers<br>2022 - 2025 | Those projects relates to the incease of the service life of polymer membranes, assessing the option/feasibility of salt water electrolysis and understanding the effects of intemittency on electrolyser performance | Various - contact Dr Nikolai Kinaev / CSIRO | CSIRO Hydrogen FSP, RMIT, Victoria Uni. | Complete |
| | | | Integrated hydrogen and ammonia production from organic wastes<br>2019 - 2024 | Integrating solar thermal into microbial digestion of biological waste for hydrogen and ammonia production | Dr Andrew Beath /CSIRO | CSIRO Hydrogen FSP | Complete |
| | | | Basic R&D for photoelectrochemical hydrogen generation using perfect photo-absorber materials<br>2019 - 2026 | Develop catalysts and semiconductor materials + cell design for hydrogen generation | Dr Noel Duffy / CSIRO | CSIRO Hydrogen FSP | Complete. Next stage of projects will look at new materials and larger scale systems for increased generation. Plans for demsonatration scale prototype. |
| | | Transportation / Storage | Development of metal membrane based reactor for ammonia production at low pressures by sourcing<br>2014 - 2028 | Development of catalysts, membrane materials, interfacial designs, and a prototype system to produce ammonia at a kg scale from renewable electricity | Dr Sarb Giddey / CSIRO | ARENA,GRDC | Moving into the next stage of commercialisation with additional industry partner |
| | | | Development of solid state hydrogen compressor for domestic use (small scale re-fuelling of fuell cell<br>2018 - 2025<br>Current | Development of a prototype solid state H2 compressor designed to deliver 350 bar H2, particularly with available sources of low-grade industrial or commercial waste heat | Dr Ashleigh Cousins / CSIRO | CSIRO Hydrogen FSP/ strategic areas of research | Prototype completed in 2025 - now seeking commercial partnerships and industrial applications |
| | | | R&D in subsurface hydrogen storage<br>2018 - 2025 | Understanding the hydrogen storage potential in underground reservoirs and shale lenses | Various - contact Dr Joel Sarout CSIRO | CSIRO Hydrogen FSP/ strategic areas of research, Lochard Energy, Geoscience Australia | Pilot trials in Victoria |
| | | | Commercialisation of CSIRO's metal membrane technology for ultra-high purity hydrogen production<br>Current<br>2018 - 2025 | Demonstrate the viability of exporting hydrogen in the form of ammonia and extracting ultra high purity hydrogen at point of use, suitable for fuel-cell applications | Dr. David Wong / CSIRO | Fortescue and partners | 100 kg-H2/day scale pilot trials completed in 2024-25; seeking further commercial partnerships and applications for the technology |

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| | | Transportation / Storage | 2019 - 2028 | | | | |
| | | | Basic R&D for direct ammonia utilisation in a solid oxide fuel cell for power generation<br>2019 - 2026 | Develop catalysts, materials and cell design for ammonia cracking and hydrogen oxidation in the fuel cell. | Dr Sarb Giddey/ CSIRO | CSIRO Hydrogen FSP / strategic areas of research, RMIT University | Complete |
| | | | Hydrogen Utilisation in industrial applications: evaluation of impact on materials and infrastructure<br>2022 - 2027 | improved materials and selection to reduce H embrittlement risk | Dr Liezl Schoeman | HILTCRC, CSIRO Hydrogen FSP | HILTCRC.com.au |
| | | | Ammonia Cracking using Catalytic Static Mixers<br>2021 - 2023 | Developing modular small scale ammonia cracker | Dr John Chiefari | CSIRO Hydrogen FSP | completed |
| | | Utilisation | Fractal Hydrogen Burner<br>2019 - 2024 | Developing technologies to address hydrogen flame issues (stability, lack of radiant heat) | Dr Jim Patel/ CSIRO | CSIRO Hydrogen FSP | Complete - seeking commercial partners |
| | | | Iron Production Using Ammonia as a Reductant<br>2022 - 2025 | Understand thermodynamics and kinetics of direct reduction of Australian Iron ores with Ammonia | Dr Mark Pouncby /CSIRO | CSIRO Hydrogen FSP,Swinburne University | Completed PhD program in progress |
| | | | Hydrogen refuelling station<br>2022 - 2025 | HRS to support local mobility projects | Dr Patrick Hartley/CSIRO | | complete - refueller installed - in operation |
| | | | | | | | |
| | | | Current<br>Ammonia Safety training<br>2019 - 2027 | Ammonia safety training Porgram developed to support demonstration and deployment of ammonia energy systems in maritime sector | University of Tasmania/CSIRO (Dr David Harris) | ASLET, U Tasmania (Australian Maritime College),TasRex Pty Ltd, ASTI | Training program and live ammonia release exercises developed for energy and maritime sector. Future work to establish practial training stationsa and emergency response training. |
| | | | Ammonia combustion in modified diesel engines<br>Current<br>2019 - 2027 | Slow/medium speed ammonia engines allow distributed power generation and also support decarbonisation. | Dr Louis Wibberley / CSIRO | ASLET | Development engine (500kW) installed. Ammonia fuel systems retrofit in progress. |
| | Energy Access | | <Example> ●●●● ProjectDescribe the summary of the project.[period of the project]<br>Current<br>20XX - 20XX (R&D span) | Describe the target and/or goals of the project. Note the numerical purpose (if possible).<br><br>e.g. Cost reduction of ■■ to ● kWh/yen in 2030 | Dr. ******, ●● | (Domestic) ●● Research Institute, ▲▲ University, etc.<br>(International) ●●<br>(Desired collaboration) ●● field test, ▲▲ modeling, ■■ standard, etc. | https://www.●●● |
| | Synthetic Fuels | | Biomass and waste gasifciation for renewable syngas and Hydrogen<br>Current<br>2025 - 2028 (R&D span) | biomass gasification for syngas (fuel) and reductants in heavy industry | Dr Liezl Schoeman, Dr. David Wong / CSIRO | HILT CRC, CSIRO | HILTCRC.com.au |
| | Critical Minerals | | <Example> ●●●● ProjectDescribe the summary of the project.[period of the project]<br>Current<br>20XX - 20XX (R&D span) | | | | |
| | AI for Energy | | AI infrastructure for green centralised and distributed data centres<br>Current<br>2026 - 2030 (R&D span) | Develop energy-aware AI infrastructure that can coordinate computing workloads with renewable generation, battery storage and grid conditions across centralised and distributed data centres. | Dr Sherry Xu/ CSIRO Technology | University of NSW (UNSW) | |

**Dr Dietmar Tourbier, Director, Energy, CSIRO**

**Dr Dietmar Tourbier, PhD, MBA**

Dr Tourbier is the Director of the Energy Business Unit at the CSIRO. He is leading a multidisciplinary team of scientists, engineers, economists and business professionals in solving current and future energy challenges to enable the transition to lower emissions energy future.

Prior to this role Dr Tourbier served as the Science Director and Deputy Director of the Energy Business Unit and as the Director of the Australian Solar Thermal Research Institute (ASTRI) providing the vision, direction and strategic oversight for the delivery, adoption and impact of the ASTRI objectives.

Prior to joining CSIRO, Dr Tourbier worked at General Electric (GE) for over 20 years and held various leading positions in corporate research including the leadership roles of GE's solid oxide fuel cell (SOFC) division in California, the global power electronics technology research group and, most recently, GE's European research division.

Dr Tourbier received his masters in aerospace engineering from the University of Stuttgart and his PhD in aerospace engineering from the University of Arizona. He also received his MBA from the UCLA Anderson School of Management.

# Canada

NRC

National Research Council Canada

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| | Clean Energy | Advanced Clean Energy (ACE) | Critical Battery Materials Initiative<br>As a result of a gap identified in Canada's battery materials midstream supply chain between critical mineral mining and battery manufacturing, the initiative establishes self-driving labs to accelerate and link discoveries in new battery materials with more economically and environmentally sustainable approaches to processing battery minerals.<br>Current<br>2023-2027 | Accelerate the discovery of new battery materials and the development of more economically and environmentally sustainable battery mineral processing pathways, contributing to the growth of a sustainable Canadian battery supply chain. | Lawrence Charlebois | (Domestic) Natural Resources Canada, Industry and Academic grant and contribution recipients; (International) Germany | https://nrc.canada.ca/en/research-development/research-collaboration/programs/critical-battery-materials-initiative |
| | | | Scalable Lithium Production<br>Scaling-up modular lithium processing technologies from spodumene, brines, and black mass to establish domestic lithium refining, purification and active-material production capabilities. Activities include AI-enabled process development, pilot-scale processing, pCAM/CAM synthesis and validation.<br>Current<br>2026-2030 | Establish baseline kg-scale $LiOH/Li_2CO_3$ production by 2028; develop multi-feedstock lithium processing by 2029; deploy client-accessible mini-pilot modules by 2030 to strengthen Canada's battery value chain. | Krystal Davis | (Domestic) Nemaska, Frontier Lithium, Summit Nanotech, Mangrove Lithium, E3 Lithium, Saltworks, CanmetMINING, COREM. (International) Germany battery consortia, AIST Japan. (Desired collaboration) Lithium refining, validation, standards and pilot-scale processing. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/advanced-clean-energy-program |
| | | | Carbon Electrode Materials Processing<br>Development of lower-intensity processing pathways for natural graphite, recycled carbon, hard carbon and artificial graphite to support domestic anode active material production and battery manufacturing.<br>Current<br>2026-2030 | Streamline graphite purification and transformation by 2028; scale key processing steps beyond kg-level by 2029; establish advanced validation and cell prototyping capabilities by 2030. | Mathieu Toupin | (Domestic) Nouveau Monde Graphite, Northern Graphite, Lomiko Metals, Green Graphite Technologies, COREM. (International) Germany battery materials partners. (Desired collaboration) Carbon processing, anode validation and supply-chain development. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/advanced-clean-energy-program |
| | | | Next-Generation Energy Materials Scale-Up<br>AI-enabled discovery, scale-up and validation of next-generation lithium-ion and sodium-ion battery materials optimized for Canadian, defence and cold-climate applications. Integrates self-driving laboratories, materials acceleration platforms and pilot-scale battery validation.<br>Current<br>2026-2030 | Accelerated identification of optimized electrode chemistries by 2028; establish pilot-scale pCAM/CAM production and prototype-cell validation with industry by 2030. | Peter Kovacik | (Domestic) Hydro-Québec, Novonix, Chemtrade, Nanode, DND/DRDC. (International) Germany, AIST Japan. (Desired collaboration) Battery materials discovery, cold-climate validation and AI-enabled materials development. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/advanced-clean-energy-program |
| | | Industrial Carbon Management (ICM) | Targeted Industrial Carbon Capture for Heavy Industry<br>Development and validation of retrofit-ready carbon capture technologies for steel, cement, mining and oil and gas sectors. Activities include advanced sorbents, membranes, durability testing, corrosion science, TEA/LCA and industrial pilot validation.<br>Current<br>2026-2030 | Demonstrate >90% $CO_2$ capture efficiency at less than \$50/t$CO_2$; validate systems under Canadian industrial conditions and support deployment of integrated industrial capture pilots by 2030. | Naiying Du | (Domestic) Svante, Carbon Engineering, Lafarge, ArcelorMittal, Oil Sands Alliance, CanmetENERGY. (International) RD20 partners. (Desired collaboration) CCUS demonstrations, LCA methodologies and industrial validation. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/industrial-carbon-management-program |
| | | | Low-Carbon Hydrogen and Fuels Production<br>Development of PFAS-free AEM electrolyzers, green hydrogen production systems and low-carbon fuel pathways including SAF, methanol and waste-gas fermentation technologies.<br>Current<br>2026-2030 | Advance AEM electrolyzer technologies toward TRL 8 by FY2029; establish scalable SAF and methanol production pathways; deliver Canada's first NRC-validated NATO-compliant SAF by FY2030. | Laurent Spreutels & Wei Qu | (Domestic) Ionomr, Cipher Neutron, Next Hydrogen, NRCan, DND/DRDC. (International) Fuel and hydrogen collaborators. (Desired collaboration) Hydrogen systems, SAF qualification and fuel-production scale-up. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/industrial-carbon-management-program |
| | | | Infrastructure Integrity and Codes for Export Readiness<br>Development of corrosion-resistant materials, monitoring systems, leak detection technologies and standards for hydrogen and $CO_2$ transport infrastructure.<br>Current<br>2026-2030 | Develop compatibility databases and monitoring systems by 2028; support updated CSA and ISO standards and enable investment-ready hydrogen and CCUS infrastructure by 2030. | Oscar Zambrano | (Domestic) CSA Group, SCC, Enbridge, ATCO, FortisBC, NRCan, universities. (International) ISO and standards partners. (Desired collaboration) Infrastructure testing, standards harmonization and safety validation. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/industrial-carbon-management-program |

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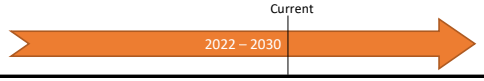
|---|---|---|---|---|---|---|---|
| National Research Council (NRC) / Canada | | Defence Clean Energy Demonstrator (DCED) | Resilient Deployable Microgrids<br>Development and validation of deployable hybrid microgrids integrating renewables, batteries, hydrogen systems, advanced controls and digital twins for defence, northern and remote applications.<br>Current<br>2026-2030 | Operational validation at NRC Vancouver by 2028; field validation in northern and remote environments by 2030; development and demonstration of digital-twin-enabled microgrid operation. | Will Skrivan | (Domestic) DND/DRDC, Canadian Coast Guard, NRCan, Indigenous and northern partners, UBC, BMT Canada. (Desired collaboration) Microgrid deployment, controls and extreme-environment testing. | https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/clean-energy-innovation-research-centre |
| | | | Interoperable Low Carbon Fuels:<br>Validation and deployment of renewable diesel, sustainable aviation fuel, methanol, ammonia and hydrogen-derived fuels in defence and remote applications. Includes engine testing, emissions characterization and cold-climate validation.<br>Current<br>2026-2030 | NRC-supported DND exercise using 100% low-carbon fuels by FY2028; Arctic demonstration of 100% low-carbon fuel-powered generators by FY2030. | Shouvik Dev | (Domestic) DND/DRDC, Canadian Coast Guard, Transport Canada, Caterpillar, Canadian Fuels Association, C-SAF. (International) Allied defence partners and RD20 collaborators. (Desired collaboration) Fuel qualification, interoperability standards and cold-weather validation. | https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/clean-energy-innovation-research-centre |
| | Aerospace | Low Emission Aviation Program | Aviation GHG emission reduction program on four main themes: 1) Future platforms and performance assessment, 2) Electric propulsion systems, 3) Clean fuel technologies, 4) Batteries in aviation [2022-2030]<br>Current<br>2022 - 2030 | 1) Rapidly develop market-ready solutions and de-risk potential high impact technologies.<br>2) Establish a collaborative ecosystem that will stimulate Canadian industry's transition towards low emission aviation.<br>3) Support other government departments in development of policies by providing science-based recommendations. | Pervez Canteenwalla | (Domestic) Department of National Defence, Transport Canada, Natural Resources Canada, academia, industry.<br>(International - Germany, France, UK, ) academia, government RTOs | https://nrc.canada.ca/en/research-development/research-collaboration/programs/low-emission-aviation-program |
| | Automotive | Clean and Energy-Efficient Transportation (CEET) | Hydrogen: Advance clean transportation adoption supported by an innovative and cost-competitive world-class hydrogen technologies ecosystem in Canada [2021-2028]<br>Current<br>2021 - 2028 | Hydrogen based propulsion system simulation & modelling<br>Application of risk mitigation research to real-world hydrogen fuel cell rail locomotive in-service use<br>Air filter sensors for maintenance action | Eddy Zuppel, P. Eng. | (Domestic) Transport Canada, Department of National Defence, Natural Resources Canada | https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program |
| | | | Energy Management Systems: Advancement of innovative and cost-competitive battery technologies and their applications in vehicles [2021-2028]<br>Current<br>2021 - 2028 | Development of new battery safety standards and pack design supported by physical and virtual testing with novel battery characterization test methods.<br>Advanced diagnostics techniques for cell characterisation<br>LiBTec community of interest on battery innovation across Canada | Dr. Dean MacNeil | (Domestic) Transport Canada, Department of National Defence, Natural Resources Canada | https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program |
| | | | Development and deployment of aerodynamic technologies and methods that meet the needs of current and emerging transportation frameworks [2021-2028]<br>Current<br>2021 - 2028 | Advanced aerodynamics evaluation methods (wind-tunnel, road and track, traffic aerodynamics)<br>Emerging aerodynamic concepts for LDVs and HDVs<br>Climate impact for aerodynamics (rain, ice, snow) | Dr. Brian McAulife | (Domestic) Transport Canada, Natural Resources Canada, Environment and Climate Change Canada | https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program |
| | | | Development of innovative, cost-competitive, efficient and durable electrical machine solutions [2021-2028]<br>Current<br>2021 - 2028 | Processing of soft and magnetic composites.<br>Advanced manufacturing of hard and soft magnetic materials.<br>New motor topologies development and prototyping<br>Permanent magnet recycling | Dr. Fabrice Bernier | (Domestic) Natural Resources Canada, Polytechnique de Montreal | https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program |
| | | | Provide tools and guidance on vehicle fleet transition to lower emissions and energy efficient operations. [2021-2028]<br>Current<br>2021 - 2028 | Modeling and simulation for energy management of fleets<br>Data analytics of real-world trials.<br>Evaluation of hybrid propulsion in energy demanding scenarios.<br>Emissions reduction benefits of connected and autonomous vehicles | Christopher Rabbit, P.Eng. | (Domestic) Transport Canada, Natural Resources Canada, Environment and Climate Change Canada, Royal Canadian Mounted Police, Department of National Defence | https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program |
| | | Advanced Manufacturing Program (AMP). | Advanced Manufacturing Program (AMP). Supports development and adoption of advanced manufacturing technologies using advanced materials, digital manufacturing, automation, modelling, and process optimization to improve productivity and accelerate commercialization.<br>Current<br>2019-2026 | Transform Canada into a global leader in smart manufacturing to strengthen the competitiveness of Canada's manufacturing sector: 1) Raise digital awareness of Canadian manufacturing industry, digital technologies are increasingly adopted and used by Canadian industry to improve manufacturing productivity and competitiveness; 2) Strengthen Canadian manufacturing sector ecosystem with novel value chains, strengthened supply chains, increased research capacity. | Nathalie Legros | (Domestic) Canadian transportation equipment manufacturers, manufacturing SMEs, academic institutions, and regional innovation hubs; (International) Global digital-twin consortia, foreign research and technology organizations (RTOs), and manufacturing and advanced materials networks. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/advanced-manufacturing-initiative |
| | | e-Auto Challenge Program. | e-Auto Challenge Program. Supports development and commercialization of Canadian zero-emission vehicle technologies through innovations in electric powertrains, battery technologies, power electronics, secure vehicle communications, connectivity, automation, and smart charging.<br>Current<br>2026 – 2033 | Accelerate adoption of zero-emission vehicles, strengthen Canada's automotive supply chain, improve vehicle performance and cold-climate operation, and contribute to Canada's net-zero objectives. | Sooky Winkler | (Domestic) Canadian zero-emission vehicle (ZEV) supply chain enterprises, technology SMEs, academic researchers, and battery developers; (International) Foreign automotive research institutes, international academic collaborators, and clean mobility consortia. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/e-auto-challenge-program |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Contruction | Platform to Decarbonize the Construction Sector at Scale & Low Carbon Built Environment (LCBE) Challenge | Platform to Decarbonize the Construction Sector at Scale & Low Carbon Built Environment (LCBE) Challenge. Supports building-sector decarbonization through low-carbon regulatory frameworks, construction digitalization, supplementary cementitious materials, low-carbon binders, bio-based building products, and life-cycle carbon accounting tools. | Support implementation of operational and embodied carbon provisions in the 2025 and 2030 National Model Codes and accelerate adoption of low-carbon construction materials and practices. | Chris Pezoulas | (Domestic) Cement and concrete producers, building material manufacturers, Canadian universities, Indigenous organizations, and municipalities; (International) Global built-environment research centers, foreign standard bodies, and international construction decarbonization networks. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/low-carbon-built-environment-challenge-program |
| | Oceans Coastal, and River Engineering | OCEANS Program | OCEANS Program. Supports sustainable development of Canada's ocean, coastal, Arctic, and marine resources through advanced engineering, modelling, and technology validation. Activities include marine renewable energy, resilient coastal infrastructure, Arctic operations, climate adaptation, and low-carbon energy systems for remote communities.   | Improve energy resilience, support sustainable economic development, enhance climate adaptation, and advance deployment of low-carbon energy systems in marine, coastal, Arctic, and northern environments. | Marie-Chantal Ross | (Domestic) Canadian marine tech firms, Canadian Coast Guard, Memorial University, INRS, Queen's University, Saint Mary's University, and coastal Indigenous communities; (International) Foreign ocean technology institutes, global marine safety organizations, and blue economy R&D consortia. | https://nrc.canada.ca/en/research-development/research-collaboration/programs/ocean-program |

## Jean-François Houle, PhD

Vice-President of Engineering, National Research Council of Canada

Dr. Jean-François Houle joined the National Research Council of Canada (NRC) as Director of Research and Development for the Medical Devices Research Centre in June 2014. In March 2017, he was appointed General Manager. In March 2020, he became Vice-President of the Pandemic Response Challenge program, bringing together the best Canadian and international researchers to fast-track R&D aimed at specific COVID-19 gaps and challenges identified by Canada's health experts.

Dr. Houle became the Vice-President of the Engineering division in April 2022. As the Executive Lead for the NRC's Climate Innovation strategy, Dr. Houle is responsible for delivering a co-ordinated NRC strategy to develop innovative solutions to challenges arising from the global climate crisis. As Executive Co-Sponsor for the Departmental Sustainable Development Strategy, Dr. Houle ensures that the NRC supports the Federal Sustainable Development Strategy by identifying sustainability goals and targets and implementing actions aligned with the NRC's mandate.

Prior to joining the NRC, Dr. Houle spent 14 years leading business, corporate and product development activities in privately-held and publicly-traded biotechnology firms

at various stages of development, from university spin-offs to more established companies. These activities led to collaborative research, licensing and merger agreements as well as successful product launches and financing events. Dr. Houle has a deep interest and passion for translating leading-edge research into impactful technologies that can catalyze the growth of Canadian companies and improve the lives of Canadians and people around the world.

Dr. Houle holds a PhD in Experimental Medicine from McGill University.

# Germany

HZB

Helmholz Centram Berlin

# HZB Advancing Clean Energy through Science and Global Partnerships

***Prof. Dr. Bernd Rech***
Scientific Director

## 1. Introduction

### 1.1 Helmholtz Association

**The Helmholtz Association↗ is Germany's largest research organisation, bringing together 18 research centres to address major challenges facing science, society and the economy.** *Its distinctive strength lies in combining long-term, interdisciplinary research with the development and operation of large-scale scientific infrastructure, connecting fundamental discoveries with technological applications*. With more than 47,600 employees and an annual budget of ca. 6.2 billion EUR, Helmholtz is a major contributor to the international research landscape in Germany. *A central part of Helmholtz's mission is designing, building, and operating large-scale scientific facilities, many of which offer capabilities unique worldwide.* These infrastructures are essential instruments for scientific discovery and technology development, and Helmholtz makes them available to researchers from universities, research organisations, and industry.

**Helmholtz's mission and capabilities provide a strong foundation for contributing to Germany's current research and innovation priorities.** These capabilities are particularly relevant to Germany's energy transition and its established objective of achieving net greenhouse gas neutrality by 2045. **The current research and innovation policy framework includes the High-Tech Agenda Germany↗ (HTAD - Hightech Agenda Deutschland)**, adopted by the federal government in July 2025. The HTAD prioritises six technology areas: artificial intelligence; quantum technologies; microelectronics; biotechnology; fusion and climate-neutral energy generation; and technologies for climate-neutral mobility.

**For the clean energy sector, this framework links Germany's objective of achieving net greenhouse gas neutrality by 2045 with the development of a secure, affordable and resilient energy system.** *Helmholtz's long-term research programmes, advanced infrastructure and partnerships across science and industry provide essential capabilities for developing these technologies and supporting their progression towards application.*

### 1.2 Helmholtz-Zentrum Berlin: a member of the RD20 initiative

**Helmholtz-Zentrum Berlin für Materialien und Energie↗ (HZB) pursues a mission that connects scientific discovery with technological application: "From Materials Discovery to Sustainable Solutions".** HZB works towards a climate-neutral society through science and innovation, advancing materials discovery, developing sustainable technologies and empowering the research community to contribute to this goal. This ambition closely connects HZB's research with the High-Tech Agenda Germany, particularly its priorities for climate-neutral energy generation and mobility, and its emphasis on translating scientific advances into technological and societal benefits.

With approximately 1,500 employees and an annual budget of 200 million EUR, including third-party funding, *HZB combines substantial scientific and technical capabilities in materials science and sustainable energy technologies.* Cooperation is integral to this approach; *HZB develops its research and technological contributions in close collaboration with partners from science and industry*, including other Helmholtz centres, universities, Fraunhofer institutes and

the Max Planck Society. *These partnerships connect complementary expertise and infrastructure, support joint technology development and demonstration, and strengthen the progression from laboratory research towards industrial application.* International collaboration further enables shared learning, researcher exchanges and the development of capabilities across institutions and countries.

As an RD20 member since 2025, **HZB offers its broad expertise in energy materials, advanced characterisation, technology development, and international research-industry partnerships.** RD20 provides a platform to connect these strengths with complementary capabilities worldwide and translate scientific exchange into joint research. **HZB's contribution is therefore both scientific and collaborative: helping to resolve material-level limitations while developing shared methods and partnerships that support technology validation.**

## 2. R&D activities related to clean energy technology for carbon neutrality

**Building on its mission to translate materials discovery into sustainable solutions, HZB advances clean energy technologies through research in photovoltaics, batteries, green hydrogen, and sustainable fuels and chemicals.** Across these fields, HZB combines thin-film synthesis and interface engineering with laboratory and synchrotron analysis at BESSY II, as well as device testing and modelling. AI/Data-driven methods are also integrated to accelerate materials discovery, guide experimental design and strengthen the connection between scientific understanding and technology development. These complementary capabilities enable researchers to understand the mechanisms governing performance and degradation and use this knowledge to develop more efficient, durable and resource-conscious energy technologies.

### 2.1 BESSY II as a central infrastructure for energy research and partnerships

**The BESSY II↗ synchrotron light source is central to HZB's energy materials research and its collaboration with the international scientific and industrial communities.** *BESSY II capabilities, particularly in soft X-ray spectroscopy, reveal the electronic and chemical properties of materials and interfaces that govern energy conversion and storage. In situ and operando methods enable researchers to investigate materials during processing and operation, identifying mechanisms that limit performance or cause degradation.* This supports identifying limiting mechanisms and guides subsequent material and device design.

***Figure 1.*** *BESSY II at HZB provides brilliant synchrotron radiation for investigating the structure, chemistry and electronic properties of energy materials, including their evolution during operation.*

*BESSY II is embedded in a wider infrastructure of laboratories for materials synthesis, device fabrication and complementary analysis.* The **Energy Materials *In-Situ* Laboratory Berlin (EMIL)↗**, developed jointly with the Max Planck Society, connects synchrotron characterisation with materials preparation and investigation under controlled conditions. Together with dedicated photovoltaic and battery laboratories, this infrastructure enables partners to investigate materials at different stages of development and relate analytical findings to device behaviour.

## 2.2 Photovoltaics materials for more efficient and durable solar cells

**HZB develops photovoltaic technologies that combine high conversion efficiency with long-term stability and scalable production. Its research spans absorber materials, charge-selective contacts and interfaces, solar cell architectures and module fabrication, with a strong focus on perovskite-based tandem and multijunction technologies.**

*HZB has contributed independently certified record-setting tandem solar cells and important advances in interface engineering.* A pivotal innovation in Perovskite PV is HZB's patent on self-assembled monolayers (SAMs),[1][2] developed with Kaunas University of Technology, which has become a cornerstone of device architecture across the perovskite community. This technology has significantly improved the performance and stability of perovskite solar cells, contributing to rapid advances in this promising field. Alongside conversion efficiency and long-term stability, a third crucial element of HZB PV research is scaling up perovskite deposition techniques, the corresponding contact materials, and transferring results to industry across different application areas.

The **HySPRINT Photovoltaics Lab↗** and the **Competence Centre Photovoltaics Berlin (PVcomB)↗** provide complementary infrastructure for fabrication, characterisation, stability testing and process development in collaboration with industry. Synchrotron analysis at BESSY II strengthens the understanding of the material and interface properties underlying these advances.

## 2.3 Sustainable batteries beyond conventional lithium-ion

**HZB investigates next-generation batteries for renewable energy storage and mobility, emphasising resource efficiency, durability, and scalable electrode materials. Research includes sodium-ion and metal–sulfur systems, alongside alternative material concepts intended to reduce dependence on critical resources.** Materials synthesis and colloidal engineering are linked with electrochemical testing from laboratory cells to functional pouch cells. Performance is evaluated against the requirements of the intended application, including lifetime, safety, energy density and resource use.

*A distinctive strength of HZB Battery Research is investigating batteries during operation. Laboratory and synchrotron-based methods reveal how electrode structures, electrochemical interfaces and ion transport evolve during charging, discharging and ageing.* BESSY II provides element-specific chemical information, while complementary imaging and the **TomographyLab@HZB↗** reveal structural changes within electrodes and cells. Modelling and AI-assisted analysis connect these observations with material and cell design. A flexible operando battery test stand developed at HZB enables tomography during operation across

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[1] Al-Ashouri *et al.* (2020). Science, 370:6522. DOI: 10.1126/science.abd4016

[2] Patent: Hole-transporting self-organised monolayer for perovskite solar cells, Pat No. WO2019207029A1

multiple cell formats, providing a concrete route for studying practical devices with research and industrial partners.

### 2.4 Green hydrogen and sustainable fuels and chemicals

**HZB develops materials and catalytic processes to produce green hydrogen and convert carbon-containing feedstocks into fuels and chemicals. Its portfolio encompasses solar-driven water splitting, electrolysis, $CO_2$ conversion, upgrading of biomass-derived feedstocks and thermocatalytic fuel synthesis.** This research addresses catalyst activity, selectivity, and durability, as well as the integration of materials into electrodes, devices, and reactors. These activities support renewable energy storage and replacing fossil feedstocks in transport and industry.

*HZB combines catalyst synthesis and thin-film model systems with in-situ and operando characterisation at BESSY II. By observing changes in catalyst structure, chemical state and interfaces during reaction, researchers identify active states, performance limitations and degradation pathways. This knowledge supports the design of improved catalysts and operating conditions.* Theoretical investigations, multiscale and multiphysics modelling, and AI/data-driven methods complement experimental research, linking molecular processes to transport and reactor behaviour and helping identify challenges as technologies move from laboratory experiments to larger-scale operation.

### 2.5 Energy systems analysis and design

**HZB complements materials and technology development with research into the energy systems in which these technologies will operate.** *Energy system modelling, techno-economic analysis, and life cycle assessment examine how photovoltaics, storage, and chemical energy carriers can contribute to economically viable, resilient, and low-carbon energy systems.*

These assessments identify the conditions under which technological improvements translate into environmental and economic benefits, including requirements for efficiency, lifetime, renewable energy supply and resource use. They inform research priorities and support informed decisions on technology development and deployment. By connecting materials research with system-level evaluation, HZB assesses clean energy technologies through both their technical performance and their contribution to sustainable energy provision.

## 3. Specific research activities

HZB advances clean energy technologies through targeted research that connects materials discovery, device development and technological validation. The following projects illustrate HZB's contribution to technology development and validation. Together, they show how research infrastructure, digital methods and industrial cooperation address specific barriers to application.

***Photovoltaics***

- **Solar TAP↗ — Solar Technology Acceleration Platform for emerging Photovoltaics** (Helmholtz Platforms, 2023 onwards).

  Solar TAP brings together HZB, Forschungszentrum Jülich and KIT, coordinated by the Helmholtz Institute Erlangen-Nuremberg for Renewable Energy (HI ERN). The platform provides access to research infrastructure and industrial collaboration for printed organic

and perovskite photovoltaics. HZB contributes its materials, device and process-development capabilities. Work focuses on lightweight, flexible and semi-transparent modules for buildings, agriculture and transport, connecting application requirements with module development and manufacturing processes.

- **Ready-PV↗ — Reliability Evaluation through Analytics and Data for emerging technologY in Photovoltaics** (Horizon Europe–101293084, 2026–2029).

  HZB coordinates this recently started infrastructure project to improve the assessment of emerging PV durability and degradation. It connects outdoor testbeds, accelerated ageing laboratories, synchrotron and neutron facilities, and AI-enabled diagnostics. The project is establishing transnational and virtual access with interoperable data workflows. Ready PV contributes a more comparable and credible basis for evaluating lifetime, with validated lifetime predictions.

- **LUMINOSITY↗ — Large area uniform industry compatible perovskite solar cell technology** (Horizon Europe–101147653, 2024–2028).

  Coordinated by TNO, this industry-driven European project develops flexible perovskite photovoltaics using scalable industrial processes. It targets roll-to-roll manufactured modules exceeding 20% power-conversion efficiency over an area greater than 900 cm², with demonstration at TRL 7. HZB develops and optimises coating inks and slot-die coating processes, transfers them to large-area sheet-to-sheet manufacturing with quality and homogeneity control, and tests cells and modules outdoors.

- **PEPPERONI↗ — Pilot line for European Production of PEROvskite-Silicon taNdem modules on Industrial scale** (Horizon Europe–101084251, 2022–2026).

  Coordinated by HZB in close collaboration with Qcells, PEPPERONI develops an industrial pilot line for perovskite–silicon tandem cells and modules. It addresses manufacturing scale-up, operational stability, environmental performance and the supply chain required for European production. The project targets progression from laboratory and relevant-environment validation towards prototype demonstration in an operational environment, with TRL 7 as its objective.

### *Batteries*

- **Berlin Battery Lab (BBL)↗, including the Application Laboratory for Sustainable Battery Systems** (European Regional Development Fund (ERDF/EFRE)–BE-21-27-0000000492, 2026–2028).

- BBL is a joint initiative of Humboldt-Universität zu Berlin, HZB and the Federal Institute for Materials Research and Testing (BAM). It combines electrode-material research, advanced characterisation, cell development and safety expertise, with a focus on sodium-ion and metal-sulfur systems. HZB contributes BESSY II analysis and pouch-cell capabilities and is establishing a sodium-ion pouch-cell laboratory. The application laboratory expands infrastructure to connect materials development with testing in practical cell formats and collaboration with companies.

- **HiBRAIN↗ — Holistic method of a combined data- and model-based electrode design supported by artificial intelligence** (BMWE–03ETE039, 2022–2026).

  Coordinated by Helmut Schmidt University, HiBRAIN investigated a combined simulation, experimental-data and AI approach to virtual electrode design. HZB participated alongside partners including Mercedes-Benz, BASF and Customcells. The research addressed

material selection, particle morphology, coatings and electrode structure, connecting basic understanding with industrial electrode requirements..

### *Green $H_2$ and Sustainable Fuels*

- **CARE-O-SENE↗ — Catalyst Research for Sustainable Kerosene** (BMFTR–03SF0673, 2022–2027).

  Co-led by HZB and Sasol, this German–South African project bridges academia and industry and takes a highly impactful approach, integrating fundamental research with industrial demonstration to significantly accelerate the innovation cycle and establish a viable pathway for large-scale SAF production. A key project milestone is developing highly efficient powder catalysts that achieved over 80% SAF yield during semi-commercial testing, marking a critical step toward commercialising the catalysts in 2026. Catalyst synthesis, advanced characterisation, modelling, testing and industrial demonstration operate as an iterative innovation cycle.

- **ASCEND↗ — Accelerated Solutions for Catalysis using Emerging Nanotechnology and Digital Innovation** (BMFTR–03SF0798, 2026–2031).

  Coordinated by HZB and the Fritz Haber Institute (MPG), ASCEND connects thin-film catalyst technologies with AI, simulations and self-driving laboratories to accelerate catalyst discovery for sustainable fuels and chemicals. Its closed-loop approach connects synthesis, testing, characterisation and continuously updated digital twins. ASCEND brings together research and industry partners, including BASF, Siemens Energy, Dunia Innovations and TU Berlin/BasCat.

- **GreenQUEST↗ — Greening the Production and Use of Liquefied Fuel Gas in Southern Africa** (BMFTR–03SF0688, 2022–2026).

  Led by HZB and the University of Cape Town, GreenQUEST develops pathways for green liquefied fuel gas (gLFG) from renewable hydrogen and captured $CO_2$ as an alternative to fossil LPG for cooking. Technical development is integrated with economic, environmental and social assessment of the value chain. The consortium has successfully demonstrated the use of gLFG for cooking and power generation. Additionally, HZB has led research on silver electrocatalysts for $CO_2$-to-CO conversion and paired electrolysis, contributing to the development of renewable fuel pathways.

- **PH2OTOGEN↗ — Acceleration of Photocatalytic Green Hydrogen Production to Market Readiness through Value-Added Oxidation Products** (Horizon Europe–101137889, 2024–2027).

  This project develops a scalable photocatalytic flow reactor that produces green hydrogen alongside valuable oxidation products to improve economic viability. Advanced characterisation and simulation support semiconductor selection and reactor development. The project targets an average solar-to-hydrogen efficiency above 5% over 500 hours in a 500 $cm^2$ demonstrator.

- **DECODE↗ — DE-centralised Cloud labs fOr inDustrialisation of Energy materials** (Horizon Europe–101135537, 2023–2027).

  DECODE aims to create and demonstrate a cloud platform that links multiple labs to accelerate materials development and integration for the clean energy technology sector by connecting distributed laboratories, modelling, and characterisation capabilities. AI-supported workflows coordinate complementary methods and expertise. Its initial

demonstrators focus on water electrolysis and hydrogen fuel cells; the platform is designed for broader use in energy conversion and storage. HZB's contribution spans materials science expertise, employing synchrotron radiation, neutron imaging, and FIB tomography with AI tools.

# 4. International collaboration

Partnerships at regional and international levels are integral to HZB's science strategy and its mission to translate materials discovery into sustainable solutions. Across its research portfolio, HZB builds strategic alliances with academic and industrial partners whose complementary expertise and infrastructure enable challenges to be addressed jointly.

HZB's approach rests on three principles: **integrating research with industrial development and demonstration; building lasting partnerships through mutual trust and shared objectives; and advancing co-creation, shared leadership and capacity building.** Joint laboratories, collaborative projects and researcher exchanges put these principles into practice, connecting scientific understanding with technological requirements while developing the next generation of scientists.

## 4.1 European cooperation and shared research infrastructure

At the European level, HZB participates in more than 30 collaborative Horizon Europe projects, connecting its research with universities, research organisations and companies across national borders. These collaborations combine complementary capabilities, support shared technology development and strengthen links between materials research and industrial application.

The Uppsala–Berlin Joint Laboratory on Next Generation Electron Spectroscopy↗, established with Uppsala University in Sweden, illustrates how sustained institutional cooperation creates capabilities that benefit a wider research community. The partners develop and operate dedicated instruments and beamlines at BESSY II to investigate the electronic structure and dynamics of highly sensitive functional materials. By combining expertise in instrumentation, spectroscopy and materials science, the joint laboratory supports a vibrant international user programme and advances methods relevant to energy-materials research.

## 4.2 Cooperation with South Africa and regional research capabilities

Beyond Europe, HZB combines joint research with infrastructure and scientific capacity development. A prominent example is its cooperation with the University of Cape Town (UCT) in South Africa. HZB-UCT joint laboratory operates the FAB-1 (First African Beamline)↗, Africa's first laboratory-based X-ray absorption spectroscopy setup, commissioned in February 2026. By providing regional access to advanced characterisation, FAB-1 reduces travel costs and eases constraints from limited regional instruments. The laboratory strengthens connections between catalysis researchers, industrial partners and X-ray characterisation specialists, enabling more continuous feedback between materials development and analysis. Joint training and knowledge exchange support local expertise in operating the equipment and interpreting results, while contributing to the broader development of synchrotron science in Africa. This approach combines access to international infrastructure with lasting capabilities in partner regions.

## 4.3 Industrial cooperation and reciprocal knowledge transfer

HZB pursues long-term industrial partnerships that connect fundamental research, technology development, scale-up and demonstration. **CARE-O-SENE, a German–South African collaboration, exemplifies this approach. Its integrated innovation cycle links catalyst synthesis, advanced characterisation, modelling, mechanistic understanding, reactor testing and industrial validation.** The partnership combines German research infrastructure and catalyst-science expertise with South African academic capabilities and Sasol's industrial Fischer–Tropsch expertise and scale-up facilities. Researcher exchanges, mentoring and interdisciplinary training reinforce this technological cooperation through reciprocal knowledge transfer between early-career researchers and experienced academic and industrial specialists. **Establishing an Industrial Research Fellowship at HZB further embeds industrial expertise in the research environment**, while expanding cooperation with Sasol on digitalisation shows how a joint project can grow into a broader strategic partnership. **The close integration of research and industrial development illustrated by CARE-O-SENE also underpins HZB's approach to AI-driven catalyst discovery**. ASCEND brings together BASF, Siemens Energy, Dunia Innovations and TU Berlin/BasCat to combine artificial intelligence, simulations, self-driving laboratories (SDLs) and advanced thin-film catalyst technologies.

**In photovoltaics, HZB collaborates with industrial partners across Europe and beyond, connecting its expertise in perovskite single-junction and tandem solar cells with capabilities across the photovoltaic value chain.** Examples include solar-cell and module manufacturers First Solar (USA) and Kaneka (Japan), equipment supplier FOM Technologies (Denmark), and materials suppliers Solaronix (Switzerland) and Dyenamo (Sweden). Collaborations with Oxford PV and Qcells further connect HZB to companies with substantial activities in both Germany and international markets. Together, these partnerships bring manufacturing requirements into materials and device research, supporting scalable processing, reproducibility, stability and technology transfer. **In batteries, the BBL connect HZB's research with cell development, safety assessment and industrial electrode design, providing complementary models of regional and national cooperation**.

## 4.4 Lessons for sustained international cooperation

These collaboration examples illustrate the value of organising international cooperation around shared scientific and technological objectives, complementary capabilities and sustained exchange. Practical considerations include maintaining continuity across funding periods, coordinating access to specialised infrastructure, and agreeing early on data sharing, intellectual property and responsibilities. Joint laboratories, researcher mobility, industrial fellowships and regular technical workshops provide effective mechanisms for addressing these needs and sustaining collaboration.

Within the RD20 initiative, promising priorities for joint work include the efficiency, durability, and scalable manufacture of energy technologies, as well as comparable methods for advanced characterisation, testing, and data analysis using AI/data-driven approaches. Combining these capabilities with partner infrastructure and industrial validation would support joint research that advances clean-energy technologies while strengthening long-term international innovation capacity.

## 5. Future perspectives (towards carbon neutrality)

Achieving carbon neutrality requires clean energy technologies that can be manufactured, deployed and operated reliably at scale. This transition must also deliver a resilient and socially accepted energy system. Diversifying energy sources, reducing dependence on critical raw materials and strengthening sustainable value chains are therefore closely connected to climate objectives. Renewable electricity, energy storage, green hydrogen, and sustainable fuels and chemicals will have complementary roles, particularly where direct electrification is difficult. Their development must consider resource availability, material and carbon circularity, environmental impacts and societal needs from the outset.

**For HZB, the central challenge is to connect advances in materials science with the performance, affordability and sustainability required for industrial application.** *Guided by its mission, HZB will strengthen the integration of fundamental research, technology development and international research–industry cooperation to accelerate this transition.*

Across HZB's research fields, these requirements translate into concrete technological challenges. *In **photovoltaics**, the priority is to translate advances in perovskite and tandem solar cells into durable, reproducible and scalable technologies, connecting materials and device innovation with manufacturing processes and reliable module performance.* HZB's research across the value chain provides a foundation for addressing these challenges together with industrial partners. *In **batteries**, research into next-generation cell concepts beyond conventional lithium-ion technologies will pursue sustainable, safe, and competitive alternatives.* Progress requires a deeper understanding of degradation, interfaces and operating behaviour, alongside approaches that connect materials discovery with cell development and testing. *In **green hydrogen and sustainable fuels and chemicals**, the challenge is to develop efficient, durable catalysts and conversion processes that retain their performance under industrial operating conditions.* HZB's integration of synthesis, advanced characterisation and data-driven catalyst design supports this progression towards application.

**AI/Data-driven materials research will be a central accelerator across these fields.** *HZB aims to connect experimental observations, modelling and AI to identify promising materials, understand their behaviour and guide subsequent experiments more efficiently.* Systematic data management, interoperable datasets and appropriate computing and storage capacity will be essential to make research data usable for AI, including generative applications where appropriate.

Within this context, **BESSY II and HZB's Labs are important platforms for international cooperation**, providing access to advanced analytical capabilities and enabling academic and industrial partners to investigate materials together. *Co-creation with companies strengthens the connection between scientific expertise and application needs. Strategic alliances and joint laboratories, using Helmholtz International Lab formats, offer routes to sustain collaboration around ambitious research challenges. Industrial Research Fellowships show how international project cooperation can develop into deeper academia-industry partnerships.*

**Developing people and shared capabilities is integral to this approach**. *Researcher exchanges, joint training, mentoring and industrial fellowships connect the next generation of scientists with experienced researchers and industrial experts.* Continuous learning—particularly in digital methods, advanced characterisation and technology translation—strengthens capabilities across career stages. **Through this combination of materials innovation, industrial co-creation and sustained international partnerships, HZB aims to shorten the path from scientific discovery to deployment while building the expertise and relationships needed for a lasting transition to carbon neutrality.**

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead Organization | Partnerships (if any) | Related information |
|---|---|---|---|---|---|---|---|
| Helmholtz-Zentrum Berlin (HZB) Germany | Photovoltaics | Perovskite–silicon tandems | **PEPPERONI — Pilot line for European Production of PEROvskite-Silicon taNdem modules on Industrial scale.** Develops tandem cells, modules and an industrial pilot line, addressing scale-up, durability and environmental performance. HZB connects materials and device research with Qcells manufacturing. **Period**: **Nov 2022 – Oct 2026.** Funding: EU Horizon Europe, Innovation Action. Grant: 101084251. | Targets: 26% module efficiency at industrial scale, manufacturing processes suitable for high-volume production, >30-year operational lifetime and pilot-line demonstration at TRL 7. These are project objectives. | HZB: administrative coordinator Qcells: industrial and technical leadership. | European research and industry consortium across the PV value chain.<br><br>**Germany**: Qcells and German research, equipment and materials partners. **International**: CSEM (Switzerland), Kaunas University of Technology (Lithuania), Eindhoven University of Technology (Netherlands), University of Ljubljana (Slovenia), PCCL (Austria), Dyenamo (Sweden), Yparex (Netherlands), Mondragon Assembly (Spain), Teknisolar S.r.l. (Italy), FOM Technologies (Denmark), University of Liège (Belgium), BRGM/INERIS (France), accelopment Schweiz (Switzerland). | https://pepperoni-project.eu/ |
| Helmholtz-Zentrum Berlin (HZB) Germany | Photovoltaics | Reliability and shared infrastructure | **Ready-PV — Reliability Evaluation through Analytics and Data for emerging technologY in Photovoltaics.** Integrates outdoor testbeds, accelerated-ageing laboratories, synchrotron/neutron facilities and AI-enabled diagnostics for emerging PV. **Period: Jun 2026 – May 2029.** Funding: EU Horizon Europe, Research Infrastructures, RIA. Grant: 101293084. | Provide transnational and virtual infrastructure access, harmonised degradation studies, FAIR data workflows and predictive diagnostics. Establish a credible basis for assessing emerging PV lifetime under realistic conditions. | HZB, consortium coordinator. | **Germany**: Humboldt-Universität zu Berlin, Fraunhofer ISE. **International**: AIT (Austria), CENER (Spain), CSEM/EPFL (Switzerland), ESRF/ILL/IPVF (France), imec (Belgium), Swansea University (UK), TNO (Netherlands), ATAMOSTEC (Chile). | https://cordis.europa.eu/project/id/101293084 |
| Helmholtz-Zentrum Berlin (HZB) Germany | Photovoltaics | Printed PV and technology transfer | **Solar TAP — Solar Technology Acceleration Platform for emerging Photovoltaics.** Links shared research infrastructure and industry to develop printed organic and perovskite PV for buildings, agriculture and transport. **Period: 2023 - onwards.** Funding: Helmholtz Association innovation platforms, with participating-centre contributions. | Accelerate industrial uptake of lightweight, flexible and semitransparent PV through application-driven module development, scalable processing and a sustained industry network. | Helmholtz Institute Erlangen-Nürnberg (HI ERN), Forschungszentrum Jü lich, platform coordinator. HZB, participating centre. | Industrial platform and network of companies across printed PV and application markets.<br><br>**Germany**: HZB, Forschungszentrum Jülich and KIT. | https://solartap.de/about/ |
| Helmholtz-Zentrum Berlin (HZB) Germany | Photovoltaics | Flexible perovskite modules | **LUMINOSITY — Large area uniform industry compatible perovskite solar cell technology.** Develops flexible perovskite PV with industrial coating and deposition processes. HZB develops inks and slot-die coating, large-area sheet-to-sheet processes, homogeneity control and outdoor testing. **Period: Jun 2024 – May 2028.** Funding: EU Horizon Europe / Innovation Action. Grant: 101147653. | Targets: roll-to-roll modules with >20% efficiency over >900 cm² and demonstration at TRL 7. Bridge the efficiency gap between small laboratory cells and manufactured modules. | TNO (Netherlands), consortium coordinator. HZB, coating development and outdoor testing. | **Germany**: HZB and Fraunhofer FEP. **International**: TNO, Eindhoven University of Technology, TU Delft and HyET Solar (Netherlands), CNR-ISM (Italy), Lund University (Sweden), AMIRES (Czechia). | https://luminosity-project.eu/ |
| Helmholtz-Zentrum Berlin (HZB) Germany | Batteries | Joint research platform | **Berlin Battery Lab (BBL).** Joint HZB–HU Berlin–BAM initiative combining electrode materials, cell development, advanced analysis and safety testing, with emphasis on resource-efficient sodium-ion and metal–sulfur systems.<br><br>**AL-BBL — Applikationslabor Berlin Battery Lab für nachhaltige Batteriesysteme (Application Laboratory for Sustainable Battery Systems).** Expands equipment and expertise for practical battery testing and transfer, including sodium-ion pouch-cell capabilities at HZB. **Period: Jan 2026 – Dec 2028.** Funding: State of Berlin / European Regional Development Fund (ERDF/EFRE). Grant: BE-21-27-0000000492. | Link materials discovery to prototypes, pouch-cell development and application-relevant testing. Open complementary facilities and expertise to research and industrial partners.<br><br>Broaden access to development and testing infrastructure for lithium-ion, sodium-ion, metal–sulfur and solid-state batteries. Connect electrode research to functional cells and industrial cooperation. | HZB, Humboldt-Universitä t zu Berlin (HU) and BAM, joint institutional leadership. | **Germany**: HZB, HU Berlin and Federal Institute for Materials Research and Testing (BAM). **Industry**: external research and industrial users in Germany and Europe. | https://www.bam.de/Content/EN/Projects/Berlin-Battery-Lab-BBL/Berlin-Battery-Lab-BBL.html |
| Helmholtz-Zentrum Berlin (HZB) Germany | Batteries | AI-supported electrode design | **HiBRAIN — Holistic method of a combined data- and model-based electrode design supported by artificial intelligence**. Combines simulation and targeted experimental data to optimise particle morphology, coatings and electrode structure. **Period: Jan 2022 – Jun 2026.** Funding: BMWE - 03ETE039. | Develop virtual electrode-design methods that connect materials selection and microstructure with electrochemical performance and industrial manufacturing requirements. | Helmut Schmidt University (HSU), consortium coordinator. HZB, participating research organisation. | **Germany**: HSU, Mercedes-Benz, BASF, algorithmica technologies, Customcells, KIT, HZB, Ulm University and Heidelberg University. | https://www.hsu-hh.de/am/hibrain |

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|---|---|---|---|---|---|---|---|
| Helmholtz-Zentrum Berlin (HZB) Germany | Green hydrogen, fuels and chemicals | Fischer–Tropsch catalysts for SAF | **CARE-O-SENE — Catalyst Research for Sustainable Kerosene.** German–South African consortium connecting catalyst synthesis, operando characterisation, modelling, testing and industrial scale-up for power-to-liquid SAF. **Period: Sep 2022 – Dec 2027.** Funding: BMFTR - 03SF0673. | Develop durable, selective FT catalysts and accelerate industrial validation. Reported outcome: Catalys developed with kerosene yield >80% after upgrading, tonne-scale catalyst preparation and semi-commercial testing. Further work addresses optimisation, durability, regeneration and recyclability. Researcher exchange and mentoring accompany scientific and industrial work. | HZB and Sasol, joint project leadership. | **Germany**: HZB, KIT, Fraunhofer IKTS, DLR and Sasol Germany. **International**: Sasol Research & Technology and University of Cape Town (South Africa). | https://care-o-sene.com/ |
| Helmholtz-Zentrum Berlin (HZB) Germany | Green hydrogen, fuels and chemicals | AI-guided catalyst discovery | **ASCEND — Accelerated Solutions for Catalysis using Emerging Nanotechnology and Digital Innovation.** Combines thin-film catalysis, AI, simulation and self-driving laboratories in closed-loop discovery workflows. **Period: Apr 2026 – Dec 2031.** Funding: BMFTR - 03SF0798. | Accelerate discovery and validation of catalysts for sustainable fuels and chemicals by linking synthesis, testing and characterisation to continuously updated models and selection of subsequent experiments. | HZB and Fritz Haber Institute, joint project leadership | **Germany**: HZB, Fritz Haber Institute of the Max Planck Society, BASF, Siemens Energy, Dunia Innovations and TU Berlin/BasCat. | https://ascend-project.berlin/ |
| Helmholtz-Zentrum Berlin (HZB) Germany | Green hydrogen, fuels and chemicals | Renewable fuel gas and systems assessment | **GreenQUEST — Greening the Production and Use of Liquefied Fuel Gas in Southern Africa.** Develops gLFG from renewable hydrogen and captured $CO_2$, combining conversion research with economic, environmental and social assessment. **Period: Oct 2022 – Dec 2026.** Funding: BMFTR - 03SF0688. | Demonstrate renewable alternatives to fossil LPG for cooking and power generation and assess regional value chains. Reported outcomes include Bulk Sample 8Kg produced and cooking and power generation succesfully demonstrated. | HZB and University of Cape Town, joint project leadership. | **Germany**: HZB, Forschungszentrum Jülich and other German research/technology partners. **International**: University of Cape Town, Hydrogen Energy Applications (HYENA) and Southern African application and value-chain partners. | https://greequest.africa |
| Helmholtz-Zentrum Berlin (HZB) Germany | Green hydrogen, fuels and chemicals | Photocatalytic hydrogen production | **PH2OTOGEN — Acceleration of Photocatalytic Green Hydrogen Production to Market Readiness through Value-Added Oxidation Products.** Develops a photocatalytic flow reactor producing hydrogen and valuable oxidation products. HZB contributes materials characterisation. **Period: Jan 2024 – Jun 2027.** Funding: EU Horizon Europe / Clean Hydrogen Joint Undertaking. | Targets: average solar-to-hydrogen efficiency >5% for 500 hours in a 500 cm² demonstrator. Evaluate reactor scalability and the contribution of co-products to economic viability. These are development targets. | Toyota Motor Europe (Belgium), consortium coordinator. HZB, advanced characterisation partner. | European research–industry consortium<br><br>**Germany**: HZB **Internatinal**: Toyota Motor Europe (Belgium), CEA/LGI Sustainable Innovation (France), EPFL/Solaronix (Switzerland), DIFFER (Netherlands). | https://www.ph2otogen.eu/theproject |
| Helmholtz-Zentrum Berlin (HZB) Germany | Hydrogen and digital energy materials | Cloud-connected laboratories | **DECODE — DE-centralised Cloud labs fOr inDustrialisation of Energy materials.** Connects distributed laboratories, modelling and characterisation through AI-supported workflows. Initial demonstrators address water electrolysis and hydrogen fuel cells, with wider applicability to energy materials. **Period: Dec 2023 – Nov 2027.** Funding: EU Horizon Europe / Digital, Industry and Space, RIA. Grant: | Demonstrate an interoperable laboratory platform that coordinates complementary methods and industrial validation. Combine multi-scale models, material characterisation and AI-supported orchestration to shorten development cycles. | Forschungszentrum Jü lich, consortium coordinator. HZB, advanced characterisation partner. | **Germany**: Forschungszentrum Jülich and HZB. **International**: Nel Hydrogen Electrolyser (Norway), CEA-Liten/CNRS/INPT/Euroquality/University of Strasbourg (France), Leiden University (Netherlands), CIEMAT (Spain), DTU (Denmark), PSI (Switzerland), Simon Fraser University (Canada). | https://decode-energy.eu/ |

## Prof. Dr. Bernd Rech

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**Current Positions**

- Scientific Director and Spokesperson of the Management Board of the Helmholtz-Zentrum Berlin für Materialien und Energie (HZB) (since June 2022).
- Vice-President: Helmholtz Research Field Energy (since October 2023).
- Professor at Technische Universität (TU) Berlin, Faculty of Electrical Engineering and Computer Science (Chair of Photovoltaics) (since January 2007).
- Member of the Board of Directors (2026–2028) and Vice Chair, LEAPS: League of European Accelerator-based Photon Sources (since January 2026).
- Coordinator of Natural Sciences Unit at Berlin Research 50 (BR50) - since January 2026.

**Education and Carreer Background**

- 2019–2022: Scientific Director (Energy & Information Divisions) – HZB
- 2017–2019: Acting Scientific Director – HZB
- 2006–2017: Head of the Institute for Silicon Photovoltaics – HZB
- 1999–2006: Head of the Solar Cell Technology Group – FZJ
- 1996–1999: Research Associate at the Institute of Photovoltaics – Forschungszentrum Jülich (FZJ)
- 1997: PhD in Physics – RWTH Aachen

**Advisory Board Memberships (Non-Exhaustive List)**

- Member of the advisory board – Institut für Solarenergieforschung (ISFH) Member of the board of trustees – Physikalisch-Technische Bundesanstalt (PTB)
- Member of the energy research advisory board – Federal Ministry for Economic Affairs and Energy (BMWE)

# Indonesia

BRIN

National Research and Innovation Agency

**The 8th RD20 conference, Oct. 19-23, 2026**

**(Activity Summary Template)**

# Research and Development on Clean Energy Technologies and Policy Solutions for the Net-Zero Transition

Dr. Ratih Damayanti, Arfie Ikhsan Firmansyah, Arini Mulia Salsabila, Rieny Fadhilah Rahmi
National Research and Innovation Agency/ BRIN

## 1. Introduction

Please describe the background of research and development of clean energy technologies at your institute based on energy policy in your country. (Times New Roman or Times-Roman 12 pt)

Indonesia's transition towards a low-carbon energy system is an important component of its national development agenda and international climate commitments. Under its 2022 Enhanced Nationally Determined Contribution (ENDC), Indonesia committed to reducing greenhouse gas emissions by 31.89% through domestic efforts and by up to 43.20% with international support by 2030 [1]. Building on this commitment, Indonesia submitted its Second Nationally Determined Contribution in 2025, which establishes an emissions pathway for 2031–2035 and maintains the long-term objective of achieving Net Zero Emissions (NZE) by 2060 or sooner [2]. The energy sector plays a central role in achieving these objectives through the wider deployment of renewable energy, improvements in energy efficiency, and a gradual reduction in dependence on fossil fuels.

At the national level, the energy transition is guided by the National Energy Policy under Government Regulation No. 40 of 2025 and Presidential Regulation No. 112 of 2022 on the Acceleration of Renewable Energy Development for Electricity Supply [3], [4]. These policies provide a framework for diversifying the national energy mix, accelerating renewable-energy deployment, strengthening energy security, attracting investment, and reducing emissions from the power sector. They also emphasise the importance of energy availability, affordability, accessibility, and acceptability.

Within this policy context, the National Research and Innovation Agency (BRIN) generates scientific evidence, technologies, and policy recommendations to support the energy transition. Its research and innovation activities cover strategic fields including hydrogen, biofuels and biomass, solar and wind energy, geothermal and marine energy, nuclear energy, and other low-carbon technologies [5]. These activities support improvements in technological performance and readiness, as well as demonstration, deployment, and wider adoption.

Recognising that technology readiness alone does not ensure deployment, BRIN complements technology R&D with techno-economic assessment, investment analysis, and policy research. This includes evaluating fiscal incentives such as tax holidays and tax allowances and examining other measures that could improve the financial viability of renewable-energy projects [6], [7].

Through this multidisciplinary approach, BRIN seeks to connect technological development with implementation and support clean-energy solutions that are technically reliable, financially viable, scalable, and responsive to Indonesia's development priorities.

## 2. R&D activities related to clean energy technology for carbon neutrality

Please review and describe the research and development (R&D) status of clean energy technologies for carbon neutrality at your institute.

In response to Indonesia's energy and climate priorities, BRIN conducts multidisciplinary R&D spanning clean-energy technologies, system integration, and policy and techno-economic analysis. Its current focus areas are summarised below:

- **Hydrogen and the Hydrogen Ecosystem:** Research maps Indonesia's green-hydrogen potential across the value chain, from production and storage technologies to potential utilization.
- **Biofuels and Biomass-Based Clean Fuels:** Research focuses on bioethanol and other biomass-based clean fuels, including the utilization of sorghum as a non-food alternative feedstock.
- **Renewable Energy and Expansion of Renewable Electricity Capacity:** Activities support the wider utilization of wind and solar energy. BRIN also assesses how fiscal incentives, including tax holidays and tax allowances, could improve project economics and encourage investment in renewable-energy generation.
- **Low-Carbon Technologies:** Research examines the integration and diversification of renewable-energy sources as pathways to reduce dependence on fossil fuels.
- **Nuclear Energy:** BRIN assesses the potential role of nuclear power as part of Indonesia's future low-carbon energy portfolio.
- **Policy and Techno-Economic Assessment:** BRIN provides evidence-based policy recommendations using cost-benefit analysis and other techno-economic assessments to evaluate the sustainability and financial feasibility of energy-transition projects.

## 3. Specific research activities

Please review and describe the R&D status of specific technologies.

*Related programs/projects conducted by the institute*

- Project title and topic (20XX-20YY)
- Project title and topic (20XX-20YY)
- ……

BRIN supports the clean-energy transition through technological R&D and complementary economic, regulatory, and implementation studies. The following table summarises selected research and project activities across these areas.

| No. | Topic/scope | Research/project title (partner) | Period |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 1 | Carbon pricing and renewable-energy investment | The Economic Impact of Carbon Tax in the Energy Sector (KESDM, DEN, and Bappenas) | 2025 |
| | | Policy Study on the Economic Value of Carbon for New and Renewable Energy (KESDM, DEN, and Bappenas) | 2024 |
| | | Carbon Rights in New Renewable Energy for the Implementation of the Economic Value of Carbon (KESDM, DEN, and Bappenas) | 2024 |
| | | The Role of the Economic Value of Carbon in Driving Investment in New and Renewable Energy through Stakeholder Identification and Supporting Conditions (KESDM, DEN, and Bappenas) | 2024 |
| 2 | Biojet fuel development | Roadmap for Biojet Fuel Development: Readiness of Alternative Raw Materials and Biojet Fuel Conversion Technology (KESDM, DEN, and Bappenas) | 2024 |
| | | The Potential of Rubber Seeds as Alternative Raw Materials for Biojet Fuel (KESDM, DEN, and Bappenas) | 2024 |
| | | Raw Material and Refinery Infrastructure Needs for Biojet Fuel Implementation (KESDM, DEN, and Bappenas) | 2024 |
| 3 | Energy storage, grids, and hydrogen | Response to the COP29 Presidency Initiative on Global Energy Storage and Grids Pledge, Green Energy Zones and Corridors, and Hydrogen Agenda (KLHK) | 2024 |
| 4 | Transport electrification | Impact and Efforts to Increase Electric Vehicle Penetration through Conversion Programs (KESDM) | 2023 |
| 5 | Renewable energy and energy conservation | Development of Renewable Energy and Energy Conservation in Supporting Net-Zero Emission Achievement (KESDM) | 2022 |
| 6 | Net-zero transition and energy security | Study on the Impact of Net-Zero Emissions on Energy Security and the National Economy (KESDM and DEN) | 2023 |
| 7 | End-use electrification | Program for Substituting LPG Stoves with Electric or Induction Stoves (KESDM) | 2022 |

Note: KESDM = Ministry of Energy and Mineral Resources; DEN = National Energy Council; Bappenas = Ministry of National Development Planning; KLHK = Ministry of Environment and Forestry.

## 4. International collaboration

Please describe current status of international joint R&D activities and alliance/networking development at your institute with any countries, including comprehensive MOUs, joint projects, researcher exchanges, joint workshops and seminars.

Please describe your experience and concerns regarding the actual international joint project.

- Regarding specific research themes, what are the most prioritized issues/themes (in the short or long term) that research institutes should work on together within the RD20 framework?
- What are the best practices that your institution has been involved in so far, and future possible contributions on those critical issues/themes?
- What do you think is an effective measure for facilitating international cooperation?

International collaboration is central to BRIN's strategy for advancing research and innovation. Through partnerships with governments, research institutions, universities, and industry, BRIN supports the development of clean-energy technologies and long-term strategies towards Indonesia's net-zero emissions target. Selected collaborations relevant to clean energy are summarized below.

| **International joint R&D name** | **Activities and current status** | **Experience and concerns regarding joint projects** |
|---|---|---|
| APEC-ACABT (Asia-Pacific Economic Cooperation - Research Center for Advanced Biohydrogen Technology) | **Activities**: Capacity building and International networking<br>- Green Synerger Training Program<br>- Green Synergy Leadership Training Program<br>- International Conference on Biohydrogen and Bioprocesses<br><br>**Current status**: BRIN has hosted and participated in these activities. | These activities strengthen knowledge exchange and networks among APEC economies. The challenge is translating them into sustained joint R&D projects. |
| BRIN and International Coconut Community and Indonesia Japan Business Network (IJBNet) on Research and Innovation on Coconut for Sustainable Energy | **Activities:** Research and innovation on coconut for sustainable energy.<br><br>**Areas of cooperation:**<br><br>- Aeronautics, particularly SAF from coconut oil, biomass, and waste residues | The framework enables broad research cooperation. Key challenges are defining specific outputs, |

| | | |
|---|---|---|
| | - Nanotechnology and coconut-derived materials for energy storage, biofuel processing, and renewable-energy applications<br>- Life sciences and environmental assessment of coconut-derived biofuels<br>- Coconut cultivation, micropropagation, waste valorization, and bioenergy-crop optimization<br>- Economic models and community benefits of coconut-based clean-energy value chains<br>- Biofuel-production technologies, manufacturing processes, equipment, standards, and scalable clean-energy systems<br><br>**Current status:** Joint research on policies for utilizing non-standard coconuts for SAF and developing related sorting standards and manuals. | responsibilities, funding, timelines, and mechanisms for implementing the proposed standards. |
| BRIN–RIKEN Nishina Center for Accelerator-Based Science (RNC), Japan | **Activities:** Research and innovation in accelerator-based science and materials.<br><br>**Areas of cooperation:**<br><br>- Accelerator-based spectroscopy<br>- Functional and magnetic materials, including organic and inorganic superconductors<br>- Energy-conversion and storage materials<br>- Nanoparticles<br>- Computational physics<br><br>**Current statu**s: Cooperation has been established through an MoU on accelerator-based science and technology for materials research. | The cooperation advances energy-related materials research. The main challenge is translating fundamental research into industrial clean-energy applications. |
| Other institutional Memorandum of Understanding (MoU) | Cooperation agreements in low-carbon energy technology with CSIRO (Australia), CNRS (France), and other global institutions. | |

Building on these experiences, BRIN identifies the following priorities and potential contributions within the RD20 framework.

| Priority theme | BRIN experience and future contribution |
|---|---|
| Clean hydrogen and sustainable fuels | Hydrogen mapping, biomass fuels, and coconut-based SAF policy and standards |
| Renewable-energy integration, storage, and energy access | Policy and investment analysis and energy-conversion and storage materials |
| Advanced materials for clean-energy technologies | Functional and magnetic materials, storage materials, nanoparticles, and computational physics |
| Techno-economic assessment and clean-energy financing | Cost-benefit, carbon-pricing, fiscal-incentive, and investment analysis |

BRIN considers sustained joint funding, clearly defined work plans and outputs, transparent intellectual-property and data-sharing arrangements, and regular coordination important for effective cooperation. Where relevant, researcher exchanges, shared facilities, and the involvement of industry and financing institutions can support technology development and deployment.

## 5. Future perspectives (towards carbon neutrality)

Please describe future challenges in clean energy technologies, and the expected international collaborative framework at your institute

BRIN's main future challenge is bridging the gap between clean-energy research and wider deployment. Across its clean-energy portfolio, technologies must progress from research to pilot demonstration and scalable application while improving performance, reliability, cost-effectiveness, and suitability for Indonesia's diverse geographical conditions. Deployment also requires appropriate technical standards, consistent regulations, bankable project structures, affordable financing, and effective risk-mitigation mechanisms.

Within the RD20 framework, BRIN expects international collaboration to support jointly defined R&D and pilot projects, shared research facilities and data, researcher exchanges, and common testing and sustainability methods. Joint techno-economic assessment and early engagement with industry and financing institutions can further connect technology validation with investment and deployment. This framework can help translate research into clean-energy solutions that are available, affordable, accessible, and acceptable in Indonesia and other countries facing similar transition challenges.

## References

[1] Government of the Republic of Indonesia, *Enhanced Nationally Determined*

*Contribution*, Jakarta, 2022. [Online]. Available: https://unfccc.int/sites/default/files/NDC/2022-09/ENDC%20Indonesia.pdf

[2] Government of the Republic of Indonesia, *Second Nationally Determined Contribution*, Jakarta, 2025. [Online]. Available: https://unfccc.int/sites/default/files/2025-10/Indonesia_Second%20NDC_2025.10.24.pdf

[3] Government of the Republic of Indonesia, *Government Regulation No. 40 of 2025 concerning the National Energy Policy*, 2025. [Online]. Available: https://peraturan.bpk.go.id/Details/328789/pp-no-40-tahun-2025

[4] President of the Republic of Indonesia, *Presidential Regulation No. 112 of 2022 concerning the Acceleration of Renewable Energy Development for Electricity Supply*, 2022. [Online]. Available: https://peraturan.bpk.go.id/Details/225308/perpres-no-112-tahun-2022

[5] Ministry of Higher Education, Science, and Technology and National Research and Innovation Agency, *National Strategic Research Roadmap and Agenda, 2026 Edition*, Jakarta, 2026.

[6] Government of the Republic of Indonesia, *Government Regulation No. 78 of 2019 concerning Income Tax Facilities for Investment in Certain Business Fields and/or Certain Regions*, 2019.

[7] Minister of Finance of the Republic of Indonesia, *Minister of Finance Regulation No. 69 of 2024 concerning the Amendment to Minister of Finance Regulation No. 130/PMK.010/2020 on the Provision of Corporate Income Tax Reduction Facilities*, 2024.

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| Green Power Development Coorperation Japan | Sustainable Aviation Fuel (SAF) | Sorting Manual Development of Non-Standard Coconuts asraw material for ICAO Corsia Sustainable Aviation Fuel (SAF) | **2025**<br>• Review of existing standards, guidelines, and policies related to non-standard coconuts<br>• Field study/ observation rela:ed to the production process of non-standard coconuts<br>• Submission of the non-standard coconut manual for SAF feedstock to the International Co:onut Community (ICC)<br><br>**2026**<br>• Preparation of policy recommendation document related to the development and implementation of the non-standard coconut sorting manual for SAF fuel<br>• Training on sorting non-standard coconut for SAF feedstock for prospective suppliers after sorting manual is approved by the ICC<br>• Monitoring and evaluation<br><br>**2027**<br>• Training on sorting non-standard coconuts for SAF feedstock for prospective suppliers after manual is approved by the ICC<br>• Monitoring and evaluation | 1. The manual sorting of non-standard coconut as feedstock for SAF;<br>2. Policy recommendation on the deveplopment and implementation of the non-standard coconut sorting manual for SAF feedstock;<br>3. Training on sorting non-standard coconut for SAF feedstock for prospective suppliers<br>e.g. Cost reduction of ■■ to ● kWh/yen in 2030 | Dr. Ratih Damayanti, S. Hut, M.Si | （Domestic）:<br>1. Research Center for Testing and Standards ● ●<br>2. PT. Green Power Palembang ▲▲<br>3. PT. ABE Indonesia Berjaya ▲▲<br>4. Yayasan Indonesia Jepang Bersama ▲▲<br><br>（International）:<br>Green Power Development Corperation Japan ▲▲ | https://brin.go.id/dkp/DKPLHKSDAK/page/kajian-tahun-2024 |

# Mexico

CINVESTAV

Center for Research and Advanced Studies of the National Polytechnic Institute

**The 8th RD20, September 7th 2026**

# Overview of Research and Development in Renewable Energy

Alberto Sanchez-Hernandez
Centro de Investigación y de Estudios Avanzados (Cinvestav), Mexico

## 1. Introduction

Mexico's energy sector has historically relied on fossil fuels, leading to significant ecological degradation, industrial pollution, and urban environmental decay. Although shifting policy landscapes and structural setbacks have previously hindered progress, a renewed national momentum is accelerating the transition toward decarbonization. Key research institutions, led by Cinvestav and backed by an expanding network of universities and scientific centers, are providing the essential technological expertise to realize these clean energy goals.

This strategic pivot is exemplified by major public initiatives like the Sonora Plan, which targets the deployment of up to five 1 GW photovoltaic solar installations in the Puerto Peñasco desert, where early operational phases are already producing power. In tandem, substantial investments are targeting green hydrogen and green ammonia development, such as the Marengo I project. Academic and scientific institutions serve as the primary engine for this transition, driving the research, technological innovation, and skilled workforce generation required to achieve long-term carbon neutrality.

## 2. Research and Development Activities at Cinvestav

Cinvestav, a prominent Mexican research institution, plays a pivotal role in advancing clean energy technology, contributing significantly to national and international efforts in sustainable development. Among its ten campuses, four are particularly dedicated to this crucial field: Mexico City, Merida, Queretaro, and Saltillo.

The Mexico City campus focuses on a broad spectrum of renewable energy research, including advanced materials for solar panels, energy storage solutions, and the integration of smart grid technologies. Its strategic urban location fosters strong interdisciplinary collaborations with other leading research centers and industrial partners, directly facilitating the translation of innovative laboratory discoveries into practical, scalable real-world applications.

In Merida, the campus leverages the region's abundant solar radiation and unique geographical location to specialize in various cutting-edge aspects of solar energy. Key efforts include the design and development of highly efficient photovoltaic cells, the optimization of advanced solar thermal systems for both large-scale electricity generation and industrial heating processes, and targeted research into concentrated solar power technologies. Furthermore, their work frequently addresses the specific operational challenges and environmental opportunities presented by humid, tropical climates.

The Queretaro campus serves as a major hub for advanced research in hydrogen technologies and biofuels. Its multidisciplinary team of scientists is actively involved in developing sustainable and scalable methods for green hydrogen production, exploring state-of-the-art fuel cell technologies tailored for both transportation sectors and stationary power networks, and investigating advanced biorefining processes to convert diverse biomass feeds into high-value clean fuels and industrial chemicals. This campus is particularly recognized for its specialized achievements in novel catalytic processes that are vital for driving these green energy conversions efficiently.

Finally, the Saltillo campus concentrates its scientific expertise on optimizing energy efficiency and developing sustainable materials tailored specifically for clean energy applications. Researchers at Saltillo pioneer innovative, practical methodologies to significantly reduce energy consumption in both intensive industrial environments and residential sector settings. Additionally, they specialize in the synthesis and characterization of advanced functional materials that dramatically improve the overall efficiency, performance, operational lifespan, and durability of clean energy systems.

Collectively, these four specialized Cinvestav campuses stand at the forefront of pioneering sustainable, cost-effective, and highly efficient energy solutions. In doing so, they directly address critical national and global challenges related to energy security, environmental protection, climate change mitigation, and sustainable economic growth across Mexico and internationally. Their comprehensive interdisciplinary approach, combined with a firm commitment to cutting-edge scientific innovation, firmly underscores Cinvestav's ongoing leadership in the global clean energy landscape.

Specific research activities at Cinvestav include:

- **Solar Energy Innovations:** Significant advancements are being made to improve solar cell efficiency beyond traditional silicon models. Key research focuses on dye-based technologies and Cu-Zn compound thin-film solar cells, which offer lower costs and reduced environmental impact. Together, these developments aim to deliver more versatile, economical, and highly efficient solar power solutions.

- **Green Hydrogen Initiatives:** To support the global shift toward sustainable energy, Cinvestav is pioneering advanced research into green hydrogen production. By leveraging renewable energy sources to power water electrolysis, this process splits water into hydrogen and oxygen without generating harmful emissions. As a versatile and clean energy vector, green hydrogen holds immense promise across transportation, power generation, and industrial sectors by providing a zero-carbon substitute to help decarbonize high-emission activities. Through these efforts, Cinvestav plays a vital role in advancing the key technologies required to harness green hydrogen for a cleaner, more sustainable future.

- **Biofuels Research:** To curb greenhouse gas emissions and lower dependence on fossil energy, scientists are advancing sustainable biofuel production technologies. Key strategies center on processing agricultural residues—such as manure and crop waste—via thermochemical and biochemical pathways, alongside cultivating fast-growing microalgae for biofuel conversion. These initiatives strive to establish economically viable, environmentally sound energy solutions that help shrink carbon footprints.

## 3. Specific Research Projects at Cinvestav

Beyond the broad research domain, Cinvestav carries out key targeted initiatives across renewable energy generation, green hydrogen, and clean transportation:

- **Solar Water Electrolysis (2018–2028):** Focused on generating hydrogen through water electrolysis powered by solar energy, this initiative offers a sustainable and clean hydrogen source.
- **High-Efficiency Green Solar Cell Innovation (2018–2028):** To provide a more cost-effective and efficient alternative to traditional silicon photovoltaics, researchers are advancing solar cells utilizing Cu-Zn compounds.
- **Scaling Green Hydrogen Production (2020–2030):** Researchers at Cinvestav are advancing scalable synthesis techniques to lower costs and broaden the practical deployment of green hydrogen across diverse industrial sectors.
- **Dye-Sensitized Solar Cell Research (2016–2028):** This initiative investigates dye-based photovoltaic technologies to enhance solar conversion efficiency while minimizing production costs.
- **Prototype Fuel-Cell Vehicle Engineering (2016–2030):** Cinvestav is designing zero-emission prototype vehicles powered by hydrogen fuel cells, aiming to elevate local air quality and curb greenhouse gas emissions.

Progress on those projects is variable and support for R&D has been extended.

Fig. 1: Perovskite array prototype developed at Cinvestav Mérida, under characterization.

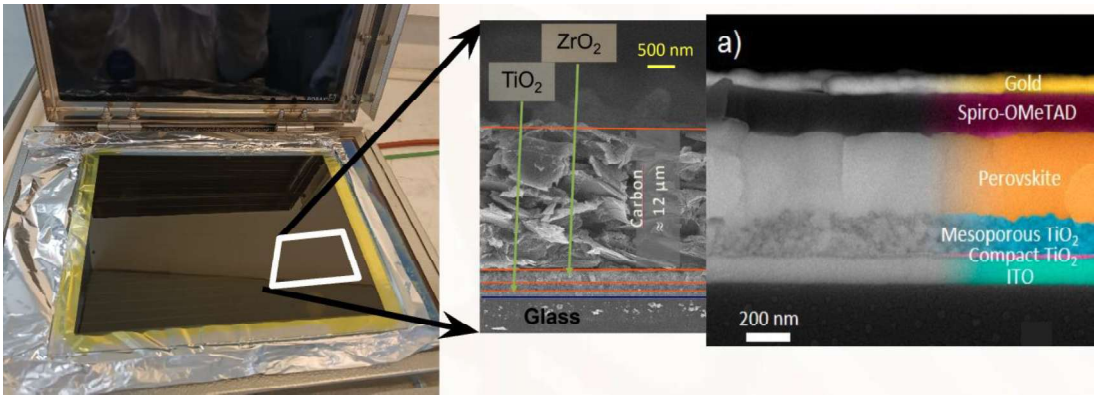



Fig. 2: Cinvestav's HIDROBIINIZA hydrogen fuel cell vehicle.

## 4. International Collaboration

Cinvestav actively engages in global partnerships to advance clean energy innovation and sustainable development. Key international collaborations include strategic alliances with French universities (University of Le Mans, Polytechnic University of Hauts-de-France, and University of Limoges) and joint proposal efforts with research organizations across G20 nations. In photovoltaic cell research, Queretaro's group collaborates with Canadian institutions—Simon Fraser University and the University of Toronto—to study semiconductor materials for next-generation solar cells. For green hydrogen, Cinvestav maintains a bilateral cooperation framework with Argentina's National Institute of Industrial Technology (INTI) and integrates its fuel cell and vehicular application research globally through international publications. Through these

multidisciplinary efforts, infrastructure, and international partnerships, Cinvestav continues to play a central role in shaping clean energy solutions for Mexico and the world.

## 5. Future Perspectives

Cinvestav's solar energy research focus is experiencing a major strategic shift, transitioning away from conventional silicon panels toward more sustainable and advanced materials, including perovskites and kesterites (CZTS). This ongoing research places a strong emphasis on achieving low-cost manufacturing processes, higher energy conversion efficiency, and flexible deployment models through open, collaborative scientific partnerships. At the same time, Mexico's broader clean energy transition acts as a crucial driver for economic growth, striving to position the nation as a leading global exporter of green hydrogen derivatives, such as methanol and ammonia, while generating millions of specialized jobs across the country by 2050.

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| Cinvestav/Mexico | Solar Cells | | Development of efficient green Solar Cells based on Cu-Zn compounds (2018-2028)<br>Current<br>2018- 2028 (R&D span) | Role of structural defects in increasing efficiencies in Cu2ZnSnS4 and CdS/CdSe based cells | Dr. Jose Mustre / Cinvestav-Merida,<br>Dr. Velumani Subramanian / Cinvestav-Mexico-City | (Domestic) Universidad Marista Merida, (International) Stanford Synchroton Radiation Lab, (International) University of Limoges, France | |
| | | | Development of Dye-based Solar Cells (2018-2028)<br>Current<br>2018- 2028 (R&D span) | Unlock the challenges related to the materials and manufacturing processes of solid-state batteries by investigating a number of innovative technologies to produce advanced SSEs from both inorganic and polymeric materials | Dr. Gerko Oskam / Cinvestav-Merida | (International) Universidad de Valencia | |
| | | | Electrolysis of water using solar energy (2017-2028)<br>Current<br>2017- 2028 (R&D span) | Development of high performance Electrolysis of water using Bismuth Oxide thin films | Dr. Gerko Oskam / Cinvestav-Merida | | |
| | Fuel Cells | | Development of fuel-cells propelled prototype vehicle for use in Mexico City (2017-2028)<br>Current<br>2017- 2028 (R&D span) | Small vehicles used for delivery and short range transportation in Mexico City | Dr. Omar Solorza / Cinvestav-Mexico-City | (Domestic) Instituto Politecnico Nacional, México | |
| | | | Green Hydrogen development (2021-2030)<br>Current<br>2021-2030 (R&D span) | Use of Bi-Pb-oxides in water electrolysis to obtain hydrogen using clean energies | Dra. Lilana Lemus / Cinvestav-Saltillo,<br>Dr. Javier Rodriguez / Cinvestav-Saltillo,<br>Dr. Jose Mustre / Cinvestav-Merida,<br>Dr. Geonel Rodriguez / Cinvestav-Merida | (Domestic) University of Yucatan, (Domestic) Instituo Politecnico Nacional, Mexico | |

# Republic of Korea

KIER

Korea Institute of Energy Research

**The 8th RD20 conference, Oct. 19-23, 2026**

# KIER's Innovative Research and Global Collaboration Towards a Low-Carbon Energy Future

Jun-Sik Cho
Korea Institute of Energy Research (KIER), Republic of Korea

## 1. Introduction

The new Korean government has identified AI and Energy as two new highways for future growth, recognizing that the next phase of national competitiveness will depend not only on advances in artificial intelligence but also on the energy systems capable of supporting an increasingly digital and electrified economy.

This vision closely links Korea's AI strategy with its energy transition. The rapid expansion of AI, data centers, advanced manufacturing, and other electricity-intensive industries is expected to significantly increase demand for reliable, affordable, and low-carbon electricity. In response, the government is pursuing the expansion of renewable energy, stronger and more intelligent power grids, distributed energy systems, and energy storage, while promoting the convergence of AI with energy technologies and industrial systems.

Korea Institute of Energy Research (KIER) plays a central role in connecting Korea's AI ambitions with the energy technologies required to realize them. KIER is advancing R&D across new and renewable energy, energy storage, energy efficiency, CCUS, sector coupling, intelligent energy systems, and AI-driven energy technologies, while translating these innovations into practical solutions for carbon neutrality, energy security, and industrial competitiveness. Through international partnerships, including the RD20 framework, KIER seeks to strengthen global collaboration in developing and deploying the energy technologies that will underpin the emerging AI era and accelerate the transition toward a sustainable, low-carbon energy future.

The Korea Institute of Energy Research (KIER) is a leading national energy R&D institute, advancing renewable energy as a central pathway toward carbon neutrality. Building on its strengths in solar, wind, hydrogen, energy storage, and CCUS, KIER is expanding its research on grid flexibility, energy efficiency, and AI-enabled energy systems to address the growing complexity of the energy transition. Its mission is to develop reliable and scalable energy technologies that connect research excellence, demonstration capabilities, and industrial application.

- **Renewable and Carbon-Neutral Innovation:** Development of next-generation solar photovoltaics, next-generation offshore wind technologies, clean hydrogen production through water electrolysis, grid-scale energy storage, and advanced CCUS processes.
- **Energy AI and System Integration**: Application of big data, digital twins, and intelligent control systems to improve renewable resource assessment, distributed energy management, grid flexibility, energy efficiency, and AI-ready energy infrastructure.
- **Strategic Global Collaboration**: Strong partnerships with leading institutes, including the National Laboratory of the Rockies, Lawrence Livermore National Laboratory, National Research Council Canada, Fraunhofer, and Helmholtz, as well as multilateral frameworks such as RD20.

Through these initiatives, KIER supports Korea's national carbon neutrality strategy and

strengthens its role as a trusted international partner in delivering sustainable, scalable, and AI-enabled clean energy solutions.

## 2. R&D activities related to clean energy technology for carbon neutrality

Hydrogen and fuel cells are KIER's main R&D areas over the last few decades. For clean hydrogen production R&D, low & high-temperature water electrolysis, natural gas reforming and ammonia cracking are the sub-areas. Hydrogen storage system using hydrogen storage alloy is also R&D area. KIER is developing electrolyte membranes, catalysts, electrodes, MEA, stacks, and systems for both PEMFCs and SOFCs, with applications across various sectors including automobiles, aircraft, and distributed power sources.

- Design of pressurized modular high-purity hydrogen production unit (2017-, reforming unit: 500kg/day, hydrogen production efficiency (HHV): 80%, purity: 99.999%)
- Development of large-scale alkaline water electrolysis cells and stack under dynamic operation (2019-, H2 production rate: 3 Nm3/h, energy consumption (stack) < 48.64 kg-H2, H2 production efficiency (HHV) > 83.5%, dynamic operating range: 10 ~ 100 %)
- Development of polymer electrolyte membrane water electrolyzers (2018-, PEMWE stack component R&D for low iridium loading and high efficiency, stack development for renewable energy integration; 2022-, AEMWE R&D for highly active and durable materials and stack)
- Development of membrane, electrode, PTL, stack, and system for MW scale-up (2024-. Energy consumption of system <52 kWh/kg-H2, electrode diameter > 800mm)
- Development of an 80 cm active diameter reference stack and a 250 kW pressurized alkaline water electrolysis system(8barg) for stack R&D and large-scale material testing.
- Development of low-cost high-performance core materials for building application fuel cells (2022-, The use of precious metals: ≤2 g/kW (@650℃, 10 × 10 cm2, ammonia conversion rate > 99%, power density> 500 mW/cm2, durability < 0.5%/kh)
- Development of hydrocarbon electrolyte membranes, non-precious metal catalysts, and a 25kW fuel cell stack and system for power generation, along with a real-time fault diagnosis tool for fuel cell stacks.
- Reliability evaluation of fresh and re-used PEMFC stacks for vehicle and stationary applications (2019-, Constructing large-scale reliability test center for PEMFC, and performance evaluation of the 100 kW fresh and re-used stacks)
- Development of Materials, Cells, Stacks, and 6Nm3/h_H2 Class Systems for Enhanced Durability and Efficiency of Intermediate-Temperature (700°C) SOECs (2024-, 20~100kW SOEC stack and system)
- Development of materials, cells and 0.4Nm3/h-class stacks for domestic production of reduced-temperature(≤650℃) solid oxide electrolysis technologies (2022-, faraday efficiency > 95%, degradation rage < 0.5%/kh)
- Advancing the Durability of Solid Oxide Electrolysis Cells: A Global Collaborative Research Framework (2025-, degradation rate < 0.5%/kh)

Renewable energy technology is at the heart of the energy transition, a global trend to overcome the climate crisis mankind faces. Large-scale penetration of renewable energy makes us confront different issues, such as a lack of installation sites, public acceptance, and energy intermittency. KIER has been conducting essential activities focusing on solar and wind energy and energy storage to provide technological solutions to energy security and environmental as well as the above-mentioned issues. High-efficiency tandem solar cells, and multifunctional (light-weight, flexible, transparent, etc.) thin-film solar cells are the recent main research topics

in photovoltaics area, driven by the pursuit of carbon neutrality and diverse application with high-added value. Innovative research on next-generation secondary batteries is also ongoing with expertise for grid-scale energy storage systems (ESS) and fast-charging electric vehicles (EV). Renewable energy resource and potential assessment have been updated in cooperation with the ICCP climate change scenarios. 'Renewable-energy resource map & integration platform', and 'next-generation offshore wind technologies' are key research fields where KIER tries to contribute to renewable energy dissemination by developing the government's policy-based public technologies in cooperation with industries and academia.

- Prosumer-type next-generation solar cell technology for urban application (2017-, High-efficiency (>35% by 2030) Perovskite/Si tandem solar cell; Flexible CIGS-based multijunction solar cell (efficiency > 32% and power-to-weight >600 W/kg) by 2031)
- Building-Integrated Photovoltaic Thermal systems for high-rise residential buildings and urban power generation (2022-, 24% thermal efficiency and 40% combined electrical and thermal efficiency by 2025)
- Downscaling of climate projection data to estimate the renewable energy potential toward 2050 (accuracy > 92%)
- Safe secondary batteries for grid-scale BESS System (LCOS<$0.05/kWh by 2030) and next-generation high-energy-density secondary batteries (400 Wh/kg by 2030)
- Next-Generation Offshore Wind Technologies for High Efficiency and Low LCOE (2020–, Achieving >10% LCOE reduction through next-generation ultra-large blade technologies, AI-based condition monitoring and fault diagnosis, and floating vertical-axis wind turbine (F-VAWT) technologies)
- Cyber-physical system technologies to interconnect distributed energy resources for RE3020 (2019-, distributed resource control achievement rate 95%)

$CO_2$ capture and utilization (CCU) technologies have been in development ever since KIER was established. KIER is also engaged in the development of fundamental technology for $CO_2$ capture new materials as well as $CO_2$ conversion technology for the production of valuable chemicals and fuels from captured $CO_2$. Currently, the development of the highly active and selective electrocatalysts and the world's most efficient electrochemical $CO_2$ conversion system (catholyte-free $CO_2$ conversion system) are being conducted for the conversion of $CO_2$ into carbon monoxide (syngas), formic acid, and ethylene.

- Development of a new gas-liquid contactor with low pressure drop and large contact area, and new absorbents for CO2 capture (Reboiler heat duty ≤2.0 GJ/tCO2, Feed CO2 concentration 20~25 vol.%, 90% CO2 capture), securing low-cost CO2 capture technology (30% reduction compared to the current level).
- Development of sustainable aviation fuel (e-SAF) production technology from CO2 and H2 (2023-, Integrated process development of RWGS-FTS-Cracking reaction (CO2 10kg/d scale), Development of highly active RWGS catalytic system at 400°C (CO/CO2 yield (RWGS): 52%, Development of highly selective FTS-Cracking tandem catalyst (Selectivity for C8-C16 in HCs: 60%)

Next generation energy management system, one of KIER's main research areas over the years, is to integrate variable renewable energy resources into the power grid. This R&D area is based on the convergence of renewable energy resources, big data information processing, and artificial intelligence technologies. Main areas of research include intelligent control of distributed energy resources, grid integration with variable energy resources, plus demand response, prognosis, and health management of DERs (Distributed Energy Resources), and energy optimization based on the real-time combined data monitoring.

- Development of Real-time Distributed Energy Resource Management System Corresponding to 50% of Variable Renewable Energy (2025-, 100kW Grid-forming Inverter, voltage fluctuation < 4% using derms)
- Development of a prognosis and health management platform for optimal operation of distributed energy resources (2025-, fault detection accuracy >95%)

## 3. International collaboration

KIER places international collaboration at the core of its mission to accelerate clean energy innovation and contribute to global carbon neutrality. In 2026, KIER is strengthening strategic partnerships with leading research institutions while advancing AI-enabled international collaboration intelligence to support evidence-based partner selection, joint R&D planning, and long-term collaboration strategies.

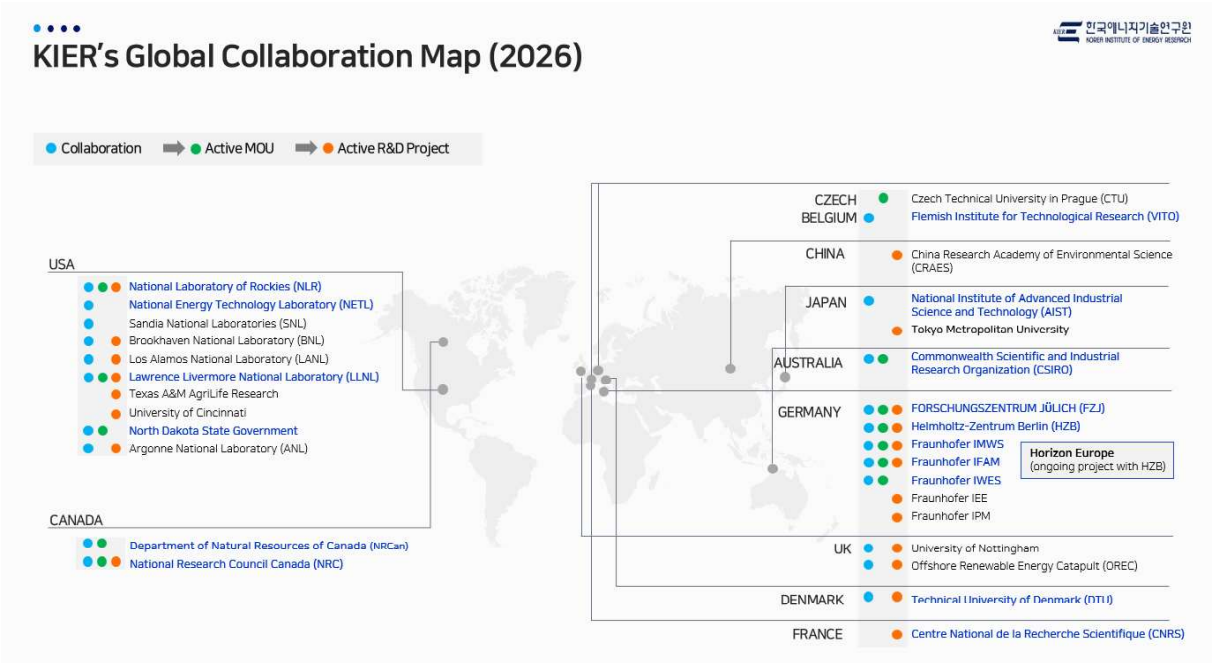
[Strategic Global Research Network Expansion]

- Strengthen strategic collaboration hubs with key international research partners, including NLR, LLNL, and NRC. Building on institutional agreements, joint R&D, and researcher exchange, KIER has deepened institution-level collaboration in strategic areas such as power and grid systems, hydrogen, energy storage, and Energy AI, establishing a foundation for sustained long-term collaboration.
- Focus international collaboration on key partners and strategic research areas, expanding joint R&D with leading research institutions in North America while strengthening collaboration with Fraunhofer and Helmholtz in Europe in key energy technology areas, including renewable energy, hydrogen, and energy storage.
- Actively engage in multilateral platforms and international research programs, including RD20 and Horizon Europe, to expand global research networks and develop opportunities for international joint research. In April 2026, KIER hosted the AI for Energy Workshop, bringing together RD20 member institutions and experts to exchange research insights and explore future collaboration opportunities in AI and energy.

[AI-Enabled International Collaboration Intelligence]

- Structure and analyze international collaboration information, including policies, institutional strategies, agreements, project records, meeting materials, key researchers, and collaboration outcomes.
- Apply AI-based landscape analysis and research mapping to identify leading institutions, key experts, emerging research trends, and potential collaboration opportunities worldwide.
- Develop a data foundation for future AI-enabled search, summarization, question answering, and strategic analysis services, including the possible use of metadata, vector databases, and retrieval-augmented generation technologies.
- Use these analytical capabilities to support the design of collaboration roadmaps, strategic partner selection, and the identification of international R&D opportunities aligned with Korea's energy and carbon neutrality priorities.

Through these initiatives, KIER strengthens its position as a trusted global partner advancing AI-enabled clean energy innovation and shaping the transition toward a sustainable and carbon-neutral energy future.




<Fig. International Collaboration Activities of KIER at 2026>

## 4. Future perspectives (Towards carbon neutrality)

Aligned with Korea's national carbon neutrality and energy transition goals, KIER is advancing five priority R&D pathways toward a sustainable energy future. These pathways reflect KIER's core research strengths in solar energy, clean hydrogen, energy storage, CCUS, and Energy AI, while providing a basis for future international collaboration under RD20.

Area 1. Next-Generation Solar Energy.

· Development of high-efficiency silicon, thin-film, and tandem solar cells, together with advanced module evaluation and building-integrated photovoltaic technologies.

· Application of AI-based solar resource assessment, performance prediction, and system optimization to improve the reliability and deployment of solar energy.

Area 2. Clean Hydrogen Production through Water Electrolysis.

· Development of alkaline, PEM, AEM, and solid oxide electrolysis technologies for efficient and scalable clean hydrogen production.

· Advancement of high-performance materials, cells, and stacks, supported by AI-assisted diagnostics, durability assessment, and lifetime prediction.

Area 3. Advanced Batteries and Energy Storage Systems

· Development of next-generation batteries, including lithium-ion, non-lithium, and flow battery technologies, for grid-scale and long-duration energy storage.

· Advancement of AI-based materials design, battery lifetime prediction, recycling technologies, and storage system optimization to support renewable integration and grid flexibility.

Area 4. Carbon Capture, Utilization, and Sustainable Carbon Management

· Development of low-energy capture materials and processes, electrochemical $CO_2$ conversion, and CCU technologies for industrial decarbonization.

· Development of integrated low-carbon fuel pathways, including sustainable aviation fuel, to support the transition of hard-to-abate sectors.

Area 5. Energy AI and Integrated Energy Systems

· Application of AI, digital twins, and autonomous control to renewable energy integration, distributed energy resource management, grid flexibility, and building and industrial energy efficiency.

· Development of AI-ready energy infrastructure, including data-center energy management, AI-DERMS, grid digital twins, and intelligent energy optimization systems.

Through these five pathways, KIER aims to deliver scalable and reliable technologies that accelerate carbon neutrality, strengthen energy security, and support the global transition toward sustainable and AI-enabled energy systems.

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| KIER/Korea | Renewable Energy | PV | Prosumer-Type Next-Generation Solar Cell Technology for Urban Application<br>2017 - 2031 (R&D span)<br>Current | 1) High-efficiency Perovksite/Si tandem solar cell/ conversion efficiency >35% by 2030<br>2) Flexible CIGS-based multijunction solar cell (efficiency > 32% and power-to-weight >600 W/kg) by 2031 | SeJin Ahn, Ph.D. / KIER | (Domestic) KAIST, DGIST, UNIST, Korea Univ., Hanbat Natl. Univ., Ewha Womans Univ., Hanyang Univ., Chonnam Natl. Univ., KHNP, Seoul Energy Corp., Shinsung E&G, Hanwha Solutions, Hyundae Energy Solutions, etc.<br>(US) NREL, Univ. Delaware, etc.<br>(EU) EPFL, Frounhofer, imec, HZB, EMPA, Julich etc. | - |
| KIER/Korea | | Wind | Offshore-wind farm optimal design for high efficiency<br>2023 - 2030<br>Current | LCOE reduction >10% through next-generation ultra-large blade technologies, AI-based condition monitoring and fault diagnosis technologies, and floating vertical-axis wind turbine (F-VAWT) technologies | Cheol Yoo, Ph. D. / KIER | (Domestic) Doosan Enerbility, Unison Co., Ltd, Samsung Heavy Industries, KRISO, KIMM, Gwangju Institute of Science and Techonology, Ulsan Univ., Joongang Univ., Jeju Univ., | |
| KIER/Korea | | Utilization | **Forecasting and Nowcasting Renewable Energy Variability based on Numerical Weather Predictions with Satellite Imagery**<br>Current<br>2018- 2030 | Downscaling accuracy [Balanced Accuracy] considering new normal climate system, >92% | Chang K. Kim, Ph.D. / KIER | (Domestic) Seoul Natl. Univ., Korea Univ., Chungnma Natl. Univ., Dongkuk Univ., KPX, KMA<br>(US) UCSD CER | |

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| KIER/Korea | Hydrogen and Fuel Cell | Production | 2022 -2029 (R&D span) Current | 1) AEMWE: high efficiency 43 kWh/Kg-H2 @ 1.0 A/cm2<br>2) PEMWE: high durability with low iridium loading <0.1 mg-Ir/cm2<br>3) Development of 100 kW-class stacks and materials for AEM and PEM water electrolyzer | Sang-Kyung Kim, Ph.D. / KIER | | |
| | | | 2024 - 2029 (R&D span) Current | Construction of a 400 mm and a 800 mm (electrode) diameter reference stack and a 250 kW system for R&D on pressurized alkaline water electrolysis stacks and stack components testing as well as stack components development. | Kyoung Soo, Kang, Ph.D./KIER | | National Hydrogen Hub Laboratory (Ministry of Science and ICT in ROK) |
| KIER/Korea | | | Development of Planar Type of SOC Stack Module for Green Hydrogen Production and Distributed Power Generation<br>2019 - 2029 (R&D span) Current | 10kW SOFC module<br>Durable SOEC module<br>(degradation rate < 0.5%/kh) | Ji Haeng Yu, Ph.D. / KIER | (Domestic) Bumhan Fuel Cell, SAMSUNG ELECTRO-MECHANICS, Dentium<br>(Foreign) DTU, DLR, Fraunhofer-IKTS | |
| KIER/Korea | | | Development of clean hydrogen manufacuring by high-temperature electrolysis<br>2024 - 2029 (R&D span) Current | Development of Materials, Cells, Stacks, and 6Nm3/h_H2 Class Systems for Enhanced Durability and Efficiency of Intermediate-Temperature (700°C) SOECs | Sun-Dong Kim / KIER | | National Hydrogen Hub Laboratory (Ministry of Science and ICT in ROK) |
| KIER/Korea | | Utilization | Development of low-cost high-performance core materials for building application fuel cells<br>2022 - 2026 (R&D span) Current | Development of hydrocarbon electrolyte membranes, non-precious metal catalysts, and a 25kW fuel cell stack and system for power generation, along with a real-time fault diagnosis tool for fuel cell stacks | Byungchan Bae, Ph.D. / KIER | (Domestic) Hyundai Motors, S-fuel cell, Hyundai Oil Bank, W-Scope, Koreans RTX, KIST | |
| KIER/Korea | | Utilization | Reliability evaluation of fresh and re-used PEMFC stacks for vehicle and stationary applications<br>2019-2026 (PEMFC reliability evaluation) Current | 100 kW PEMFC stack performance and reliability evaluation (2019-2024) & Long-term cyclelife evaluation of reused PEMFC stack (2021-2026) | Chi-Young Jung, Ph.D. / KIER | (Domestic) Gwangju Institute of Science and Techonology, Ewha Womans University, Hanyang University, Kunsan National University, Korea Automotive Technology Institute, Korea construction equipment technology institute | |

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| KIER/Korea | | | Development of Sustainable Aviation Fuel (e-SAF) Production Technology from Carbon Dioxide and Hydrogen<br>Current<br>2023~ | Development and demonstration of RWGS-FTS-Cracking integrated process for CO2-derived sustainable aviation fuel (e-SAF) production (CO2 10kg/d scale, CO/CO2 yield (RWGS): 52% (T<400°C), Selectivity for C8-C16 in HCs (FTS): 60% | Dr. Min Hye Youn / KIER | | |

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| KIER/Korea | DER | | Development of Real-time Distributed Energy Resource Management System Corresponding to 50% of Variable Renewable Energy<br>2025 - 2029 (R&D span) | 1) Advanced Inverter (Grid-forming Inverter 100kW)<br>2) Edge-DERMS platform (Voltage fluctuation < 4%) | Jongbok Baek, Ph.D. / KIER | (Domestic) Seoul National University | |
| KIER/Korea | DER | | Development of Prognosis and Health Management for Optimal Operation of Distributed Energy Resources<br>2025 - 2029 (R&D span) | Fault Detection Accuracy >95% | Kuk Yeol Bae, Ph.D. / KIER | (Domestic) POSTECH | |

## Profile of the Acting President of KIER

Dr. Jun-Sik Cho
Korea Institute of Energy Research (KIER)

Dr. Jun-Sik Cho has served as Acting President of the Korea Institute of Energy Research (KIER) since August 2026 and is Director of its Renewable Energy Institute. He also serves as a Representative Professor at the University of Science and Technology (UST) and as Vice President of the Korea Photovoltaic Society.

With nearly two decades of experience in photovoltaics and renewable energy R&D at KIER, Dr. Cho has built extensive expertise in solar energy research, organizational leadership, and national energy R&D planning and management. Since joining KIER in 2007, he has held key leadership positions in photovoltaic research, including Director of the Photovoltaics Research Division. From 2022 to 2024, he served as Director of the Energy and Environment Division at the National Research Foundation of Korea (NRF), overseeing national R&D programs in the energy and environmental fields. In 2025, he served as Director of KIER's R&D Planning and Coordination Office before being appointed Director of the Renewable Energy Institute in October 2025.

Dr. Cho has also contributed broadly to the academic and professional communities in the photovoltaic field. He has served as a faculty member at UST since 2009 and as a board member and Vice President of the Korea Photovoltaic Society since 2016.

Dr. Cho received his B.S., M.S., and Ph.D. degrees from the Department of Ceramic Engineering at Yonsei University, Korea, earning his Ph.D. in 2000.

# Saudi Arabia

KACARE

King Abdullah City for Atomic and Renewable Energy

**The 8th RD20 conference, Oct. 19, 2026**
**(Activity Summary Template)**

**Title (Times New Roman or Times-Roman 12 pt)**

Eng. Hamad Mudij
King Abdullah City for Atomic and Renewable Energy

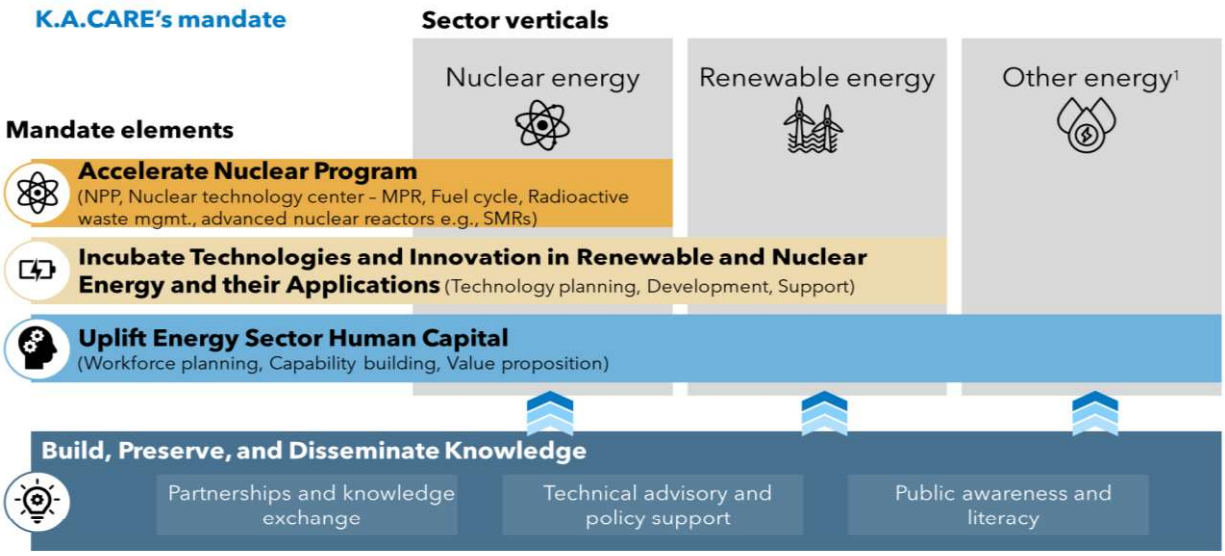
## 1. Introduction

Please describe the background of research and development of clean energy technologies at your institute based on energy policy in your country. (Times New Roman or Times-Roman 12 pt)

Saudi Arabia has placed research, development, and innovation (RDI) at the center of its long-term economic and technological ambitions, with the aim of becoming a global leader in RDI and reaching annual investment equivalent to 2.5% of GDP by 2040. In the energy sector, rising energy demand, the expansion of renewable energy under Vision 2030, and the national emphasis on technology deployment and localization have made clean energy technology development increasingly important.

In parallel, the Kingdom is accelerating the deployment of renewable energy, targeting approximately 50% of power generation from renewable sources by 2030. Achieving these ambitions requires not only large-scale deployment, but also continued R&D and innovation to develop, adapt, validate, and localize technologies that address national needs and perform effectively under Saudi Arabia's environmental and operational conditions.

Within this context, King Abdullah City for Atomic and Renewable Energy (K.A.CARE) plays an active role in advancing research, development, and innovation in renewable energy technologies. K.A.CARE works with national universities, research institutions, industry, and international partners to identify promising technologies, support their development, and advance their technical and commercial readiness.



Building on this role, K.A.CARE's technology development activities span the innovation cycle, from applied R&D and prototype development to testing, validation, demonstration, and preparation for deployment and commercialization. Key areas include advanced photovoltaic technologies, energy storage, hydrogen, wind energy, and other emerging renewable energy technologies. Particular emphasis is placed on technologies with strong potential for application and localization in the Kingdom.

K.A.CARE also seeks to bridge the gap between research and market application by supporting locally developed technologies and the adaptation and validation of promising international technologies under Saudi conditions. Through collaborative R&D programs and technology partnerships, these efforts aim to accelerate technology maturation, enable knowledge transfer, strengthen local capabilities, and create pathways toward commercialization and private-sector participation. These activities are complemented by K.A.CARE's renewable energy resource measurement and data capabilities, which provide reliable solar and wind resource information to support research, technology assessment, validation, and deployment.

## 2. R&D activities related to clean energy technology for carbon neutrality

Please review and describe the research and development (R&D) status of clean energy technologies for carbon neutrality at your institute.

King Abdullah City for Atomic and Renewable Energy (K.A.CARE) seeks to advance Saudi Arabia's transition toward carbon neutrality by focusing on the development and localization of clean energy technologies. Its efforts cover both nuclear and renewable energy, aligned with Vision 2030 and the Kingdom's Net Zero 2060 commitment.

K.A.CARE's work includes:

- **Nuclear Energy:** Establishing safe and economically viable civil nuclear infrastructure to complement renewables and diversify the energy mix.
- **Renewable Energy**: Developing and advancing renewable energy technologies through R&D, technology assessment, prototype development, testing, validation, and demonstration, with the aim of improving their technical and commercial readiness and accelerating their transition toward deployment, commercialization, and localization. Key technology areas include:
    - Efficient and advanced materials
    - Photovoltaics (PV)
    - Concentrated Solar Power (CSP)
    - Wind turbine technologies
    - Renewable hydrogen production technologies
    - Energy storage systems and applications
    - Smart grid solutions
    - Application of emerging digital solutions (AI, IoT, digital twins) to enable renewable integration.

## 3. Specific research activities

Please review and describe the R&D status of specific technologies.

*Related programs/projects conducted by the institute*

- Project title and topic (20XX-20YY)
- Project title and topic (20XX-20YY)
- ……

A primary strategic objective for King Abdullah City for Atomic and Renewable Energy (K.A.CARE) is "Commercially feasible, locally developed and deployed technologies and applications." To achieve this, K.A. CARE supports universities and R&D entities with emerging technologies in renewable energy, mainly through direct funding, supervision, and guidance below are some examples of projects under K.A. CARE's technology localization initiative:

- Prototype development for renewable energy technologies – King Saud University. Design and test an innovative system for a sand particle concentrated solar power tower. (2022-2024)
- Prototype development for renewable energy technologies – Imam Abdulrahman bin Faisal University. Design and test an enhanced concentrated photovoltaic module. (2022-2024)
- Prototype development for renewable energy technologies – King Abdullah University of Science and Technology. Scale-up perovskite silicon tandem solar cell. (2024-2025)
- Development of an integrated water desalination system using solar thermal energy and forward osmosis – The Water Technologies Innovation Institute and Research Advancements. Design and implement an integrated pilot system relying on concentrated solar power as a heat source, along with forward osmosis technology (2023-2025).
- Demonstrate an energy management system integrating hybrid solar and wind generation with battery storage on the distribution grid – NEDO, Saudi Energy (SE) and OCG Japan. Energy Management System Demonstration for Hybrid Renewable Energy and Battery Storage at Huraymila, Saudi Arabia. (2025-2029)

## 4. International collaboration

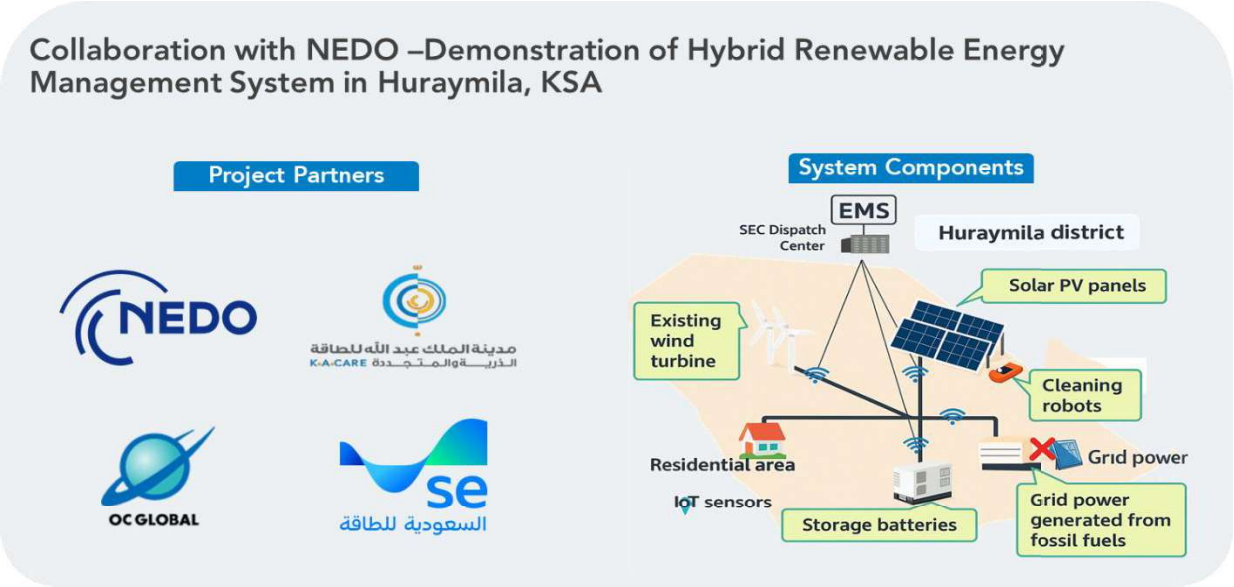
Please describe current status of international joint R&D activities and alliance/networking development at your institute with any countries, including comprehensive MOUs, joint projects, researcher exchanges, joint workshops and seminars.

Please describe your experience and concerns regarding the actual international joint project.

K.A.CARE is actively expanding its international R&D partnerships and networks to support renewable energy technology development, validation, localization, and knowledge exchange. These collaborations bring together international research and technology partners with Saudi universities, research institutions, and industry to develop technical collaboration opportunities and joint R&D projects.

Building on these efforts, K.A.CARE engages with leading organizations across Japan, Germany, Singapore, China, the United Kingdom, and other countries, as well as through multilateral platforms such as RD20. These engagements cover next-generation photovoltaics, energy storage, clean hydrogen, smart grids, emerging digital solutions, and renewable energy technology validation. Several collaborations have already progressed from initial engagement to technical scoping and project development.

Examples include collaboration with NEDO in Japan on the ongoing Huraymila demonstration project, integrating solar and wind generation with battery storage and an energy management system.




Other international collaboration activities include:

- MOUs and Joint R&D projects: K.A.CARE is partnering with leading international research institutes (e.g. NEDO, KAERI) to co-develop and localize technologies in different relevant fields (renewable energy, atomic energy, energy storage, ...etc.).
- Human capacities building in the energy field: to ensure continuous expertise transfer and sustained development of Saudi capabilities, K.A.CARE is implementing year-round programs, including joint workshops, technical seminar, exhibitions, and advanced training programs, in collaboration with leading international partners and prestigious universities (e.g. IAEA, IRENA, MIT, Texas A&M …etc.).
- Cooperation and Exchange of information, Data and Expertise: K.A.CARE is cooperating, exchanging knowledge and expertise, and developing resources and knowledge with partners by promoting optimal use of resources and infrastructure.
- Innovation and Entrepreneurship: in cooperation with its partners, K.A.CARE is launching programs and initiatives to support future entrepreneurs and startup companies and provide an inspiring sustainable environment to stimulate creativity and innovation in areas of open innovation and creative design.

## 5. Future perspectives (towards carbon neutrality)

Please describe future challenges in clean energy technologies, and the expected international collaborative framework at your institute.

Saudi Arabia has set ambitious energy transition objectives, including achieving net-zero emissions by 2060 and targeting approximately 50% of power generation from renewable energy by 2030. This rapid deployment creates a growing need for continued R&D and innovation to improve the performance, reliability, scalability, and cost competitiveness of clean energy technologies and accelerate their transition from development to deployment and localization. Key challenges also include advancing technology readiness through testing, validation, and demonstration, ensuring performance under Saudi climatic and operating conditions, and developing enabling technologies such as energy storage and grid integration.

Looking ahead, K.A.CARE's international collaborative framework will increasingly focus on project-oriented and technology-focused partnerships with leading research institutions, universities, technology developers, and industry. Collaboration will include joint R&D and technology development, testing and validation, demonstration projects, researcher and knowledge exchange, and specialized technical workshops, while connecting international expertise with Saudi research and industrial capabilities to accelerate technology development, commercialization, and localization in the Kingdom.

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| KACARE | CSP | Particle Based System | Prototype development for renewable energy technologies . Design and test an innovative system for a particle based concentrated solar power tower. (2022-2024) | Developed a long duration high temperature thermal energy storage bin and successfully operated an innovative practical lift system | Dr. Hany Al-Ansary / King Saud University | King Saudi University | N/A |
| KACARE | Photovoltaics | Concentrated Photovoltaics | Prototype development for renewable energy technologies . Design and test an enhanced concentrated photovoltaic module. (2022-2024) | Developed an enhanced concentrated photovoltaic module which succeeded in reducing the operating temperature of cells. | Dr. Fahad Al-Amri / Imam Abdulrahman bin Faisal University | Imam Abdulrahman bin Faisal University | https://www.linkedin.com/posts/king-abdullah-city-for-atomic-and-renewable-energy-ka-care %D9%85%D8%AF%D9%8A%D9%86%D8%A9-%D8%A7%D9%84%D9%85%D9%84%D9%83-%D8%B9%D8%A8%D8%AF%D8%A7%D9%84%D9%84%D9%87-%D9%84%D9%84%D8%B7%D8%A7%D9%82%D8%A9-%D8%A7%D9%84%D8%B0%D8%B1%D9%8A%D8%A9-%D9%88%D8%A7%D9%84%D9%85%D8%AA%D8%AC%D8%AF%D8%AF%D8%A9-activity-7270514873464197120-sSPQ?utm_source=share&utm_medium=member_ios&rcm=ACoAACu0bwQBabJZwcK-WcKWfAwixDdCcnHnolc |
| KACARE | Photovoltaics | Advanced Photovoltaics | Prototype development for renewable energy technologies. Scale-up perovskite silicon tandem cell . (2024-2025) | Scale-up of a perovskite silicon tandem solar cell to a 100 cm2 mini-module | Prof. Stefaan De Wolf / King Abdullah University of Science and Technology | King Abdullah University of Science and Technology | N/A |
| KACARE | Renewable Desalination | Solar Thermal Desalination | Development of an integrated water desalination system using solar thermal energy and forward osmosis – The Water Technologies Innovation Institute and Research Advancements. Design and implement an integrated pilot system relying on concentrated solar power as a heat source, along with forward osmosis technology (2023-2025). | Assess the compatability and integration between Forword osmosis and Concentrated solar thermal technologies | n/a | The Water Technologies Innovation Institute and Research Advancements | https://www.energy.gov.sa/ar/mediacenter/news/Pages/NEWAS---july-2025.aspx |
| KACARE | Renewable Energy | Energy Management Systems | Demonstrate an energy management system integrating hybrid solar and wind generation with battery storage on the distribution grid. (2025-2029) | Energy Management System Demonstration for Hybrid Renewable Energy and Battery Storage at Huraymila, Saudi Arabia | n/a | NEDO, Saudi Energy and OCG Japan. | N/A |

(Please attach the leader's profile (with photo), if you have not provided us separately as per our request. For some participants, we have prepared draft profiles based on the materials submitted in previous years. We would appreciate it if you could review and revise the content as needed.)

Eng. Hamad Mudij is Senior Vice President of Renewable Energy Technology Development and Innovation sector at King Abdullah City for Atomic and Renewable Energy (K.A.CARE). He is also a board member of the Saudi Energy Efficiency Center (SEEC) and a member of the National Committee for the Clean Development Mechanism.

Before joining K.A.CARE, he held several positions at SABIC and its affiliates, the most recent of which was Senior Manager of Portfolio Management at SABIC Investment and Local Content Development Company (Nusaned Investment). Prior to that, he held various roles in the Technology and Innovation and Corporate finance units at SABIC.

He holds an MBA from King Saud University, a Master's degree in Chemical Engineering from Stanford University, and a Bachelor's degree in Chemical Engineering from King Saud University. He is also a licensed Professional Engineer (PE), a Chartered Financial Analyst (CFA), and has completed several executive programs and professional certifications.

# Japan

NIMS

National Institute for Materials Science

**The 8th RD20 conference, Oct. 19-23, 2026**

# Carbon Neutral Initiatives at NIMS
# -Materials science research toward "Carbon Neutrality in 2050"-

Kazuhiro Hono
National Institute for Materials Science (NIMS),
Japan

## 1. Introduction

Toward the goal of achieving carbon neutrality by 2050, NIMS focuses on two main areas- (1) materials research targeting the development of all types of secondary batteries (2) materials essential for a hydrogen society. The development of advanced energy storage technologies and hydrogen-based solutions is crucial to meeting the global demand for clean energy. Secondary batteries, such as all-solid-state lithium-ion and magnesium-ion batteries, are expected to play a central role in stabilizing renewable energy sources and powering next-generation electric vehicles. At the same time, hydrogen technologies, including efficient hydrogen production, storage, and liquefaction, will form the backbone of a sustainable energy infrastructure. By advancing materials science in these areas, NIMS aims to overcome the technical challenges that hinder the widespread adoption of these technologies and accelerate the transition to a carbon-neutral society. Through cutting-edge research and international collaboration, NIMS is laying the groundwork for the future of clean energy, creating innovative solutions that will lead both Japan and the world to a sustainable and energy-efficient future.

## 2. R&D activities related to clean energy technology for carbon neutrality

Maximizing the use of renewable energy is a prerequisite for achieving carbon neutrality by 2050, and closely aligns as well with Society 5.0-Japan's vision for a human-centered, technology-enabled society. To this end our activities focus on two core elements, electrification and hydrogen. On both fronts we strive to develop the relevant energy and environmental materials, together with enabling technologies that will help thrust this effort forward.

With regard to electrification, we target materials which will impact future energy storage and conversion, including those related to advanced batteries, all-solid-state batteries, thermoelectric power generation, and solar cells. Thermoelectric materials that are free of rare or toxic elements, and stable low-cost perovskite solar cells are important examples. We place special emphasis on integrating the progress in these areas into practical devices and other uses. The efforts described above align with the urgent demand to meet a wide range of necessities—from IoT devices to electric vehicles and stationary energy storage.

Our focus regarding hydrogen is driven by the need to promote the widespread adoption of a hydrogen-based society. Much of our effort centers around the liquefaction technology required for hydrogen storage and transportation, which are indispensable for establishing advanced magnetic refrigeration systems. Specifically, we are aiming to (1) establish technologies relevant to magnetic energy conversion, and (2) develop superconducting materials which operate in the low to intermediate temperature range. Other avenues of our engagement include developing catalyst materials for hydrogen production, pursuing the improvement on the efficiency of water electrolysis, and advancing technologies for controlling hydrogen materials.

Accelerating the development of energy and environmental materials detailed above also calls for a significant improvement on the accuracy and efficiency of the technologies involved: these encompass hydrogen materials measurements, advanced operando measurements, electrochemical analysis, and computational and data science. Progress in each technology will

help us to establish guiding principles for controlling processes common to our targeted areas, such as electrochemical reactions and phase transitions. They are also imperative from the viewpoint of the advancement of Materials DX (data transformation), e.g. the enhancement of the efficiency of smart laboratories, which heavily rely on the integration of these technologies.

Having outlined in general terms the current status of our R&D activities, we turn to specific progresses and achievements for fiscal year 2025.

Regarding batteries, our investigation on sintering aids and reaction sintering mechanisms contributed important advances to low-temperature sintering technologies for solid electrolytes, which we are pursuing with the objective of realizing an oxide-based all-solid-state batteries. Our new findings on this front, which demonstrate that sinterability depends on the elemental substitution site, adds further information beyond our previous identification of the low-temperature sintering mechanism involving the formation of low-melting-point phases. In a separate study, we developed joining technologies with non-oxide electrodes, and in parallel conducted studies on the ion-conduction mechanisms in the bulk and at interfaces of solid electrolytes. Together they lead to a room-temperature in-situ bonding of graphite particles, which was achieved by a coating with a silicon thin film. In yet another study, our research team successfully achieved fast Li-ion conduction at lattice-matched interfaces, leading them to establish design guidelines for all-solid-state batteries [D. Ito, et al., *Nature Commun.*, 16, 7372 (2025)]. In another line of investigation, operando SIMS visualization of Li-ion transport and reaction distributions provided insights into reaction bottlenecks [S. Xing, et al., *ACS Energy Lett.*, 11, 1889 (2026)].

Numerous outcomes on liquid-electrolyte rechargeable batteries followed from our pursuit for cathode materials and electrolytes with enhanced functionality. They include improved cycle life of high-capacity, low-cost $MnO_2$ cathodes for Li-ion batteries [C. Lin, et al., *J. Power Sources*, 648, 237417 (2025)]; application of a hydrogen-bonded polymer gel electrolyte to an artificial SEI [H. Wang, et al., *J. Power Sources*, 641, 236801 (2025)]; the achievement of high power in Li-air batteries using an amide-based electrolyte [A. Nomura, et al., *Energy Technology*, 13, 2500556 (2025)]; the proposal of a high-performance electrolyte for Mg batteries based on a new design concept to which we coined the term “mixed-coordination electrolytes” [Japanese Patent Application No. 2026-015597]. In addition, a comprehensive investigation was conducted on the correlation between electrolyte composition and the characteristics of Mg batteries, based on which an evaluation protocol for activity diagnostics was proposed[T. Mandai, *ChemSusChem*, 18, e202500418 (2025)].

Turning to solar cells, both lead-based and lead-free perovskite materials were developed, as well as new fabrication processes for tandem structures. For lead-free perovskite solar cells, a new hole-transport layer (HTL) material was developed to replace conventional PEDOT:PSS, achieving retention of 90% of the initial efficiency after more than 1,000 hours of continuous power generation. In addition, a power conversion efficiency exceeding 10% was achieved in a 1.0 cm × 1.0 cm device [J. Ferdous, et al., *Solar RRL*, 9, 2500047 (2025)].

In the hydrogen field, we assessed the relevant magnetic refrigeration materials and undertook the construction of a prototype large-scale magnetic refrigerator, resulting in the completion of a large-scale prototype. We also fabricated and operated a high-efficiency heat exchanger and a superconducting magnet, both key components of the magnetic refrigerator, achieving a thermodynamic efficiency of 60% for hydrogen liquefaction [K. Kamiya, et al., *Cryogenics*, 152, 104205 (2025)].

Related efforts included developing superconducting magnets to be used for magnetic refrigeration, and superconducting devices operating in the intermediate-temperature range

which includes hydrogen temperatures, along with associated technologies. This culminated e.g. in superconducting joints of rare-earth-based high-temperature superconducting wires that were found to exhibit a critical current with an angular dependence on the applied magnetic field comparable to that of the wires themselves over a wide temperature range, again including hydrogen temperatures [Y. Takeda, et al., *Supercond. Sci. Technol.*, 38, 125003 (2025)]. We also developed fundamental and supporting technologies for ultrafine superconducting wires and bundled cables capable of utilizing the cold energy of liquid hydrogen. These efforts produced important results confirming that ultrafine $MgB_2$ stranded wires exhibit extremely low AC losses [J. Kováč, et al., *Supercond. Sci. Technol.*, 38, 055028 (2025)].

With regard to hydrogen production, we developed highly active, durable catalyst materials for clean hydrogen production and carbon recycling. Key achievements include the discovery of a novel metal-hydride electrocatalyst capable of producing formic acid with 90% selectivity [patent application in preparation], and the development of a new elastic recoil detection analysis system for determining the location and composition of hydrogen on electrode surfaces [T. Suzuki, et al., *Surf. Sci.*, 769, 122967 (2026)]. We also found that carbon produced as a by-product of hydrogen production exhibits high hydrophilicity, enabling applications in aqueous-solution purification and as a bridging material between oxide particles [Japanese Patent Application No. 2026-064463].

In addition to the above, developing techniques for analyzing reaction mechanisms in water-electrolysis catalysts lead to significant findings demonstrating that specific elements interact synergistically to enhance catalytic performance [M. Wang, et al., *J. Phys. Chem. C*, 130, 931 (2026)].

Finally, as cross-cutting technologies supporting the aforementioned research areas, we achieved a further enhancement of the functionality of an automated electrochemical experimentation system by diversifying measurement methods and improving data analysis techniques. This work resulted in materials design guidelines for electrolytes for sodium-ion batteries [M. Ono, et al., *ACS Applied Energy Mater.*, 9, 1405 (2026)].

We also developed measurement technologies for multiscale observation of physicochemical phenomena in batteries and applied them to test cells. This led us to (1) elucidate the spatiotemporal propagation mechanism of lithium insertion reactions in silicon-based anodes in all-solid-state batteries and (2) establish guidelines for achieving high cycling performance [T. Iwama, et al., *J. Phys. Chem. Lett.*, 17, 2181 (2026); R. Putra, et al., *ACS Energy Lett.*, 10, 6549 (2025)]. Furthermore, we expanded the capabilities of electron microscopy sample holders and cells for in-situ and operando observations, successfully achieving high-resolution imaging of crystals in liquids [M. Takeguchi, et al., *Micron*, 198, 103888 (2025)]. As a related analytical technique, we also successfully extracted defect structures from videos capturing structural changes in graphene [R. Eguchi, et al., *APL Materials*, 14, 011108 (2026)].

In addition, we developed computational techniques for high-throughput materials exploration, sampling calculations, and machine-learning force fields, and applied them to the analysis of battery electrolytes. Through such efforts we identified nitrogen-doped $Li_6Zr_2O_7$ as a potential solid electrolyte with an ionic conductivity of $10^{-4}$ S $cm^{-1}$ [R. Jalem, et al., *Small Methods*, 9, e01289 (2025)].

We also investigated the microscopic mechanisms of battery and catalyst systems using first-principles calculations and related approaches. This resulted in an elucidation of ion-diffusion mechanisms in a variety of next-generation battery materials, and enabled us to establish important guidelines for designing new materials [B. Gao, et al., *J. Mater. Chem. A*, 13, 30370 (2025); D. Ito, et al., *J. Am. Chem. Soc.*, 147, 25441 (2025)].

## 3. Specific research activities

- NIMS Battery Research Platform, research facilities for next-generation battery R&D covering everything from battery cell assembly to materials analysis（2014–）
- Innovative hydrogen liquefaction technologies desired in future society / Development of advanced hydrogen liquefaction system by using magnetic refrigeration technology (JST, 2018–2027)
- Materealize Project / Establishment of process science for realizing all-solid-state batteries (MEXT, 2019–2026)
- Materials Open Platform for All Solid-State Batteries / Development of oxide-type all-solid-state batteries (2020–2025)
- The program on open innovation platform for industry-academia co-creation (COI-NEXT), Center for Advanced Battery Collaboration (JST, 2020–2030)
- GteX (Green Technologies of Excellence) / Operation of research infrastructure and database and development of in situ/operando characterization techniques and AI-driven data analysis tools for battery research and development (JST, Phase 1: 2023–2028).
- Developing a foundation for material evaluations to support R&D on liquefied hydrogen-related equipment (NEDO, 2021–2025)
- K program/ Development of oxide-based solid-state batteries applicable to isolated and extreme environments (JST, 2025-2030)

## 4. International collaboration

NIMS promotes strategic international collaboration in order to address global scientific and technological challenges. Collaborative partners are selected based on complementary research strengths and shared strategic interests. Current MOU partners at the departmental level include the University of New South Wales (Australia), Chiang Mai University (Thailand), Forschungszentrum Jülich (Germany), the University of Münster (Germany), and Florida State University (USA), while Argonne National Laboratory (USA) is an institutional-level MOU partner.

## 5. Future perspectives (towards carbon neutrality)

Materials innovation is essential for achieving carbon neutrality, as it holds the key to enhancing the efficiency of energy generation, storage, and utilization. NIMS will continue to contribute to this goal through world-leading materials research.

During its current medium- to long-term planning period, NIMS is strategically promoting research and development in two priority areas with the aim of achieving carbon neutrality: advanced battery materials and hydrogen-related materials. NIMS will continue to push forward the research in these key areas by leveraging various research funding sources and strengthening strategic domestic and international research collaborations.

| Institute/Country | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| NIMS/Japan | Battery | | We aim to establish a diverse range of battery systems ranging from large- to ultra-compact scale that are essential for achieving carbon neutrality and Society 5.0-Japan's vision for a human-centered, technology-enabled society. To this end we will develop materials and enabling technologies that offer high energy density, enhanced reliability, and advantages in terms of resource availability.<br>[2023-2030]<br>2023 - 2030 (R&D span)<br>Current | ▪Development of next-generation battery materials, including advanced rechargeable batteries and all-solid-state batteries<br>▪Development of thermoelectric power generation materials free of rare and toxic elements<br>▪Development of stable and low-cost perovskite solar cells | Research Center for Energy and Environmental Materials (GREEN) | | https://www.nims.go.jp/nims-green/ |
| NIMS/Japan | Hydrogen | | Through the development of novel magnetocaloric materials and magnetic refrigeration systems, we will construct a prototype of a high-efficiency magnetic refrigeration system for hydrogen liquefaction. We will also develop materials and enabling technologies for catalysts for the production of green hydrogen from water and turquoise hydrogen from fossil-fuel resources.<br>[2023-2030]<br>2023- 2030 (R&D span) | ▪Realize an efficient hydrogen production via high-performance catalysts and improved water electrolysis efficiency<br>▪Establish low-temperature hydrogen liquefaction technologies centered on magnetic refrigeration for efficient hydrogen transportation<br>▪Develop magnetic energy conversion materials and superconducting materials for the above applications | Research Center for Energy and Environmental Materials (GREEN) | | https://www.nims.go.jp/nims-green/ |
| NIMS/Japan | Core Technologies for Battery/Hydrogen | | We will develop foundational technologies for high-throughput materials exploration centered on autonomous experimentation to establish synthesis–characterization–prediction loops, a suite of laboratory measurement techniques for multiscale analysis, and advanced computational and data science technologies for battery and catalyst analysis, thereby enabling an increased sophisticated materials and reaction design.<br>[2023-2030]<br>2023- 2030 (R&D span) | ▪Advancement of cutting-edge measurement, computational, and data science technologies to understand/control the synthesis and functionality of target materials<br>▪Develop materials technologies contributing to digital transformation in materials R&D, including smart laboratories integrating synthesis, measurement, computation, and data science | Research Center for Energy and Environmental Materials (GREEN) | | https://www.nims.go.jp/nims-green/ |

## Kazuhiro Hono, PhD.

**Kazuhiro Hono** is President of Japan's National Institute for Materials Science (NIMS). He received his B.S. and M.S. degrees in materials science and engineering from Tohoku University, and his Ph.D. from Pennsylvania State University in 1988. After a postdoctoral fellowship at Carnegie Mellon University, he joined the Institute for Materials Research at Tohoku University before moving to NIMS in 1995. During his 27-year research career at NIMS, he served as Director of the Research Center for Magnetic and Spintronic Materials, NIMS Fellow, and Executive Vice President, before becoming President in 2022.

Dr. Hono's research focuses on microstructure–property relationships in metallic materials, using atom probe tomography (APT) and transmission electron microscopy (TEM), with particular emphasis on rare-earth permanent magnets, nanocrystalline soft magnets, FePt-based heat-assisted magnetic recording media, and spintronic materials. He was also a professor at the University of Tsukuba until 2022, supervising 34 Ph.D. students. He has received numerous awards for his achievements in materials science and engineering, including the TMS Fellow Award, the Acta Materialia Gold Medal, the Medal with Purple Ribbon, and the Japan Institute of Metals and Materials Gold Medal Award.

# Japan

AIST

National Institute of
Advanced Industrial Science and Technology

# Current Status and Future Perspectives (“Now and Future”) of Clean Energy Technologies in AIST

MATSUOKA Koichi
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## 1. Introduction

Japan has a long history of research and development in energy technologies to enhance energy security and ensure a stable energy supply. For example, Japan's long-term Sunshine Project to develop new energy technologies, including renewable energy technologies was launched in 1974, and the long-term Moonlight Project to develop energy conservation technologies began in 1978. These projects achieved their common objective of world class R&D in clean and renewable energy technologies and now serve as a solid foundation of today’s society that is moving toward a carbon-neutral society based on renewable energy.

In response to recent global environmental challenges and changes in energy policy following the accident at the Fukushima Daiichi Nuclear Power Station in 2011, research and development at the national level have accelerated through collaboration among academic, government, and industry. The “Seventh Strategic Energy Plan” published in 2025 outlines Japan's energy policy toward 2050, with the goal of achieving a stable energy supply, economic growth, and decarbonization simultaneously. Reflecting the growing global momentum toward decarbonization since the adoption of the Paris Agreement, the Japanese Government declared its commitment to achieving carbon neutrality by 2050 in October 2020, aiming to create a positive cycle of economic growth and environmental protection. To that end, AIST explores and pursues all possible options which contribute to reducing greenhouse gas emissions and environmental impacts while ensuring a stable supply of energy resources.

## 2. R&D activities related to clean energy technology for carbon neutrality

To promote green innovation, AIST is developing technologies for expanded utilization of renewable and other low-carbon energy sources, high-density energy storage, highly efficient conversion and utilization of energy, effective utilization of

energy resources, and assessment and mitigation of environmental risks.

AIST has established two research centers to advance green innovation: the Renewable Energy Advanced Research Center (READ) and the Global Zero Emission Research Center (GZR). READ focuses on renewable energy technologies such as solar, wind, geothermal, energy management for smart grids, and hydrogen-based energy storage and carrier technologies, from an application-oriented point of view. GZR addresses fundamental technologies thermoelectric energy conversion, hydrogen-related materials, carbon utilization, artificial photosynthesis and assessments for decarbonization. Both research centers will play a vital role as global open innovation platforms for decarbonization, and ultimately for a zero-emission society, through collaboration with academic and industrial partners all over the world.

## 3. Specific research activities

The following are examples of AIST's state-of-the-art research activities in clean energy technologies.

- Energy management system with battery storage

  A new energy management system (EMS) is required in addition to the individual component technologies to achieve mass introduction of renewable energy into electrical systems. We are developing optimization technologies for the operation of distributed energy resources (DERs) such as solar photovoltaics and wind power systems, microgrid technology, and for the integration of multiple DERs with energy storage systems. Development of individual technologies, including battery energy storage, is also underway.

- Hydrogen / Ammonia

  Hydrogen serves as a storage medium for surplus renewable electricity and helps maximize the use of variable renewable energy. Renewable-derived hydrogen also supports decarbonization in sectors where electrification is difficult. To advance a hydrogen society, AIST is developing performance evaluation technologies for water electrolyzers. Our work focuses on assessing stack and system efficiency and durability under practical operating conditions, including fluctuating power input and high-pressure operation. Hydrogen can be transported and stored by being converted to hydrogen energy carriers such as MCH, ammonia, and formic acid. Research on ammonia synthesis and utilization has been conducted at AIST and demonstrated a continuous system encompassing ammonia synthesis from renewable energy and subsequent power generation.

- PV

  In Japan, where available land is limited, installing photovoltaic panels on factory roofs with low load capacity or on building walls is an important option for expanding solar power deployment. This requires next-generation solar cells that are lightweight, flexible enough for curved surfaces, and offering performance comparable to silicon solar cells. AIST is developing core technologies to advance the practical application of perovskite solar cells. To promote their commercialization, we are committed to overcoming technical challenges through research and development, from analytical evaluation to manufacturing.
- CCUS

  AIST established a new Integrated Research Center for CCUS Implementation in April 2025. The center integrates key technologies ranging from $CO_2$ capture and separation to utilization, storage, life-cycle assessment (LCA), and techno-economic assessment (TEA). Through bench-scale and pilot-scale demonstrations, and by demonstrating the effectiveness of CCUS systems, the center aims to design and implement a highly efficient CCUS value chain in society. Research and development on next-generation FT reaction and integrated production process for synthetic liquid fuels has been conducted aiming to efficient production of drop-in liquid fuels such as gasoline and diesel from $CO_2$ and renewable hydrogen. In addition, a bench-scale integrated plant using co-electrolysis with Solid Oxide Electrolysis Cells (SOECs) is being demonstrated.
- Others: Thermoelectrics

  Since about 60% of primary energy is lost as waste heat, research and development on thermoelectric conversion and thermal management technologies for waste heat recovery is crucial. We are contributing to cutting-edge research in all aspects of thermoelectric technology, including its practical application.

## 4. International collaboration

### 4-1 Status of international collaboration

AIST has concluded comprehensive MOUs with the following RD20 members in the field of energy and environment as of 14 July 2026: Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia), National Research Council of Canada (NRC, Canada), Joint Research Centre of the European Commission (JRC, EU),

Centre National de la Recherche Scientifique (CNRS, France), Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. (FhG, Germany), and National Laboratory of the Rockies (NLR, U.S.A.).

The following are representative examples of recent collaborative activities.

- International collaboration on CIS-based tandem PVs (HZB)
- Development of Evaluation Methods for Ammonia Adsorption/Desorption Under Severe Conditions (Fh-ISE)
- International Joint Research on Redox Flow Batteries Using Ubiquitous Elements (MAX IV)
- International Joint R&D on Data-Driven DSR Control Technology for Energy Sharing (UC DAVIS)

We hope we can expand international collaborations with other RD20 members and research institutes worldwide for clean energy technology R&D.

### 4-2 Issues/themes for promoting international collaboration

AIST, NLR and Fh-ISE co-organized the Gigaton Hydrogen Workshop and the Terawatt Workshop series. These workshops provide opportunities to address global challenges from a technological perspective as well as to recognize the necessity of cross-border initiatives toward solving these global challenges. One of the challenges in these symposia, taking into account differences in regional circumstances, is identifying and prioritizing themes to be tackled globally. For example, the aim of the Gigaton Hydrogen Workshop is to identify barriers and pathways in order to accelerate the development and deployment of hydrogen technologies across various sectors of society, and to meet energy and resource demands on a gigaton scale. At the same time, it is also important to develop young leaders with international perspectives in this technological field. “Summer School” program, which was launched in 2023 by the suggestion to promote exchanges among young researchers from RD20 member institutions, is held annually.

## 5. Future perspectives (towards carbon neutrality)

In January 2020, Japan formulated the “Environment Innovation Strategy” to promote innovation in the energy and environment fields. This strategy aims to achieve cost-competitive deployment of innovative technologies, and to contribute to significant reductions in greenhouse gas (GHG) emissions not only in Japan but also worldwide. The strategy includes “Innovation Action Plans,” which serve as “technology compasses” to establish innovative energy and environmental technologies by 2050. There are five

key technological areas outlined in the Plans: non-fossil energy, energy network, hydrogen, carbon recycling and CCUS, and zero-emission agriculture, forestry and fisheries. Furthermore, the “Green Growth Strategy Through Achieving Carbon Neutrality in 2050” formulated in December 2020 and updated in June 2021 identifies current challenges and outlines future actions to achieve carbon neutrality. Since AIST is conducting advanced research in these key technological areas, we will contribute to the realization of the “Innovation Action Plans” by conducting comprehensive research, i.e., from fundamental to applied research as well as demonstration research for clean energy technologies with the ultimate goal of achieving a zero-emission society.

| stitute/Count | Theme | Sub Theme | Related programs (with short summary) | Target / Goal Outcome | Lead person / Organization | Partnership (if any) | Related information |
|---|---|---|---|---|---|---|---|
| AIST/Japan | Battery | | Research and Development Program for Promoting Innovative Clean Energy Technologies Though International Collaboration /International Joint Research on Redox Flow Batteries Using Ubiquitous Elements<br>[2024-2027]<br>2024 - 2027 | Development of low-cost, high-performance redox flow batteries with high energy density and high cycle stability | Dr. HOSONO Eiji / AIST | (Sweden) MAX IV | |
| AIST/Japan | EMS | | Research and Development Program for Promoting Innovative Clean Energy Technologies Though International Collaboration / International Joint R&D on Data-Driven DSR Control Technology for Energy Sharing<br>[2023-2026]<br>2023 - 2026 | Data-Driven DSR Control Technology for reducing CO2 emission and cost saving | Dr. HONDA Tomonori / AIST | (US) University of California, Davis | |
| AIST/Japan | Hydrogen | Production | Construction of technology platform for evaluation of water electrolysis under a renewable energy system environment<br>[2021-2026]<br>2021 - 2026 | Electrolyzer capital cost of 52 thousand yen/kW for alkaloine and 65 thousand yen/kW for PEM in 2030 | Dr. FURUTANI Hirohide / AIST | | |
| AIST/Japan | Hydrogen | Production | International Collaborative R&D on Innovative Porous MultiComponent Alloy Catalysts for Water Electrolysis<br>[2026-2028]<br>2026 - 2028 | To create a porous multi-component alloy catalyst with less or no iridium that exhibits high performance and durability at the single-cell level | Dr. KOBAYASHI Yasukazu / AIST | (Domestic) Nagoya Univ., UNITIKA Ltd., Enoah Inc., Toyota Central R&D Labs. Inc.<br>(Australia) The University of Queensland | |
| AIST/Japan | Hydrogen | Transportation /Storage | Research and Development Program for Promoting Innovative Clean Energy Technologies Though International Collaboration / International joint research for supply technology of high-pressure and purity of hydrogen by chemical compressor using formic acid<br>[2022-2025]<br>2022 - 2025 | Development of catalyst for high pressure H2 production, CO2 resistant hydrogen storage materials to build up hydrogen purification, storage and supply technologies, and material synthesis method under high pressure hydrogen. | Dr. HIMEDA Yuichiro / AIST | (Netherlands) Delft University of Technology<br>(France) East-Paris Institute of Chemistry and Materials Science<br>(Korea) Korea Advanced Institute of Science and Technology<br>(Saudi Arabia) King Abdullah University of Science and Technology<br>(UK) Queen Mary University of London | |
| AIST/Japan | Ammonia | | Research and Development Program for Promoting Innovative Clean Energy Technologies Though International Collaboration / Development of Evaluation Methods for Ammonia Adsorption/Desorption Under Severe Conditions<br>[2024-2027]<br>2024 - 2027 | The goal is to propose an evaluation method that<br>will become a global standard by combining the findings of both organizations. | Dr. MANAKA Yuichi / AIST | (Germany) Fraunhofer-Gesellschaft | |
| AIST/Japan | Ammonia | | Green ammonia synthesis and utilization for marine transport by SOC Technology<br>[2022-2025]<br>2022 - 2025 | The objectives are to develop a highly efficient green ammonia synthesis process, develop electrode materials that enable fuel cells that directly use ammonia, and evaluate their durability | Dr. HORITA Teruhisa / AIST | (Domestic) Kyoto Univ., Kindai Univ., MORIMURA SOFC Technology<br>(Germany) Fraunhofer IKTS, EDL Anlagenbau Gesellschaft mbH | |

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| AIST/Japan | PV | | Research and Development Program for Promoting Innovative Clean Energy Technologies Though International Collaboration / International collaboration on CIS-based tandem PVs<br>[2021-2024]<br>2021 - 2024 | Achievements of low cost and high efficiency CIS based lightweight and flexible tandem PVs are expected to lead to large scale usage of PVs in society | Dr. ISHIZUKA Shogo / AIST | (Domestic) Tokyo University of Engineering<br>(Germany) HZB | |
| AIST/Japan | PV | | Development of fundamental technology for commercialization of perovskite solar cells<br>[2021-2025]<br>2021 - 2025 | Power generation cost of 20 yen/kwh for ultra-light perovskite solar cells | Dr. OBARA Haruhiko / AIST<br>Dr. Takurou N. Murakami / AIST | | |
| AIST/Japan | CCUS | | Green Innovation Fund Project / Development of Technology for Producing Fuel Using $CO_2$, etc. (Development of inovative technology for SOEC methanation)<br>[2022-2028]<br>2022 - 2028 | Deveropment of high efficiency advanced methane-base fuel systhesis technology with solid oxide co-electrolysis cells | Dr. OBARA Haruhiko / AIST<br>Dr. YAMAGUCHI Toshiaki / AIST | (Domestic) Osaka gas Corporation | |
| AIST/Japan | CCUS | | Research and Development on Next-Generation FT Reaction and Integrated Production Process for Synthetic Liquid Fuels<br>[2021-2025]<br>2021 - 2025 | Efficient production of drop-in liquid fuels from CO2 and renewable hydrogen. Deployment of a bench-scale integrated plant using co-electrolysis with SOECs. | Dr. TAKAGI Hideyuki / AIST | (Domestic) ENEOS, Seikei Gakuen, Nagoya Univ., YNU, Idemitsu Kosan, JPEC, Niterra, Institute of Science Tokyo, CRIEPI, Mitsubishi Electric Corporation | |
| AIST/Japan | Geothermal | | Understanding the Relationship Between Hot Spring Aquifers and Geothermal Reservoirs<br>[2026-2028]<br>2026 - 2028 | To encourage and expand the use of geothermal resources, this project is investigating best practices in countries that already employ the technology. Based on the results, we look at evaluation indicators that determine the potential impacts of | Dr. FUJIMITSU Yasuhiro / Kyushu Univ.,<br>Dr. YAMAYA Yusuke / AIST | (Domestic) Kyushu Univ., Mitsubishi Gas Chemical Company, Kobe Univ., Kwansei Gakuin University<br>(New Zealand) Earth Science New Zealand | |