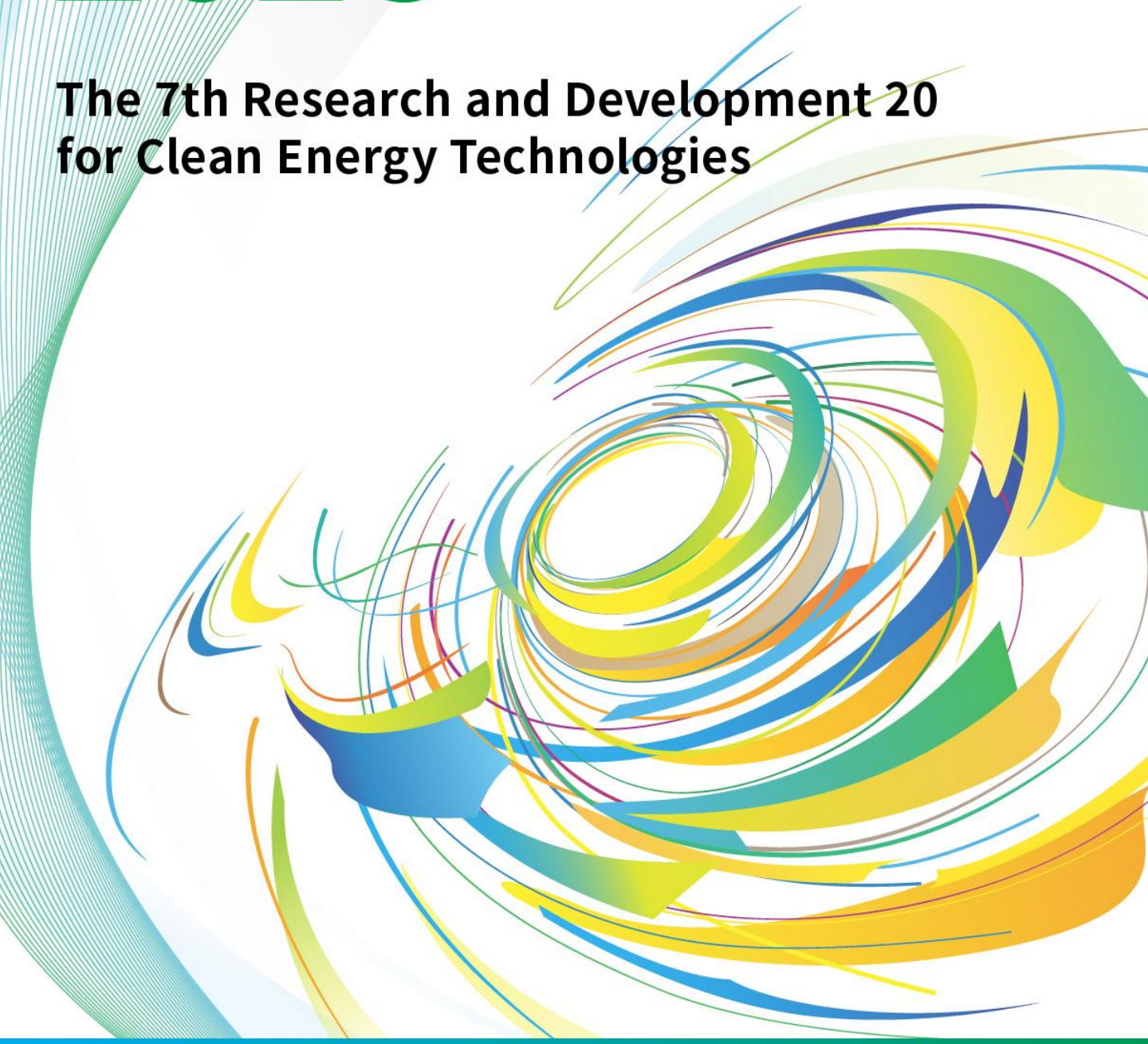
Research and Development 20
for Clean Energy Technologies

Now & Future 2025

The 7th Research and Development 20 for Clean Energy Technologies



Sep. 30 – Oct. 3, 2025

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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

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Messages

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Technical Session

Create the Future, Collaborate Together

Research and Development 20
for Clean Energy Technologies

The 7th RD20 Conference 2025

The leading edge of AI technology for energy, from Tsukuba to the World

Date: Tuesday, September 30–Friday, October 3, 2025
Venue：HOTEL NIKKO TSUKUBA (https://www.nikko-tsukuba.com/eng/)
Organizer: National Institute of Advanced Industrial Science and Technology (AIST), Japan
Co-organizers:
Ministry of Economy, Trade and Industry (METI), Japan
Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan
Ministry of the Environment (MOE), Japan
New Energy and Industrial Technology Development Organization (NEDO), Japan

Launched in 2019, the RD20 is an initiative for international research and development aiming to strengthen international collaboration and promote innovation by leading research institutes in G20 countries and regions that develop the world's most advanced technologies for achieving carbon neutrality. RD20 provides opportunities for participants to exchange R&D activities, experiences, and best practices related to clean energy technologies across countries and regions, as well as to explore the potential for international joint research. It also serves to deepen and develop new partnerships among relevant industry, academia, and government stakeholders.

The 7th RD20 Conference will be held on September 30-October 3, 2025 in Tsukuba, Japan and online. Leaders and experts of the institutes from G20 members will gather to accelerate collaboration and release the outcome all over the world.

Session	Date	Time (JST)	Attendance
Technical Session (TS)	Tue., Sep. 30 Wed, Oct. 1	9:00 – 17:10 9:00 – 17:40	Open to the public
Site Visit Tour	Thu. morning, Oct. 2	9:00 – 12:00	Invited members only
Workshop (WS)	Thu. afternoon, Oct. 2	13:00 – 17:30	Invited members only
Leaders Session	Fri. morning, Oct. 3 Fri. afternoon, Oct. 3	9:00 – 12:05 14:00 – 16:45	Open to the public Invited members only

Day 1: Technical Session (Tue., Sep. 30, 2025)

Time	Session (Open to the public)
8:15-9:00	**Registration**
9:00-10:50	**TS plenary: High level talk on energy and environment** ***Moderator: Dr. Michio Kondo (AIST, Japan)***
9:00-9:20	Dr. Koichi Matsuoka (AIST, Japan) *in-person* *AIST's Latest International Collaboration*
9:20-9:50	Dr. Jean-Francois Houle (NRC, Canada) *in-person* *Resources, Resilience and Sustainability: NRC Innovation Supporting Canada's Energy Future*
9:50-10:20	Dr. Thabo Hlalele (CSIR, South Africa) *in-person* *RD20 contribution to South Africa's G20 Presidency*
10:20-10:50	Dr. Stephane Sarrade (CEA, France) *in-person* *Return of Experiment on International Research Collaboration*
10:50-11:15	**Coffee Break**
11:15-17:10	**TS #1: Synthetic fuels including a wide range of resources, conversion processes and products** ***Moderator: Dr. Thabo Hlalele (CSIR, South Africa) and Dr. David Harris (CSIRO, Australia)***
11:15-11:40	Dr. Randy Cortright (NREL, US) *online* *Synthetic fuels- opportunities and challenges spanning biomass, e-fuels and solar fuels*
11:40-12:05	Mr. Adam Tuck (NRC, Canada) *in-person* *Advanced Hydrogen Production and Transport Technologies*
12:05-12:30	Dr. Yu Katayama (Osaka University, Japan) *in-person* *Electrochemical Ammonia Synthesis Under Ambient Conditions – NEDO Research and Development Program for Promoting Innovative Clean Energy Technologies Through International Collaboration*
12:30-13:50	**Lunch**
13:50-14:15	Dr. Mike Colechin (Cultivate Innovation Ltd/UKERC, UK) *in-person* *The potential role for biomass as a long-duration store of energy*
14:15-14:40	Dr. David Harris (CSIRO, Australia) *in-person* *Gasification and syngas potential for biomass and waste feedstocks*
14:40-15:05	Dr. Tata Sutardi (BRIN, Indonesia) *in-person* *Biofuel Development from Biomass Stock*
15:05-15:30	Dr. Claudia Bassano (ENEA, Italy) *online* *Sustainable Aviation Fuels in Italy: opportunities and research challenges faced by ENEA*
15:30-15:55	Prof. Sary Awad (CNRS, France) *online* *Sustainable fuels production for shipping and aviation sectors from microalgae via Hydrothermal pathway: insights from COCPIT project*
15:55-16:20	**Coffee Break**
16:20-17:10	**Discussion and wrap-up (Invited members only)**

Create the Future, Collaborate Together

Day 2: Technical Session (Wed., Oct. 1, 2025)

Time	Session (Open to the public)
8:15-9:00	**Registration**
9:00-12:40	**TS #2: Energy storage with a focus on grid-scale storage for renewables** ***Moderator: Dr. Pierre SERRE-COMBE (CEA, France) and Dr. Ratih Damayanti (BRIN, Indonesia)***
9:00-9:25	Dr. Emmanuel Baudrin (CNRS, France) *in-person* *Overview of Redox flow technologies, challenges, and opportunities*
9:25-9:50	Dr. Katie Harrison (NREL, US) *in-person* *Safe, Long-Life Batteries for Behind-the-Meter Grid Storage*
9:50-10:15	Dr. Euis Djubaedah (BRIN, Indonesia) *in-person* *Challenges and Opportunities in Advancing Energy Storage Technologies in Indonesia*
10:15-10:40	Dr. Callum MacIver (UKERC/University of Strathclyde, UK) *in-person* *Security of supply challenges for a weather dependent GB electricity system and the role for storage at scale*
10:40-11:00	**Coffee Break**
11:00-11:25	Dr. Julie Mougin (CEA, France) *in-person* *Role of Hydrogen for large Scale Energy Storage*
11:25-11:50	Dr. Friedrich Mendler (Fh-ISE/AIST, Germany) *in-person* *Scaling Hydrogen Production and Storage: Lessons from Supply Chain Optimisation Across all Spatial Scales*
11:50-12:40	**Discussion and wrap-up (Invited members only)**
12:40-14:00	**Lunch**
14:00-17:40	**TS #3: AI and digitalization to accelerate research for energy technology innovation, development and deployment** ***Moderator: Dr. Tomonori Honda (AIST, Japan) and Dr. Sangjin Choi (KIER, Korea)***
14:00-14:25	Dr. Ray Grout (NREL, US) *in-person* *AI applications for energy and energy R&D*
14:25-14:50	Dr. Jehyun Lee (KIER, Korea) *in-person* *Identifying Strategic Research Partners through Data-Driven Analysis of the Renewable Energy Technologies*
14:50-15:15	Dr. Hideki Shimada (AIST, Japan) *in-person* *Data-Driven DSR Control Technology for Energy Sharing – NEDO Research and Development Program for Promoting Innovative Energy and Environmental Technologies Through International Collaboration*
15:15-15:40	Dr. Aidan Rhodes (Imperial College London/UKERC, UK) *in-person* *Enhancing Electricity System Resilience with AI, Digital Twins and Digitalisation Technologies*
15:40-16:00	**Coffee Break**
16:00-16:25	Prof. Mohamed Tahar MABROUK (Imt Atlantique/CNRS, France) *in-person* *Hybrid Modeling for Smarter Energy Systems: Physics Meets AI*
16:25-16:50	Dr. Scott Smith (NRC, Canada) *in-person* *Autonomous Laboratory: Self-driving labs to accelerate battery cathode material discovery*
16:50-17:40	**Discussion and wrap-up (Invited members only)**

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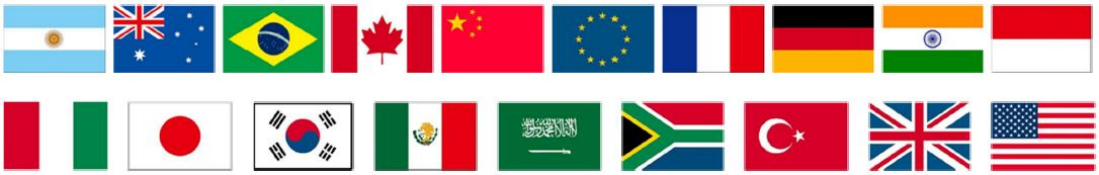
Leaders Session

Day 4: Leaders Session (Fri., Oct. 3, 2025)

Time	Morning session (Open to the public)
8:15-9:00	**Registration**
9:00-9:10	**Group Photo**
9:15-9:35	**Opening ceremony (MC: AIST Secretariat)**
9:15-9:20	Welcome address: Mr. Kazuhiko Ishimura (AIST, Japan)
9:20-9:35	Opening remarks: METI, MEXT, MOE, NEDO
9:35-10:55	**Plenary lecture, RD20 status and activities (Chaired by Dr. Vibha Dhawan)**
9:35-9:55	Plenary lecture: Dr. Akira Yoshino (AIST, Japan)
9:55-10:05	Report of TS in the 7th RD20: Dr. Koichi Matsuoka (AIST, Japan)
10:05-10:20	Report of Taskforce activity: Taskforce leaders -PV: Dr. Masahiro Yoshita (AIST, Japan) *in-person* -H_2LCA: Dr. Nawshad Haque (CSIRO, Australia) *online* -H_2TEA: Dr. Mark Ruth (NREL, US) *online*
10:20-10:30	Report of RD20 Summer School 2025: NREL
10:30-10:40	Contribution to G20: ETWG: Dr. Thabo Hlalele (CSIR, South Africa)
10:40-10:55	Discussion
10:55-11:10	**Coffee Break**
11:10-12:00	**Keynote presentations: Frameworks and Role of Leadership to Promote International Collaboration (Chaired by Mr. Kazuhiko Ishimura and Dr. Michio Kondo)**
11:10-11:20	Various collaboration scheme: Dr. Shigeki Koyanaka (NEDO, Japan)
11:20-11:40	Keynote Presentation: Prof. Dr. Bernd Rech (HZB, Germany) *Green Energy Research at Helmholtz-Zentrum Berlin – Innovations Through International Partnerships*
11:40-11:50	Q&A for presentations, Open discussion among Leaders
11:50-12:00	Approval and Announcement of the 8th RD20 Conference: Dr. Thabo Hlalele (CSIR, South Africa)
12:00-12:05	**Closing remarks**: Mr. Wataru Imamura (METI, Japan)
12:05	**Adjournment of morning session**
12:05-13:30	**Lunch** *** Media relations (12:05-12:35)**

Time	Afternoon session (Invited members only)
13:30-13:35	Introductory remarks from chairs: Mr. Kazuhiko Ishimura and Dr. Martin Keller
13:35-13:45	Reviewing Leaders Recommendation 2024: Dr. Martin Keller (NREL. US, *in-person*) and Dr. William Tumas (NREL, US, *online*)
13:45-16:40	**Moderated discussion (Chaired by Dr. Martin Keller)**
13:45-14:10	*Theme 1: Collaboration with other organizations (facilitator: Dr. Martin Keller)*
13:45-13:50	Presentation: Potential collaboration with IEA/H2 TCP: Dr. Julie Mougin (CEA, France) *online*
13:50-13:55	Presentation: Potential collaboration with MI: Dr. Helen Fairclough (MI) *online*
13:55-14:10	Discussion: continuity and new development of collaboration with G20, MI and IEA/H2 TCP
14:10-14:40	*Theme 2: Capacity building and researcher exchange within RD20 (facilitator: Dr. Abdelilah Slaoui)*
14:10-14:20	Approvals and Announcements of RD20 Summer School 2026 and 2027 Summer School 2026 @Morocco: Dr. Abdelilah Slaoui (CNRS, France) Summer School 2027 @ Scotland: Dr. Jamie Speirs (UKERC, UK)
14:20-14:25	RD20 Portal Site: RD20 Secretariat Dr. Yuji Ando (AIST, Japan)
14:25-14:40	Discussion: Expanding summer school to human resource development and creating new community, promoting researcher exchange
14:40-15:00	**Coffze Break**
15:00-16:25	*Theme 3: Activation of RD20 initiatives (facilitator: Dr. Pierre SERRE-COMBE)*
15:00-15:20	Report of WS in the 7th RD20: Dr Taha Selim Ustun (AIST, Japan), and Mr. Ron Benioff (NREL, US)
15:20-15:50	Discussion: New TF proposal, Activate TF, Future areas for collaboration (biofuels etc.): TF leaders (including new TF leader) -Biofuel: Dr.Sanjukta Subudhi (TERI, India) *in-person* (-Any comments: Dr. Masahiro Yoshita (AIST), Dr. Nawshad Haque (CSIRO), and Dr. Mark Ruth (NREL))
15:50-16:10	Discussion: Promoting international collaboration among RD20 *(facilitator: Prof. Dr. Christopher Hebling)*
16:10-16:15	RD20 membership: RD20 Secretariat Dr. Noriko Yoshizawa (AIST, Japan)
16:15-16:25	Discussion: RD20 membership and engagement, future conference
16:25-16:40	Reviewing the discussion to summarize recommendations: Dr. Martin Keller (NREL, US)
16:40-16:45	**Closing remarks**: Mr. Kazuhiko Ishimura (AIST, Japan)
16:45	**Adjournment of afternoon session**

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.

The 7th RD20, Oct. 3, 2025

Current Status and Future Perspectives ("Now and Future") of Clean Energy Technologies in INTI

MOLINA TIRADO Liliana Beatriz
Energy & Mobility Deputy – Innovation & Technological Development Management
National Institute of Industrial Technology (INTI), Argentina

1. Introduction

Argentina represents less than 1% of greenhouse gases (GHG) emissions within the United Nations Framework Convention on Climate Change (UNFCCC) countries and have signed the Paris Agreement and ratified it by National Law N°27.270 (2016). At the end of 2020, Argentina changed its Nationally Determined Contribution (NDC) objective from 483 to 349 MtCO2eq by 2030. To achieve this new NDC, Argentina has proposed several mitigation actions in the areas of Energy, Agriculture, Livestock, Forests, Transport, Industry and Infrastructure, along with a National Adaptation Plan for climate change effects. In that order, the Hydrogen National Strategy and the National Carbon Market Strategy were published.

The change of government at the end of 2023 marked a shift in national policies, especially in the areas of climate change, education, and science. Consequently, the budget for the national science and technology system was reduced, limiting the progress of research projects.

Historically, Argentina's main contribution to GHG emissions was the generation and use of energy, mainly combustion of fossil fuels to obtain electric and thermal power and transportation. In that order, there were actions implemented in two fundamental axis: energy diversification, including the participation of renewable energy in the matrix and the promotion of rational and efficient use of energy. Nowadays, due to the increase in electricity and gas rates the installation of renewable energy generation plants off grid and on grid were increased.

The maximum contribution of electrical energy from renewable sources remains in around 15%[1]. Furthermore, Argentina is discussing other initiatives towards Energetic Transition that promotes industrial production of green and blue Hydrogen, Lithium Batteries and electromobility. All these areas are being covered by the Energy & Mobility Deputy at the National Institute of Industrial Technology (INTI). INTI is a public decentralized institution created in 1957 that is part of the National Science and Technological System. Under the Trade Secretary, dependent on the National Ministry of Economy, its mission is to promote industrial development through innovation and technological transfer. INTI is also the national reference in Metrology, to strengthen the metrological capacities to spread industrial quality all over national industry. INTI has technology centers across the country specialized in different industrial sectors.

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

INTI Technological Development and Innovation Management, through its Energy and Mobility Department, works to strengthen the competitiveness and sustainability of companies, especially SMEs, through development and appropriation of innovative products and processes that contributes to reduce the GHG emissions and collaborates as technical reference with the Government in order to establish regulations.

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1 https://stcharger.com.ar/energia-verde-en-argentina-desafios-para-2024/#:~:text=El%20registro%20fue%20llevado%20a,n%C3%BAmero%20del%2015%2C1%25.

The main technologies addressed by the Energy and Mobility Department are:

- BioEnergy, Solar Collectors for residential use, Photovoltaic panels, Low Power Wind Turbines
- Storage & Conversion of Energy
- Smart Grid Integrations
- Mobility
- Energy Efficiency

3. Specific research activities

A) Energy Storage

- **Fuel cells** fed by low-carbon hydrogen produced by water electrolysis are a good alternative for renewable energy storage. Alkaline electrolyzers are currently developed, including liquid and zero gap devices.
- **Hydrogen certification:** INTI is the institution in charge of the study related to the certification of origin of green hydrogen and low carbon hydrogen. In addition, the life cycle analysis method is detailed for the estimation of greenhouse gas emissions, which will be key when certifying the origin of low-carbon hydrogen.
- **Lithium Batteries**: we work on the National Center for Lithium Batteries Project within the framework of the FONARSEC [2] fund with the aim of promoting the local development of systems that use lithium batteries in the energy and electromobility industry, in conjunction with the private and industrial sector. Both lines of work include the development of an infrastructure of 182m2 for the installation of the laboratories
- **Nanostructured Materials for Energy.** With the increase in energy consumption, new and more efficient materials for energy generation and storage are required. Moreover, the increasing use of portable electronic devices requires the development of new or more efficient energy storage technologies. Solar, tidal and wind energy´s main challenge is its storage. INTI has developed and characterized different nanostructured materials for that purpose.
- **Anion Exchange Membranes.** Low carbon footprint hydrogen, a near-zero emission energy carrier, plays a key role in many applications such as road transport, micro co-generation and de-carbonization of several industrial processes. Hydrogen technologies footprint depends on its method of production and the best option is electrochemical water splitting. However, one of its main barriers is the current costs of fuel cells and electrolyzers. Therefore, alkaline systems, which do not require precious metals such as electrocatalysts or demand corrosion-resistant components, are a good option for low temperature, membrane-based devices. New applications are currently being explored for the developed membranes.

B) Renewable Energy

- **Biomass Gasification Technology.** Argentina's bioenergetic sector is conformed by numerous agro-industrial companies that produce waste, primary producers who waste crop residues, and a sub sector of SMEs that constructs machines and equipment. To achieve the industrialization of these wasted resources, developments are required in both physical and chemical processes as in the existing machinery to achieve profitable industrialization processes (collection, pelletization, storage, conditioning, pre-treatment,

[2] FONARSEC (Fondo Argentino Sectorial) is a funding instrument at national level provided by the National Agency for the Promotion of Research, Technological Development and Innovation. Official webpage: https://www.argentina.gob.ar/ciencia/agencia/fondo-argentino-sectorial-fonarsec (in Spanish).

etc.). INTI seeks to identify opportunities for developing new bioproducts including biofuels, as well as innovation opportunities in machines and equipment that enhances new and improved degrees of biomass industrialization.

- **Utilization of pellets of agricultural harvesting and forest activities residues in biomass combustors.** Many of the agricultural crop residues are suitable to transform to solid biofuels when correctly managed. This valorization technique for these mostly unused residues can help the different agriculture industries to diversify their conventional activities and to replace the natural gas for thermal energy. During the validation process, the previous data was compared with the newest standard approved in Argentina for solid biofuels (IRAM-ISO 17225) to establish a quality basis for the industrial process.
- **Materials for offshore generation and storage of renewable energy.** Development of advanced materials and prototypes for sustainable energy production (solar, wind, wave and tidal), including energy storage through batteries and hydrogen technology in offshore platforms. This also includes the salinity gradient energy applications in Argentine lagoons of high salt concentration (reverse electro dialysis) and in oil wells.
- **Internet of Energy. Investors Interoperability.** The interoperability system is a photovoltaic inverter data acquisition system that takes the data and integrates it into a dedicated IoT platform. This INTI's developed system solves the incompatibility of data that comes from multi-brand inverters. If all the photovoltaic systems were from the same manufacturer, the communication protocols and the way in which the data is shared would be homogeneous among all, with which it would be possible to observe them in the same place; however, this situation is not in practice.
- The Project named VERSU -for their acronym in Spanish for **Power Valorization for Solid Urban Residues-** consists in a cycle-combined equipment with power generation for solid urban residues. It is located in Sarmiento City, San Juan Province, a 22.000-inhabitant city. This industrial plant is a demonstrative project, unique in Argentina.
- **CCUS Technologies**. As a national institute created to reinforce the national industry, we assist companies to improve their technologies to achieve environmental objectives.

4. International collaboration

INTI has three main strategies to promote international collaboration:

1. **Industrial Technology Transfer**

   Productive knowledge, innovative technologies and transfer promotion to countries with equal or less industrial development, with the aim of contributing to strengthening their productive and industrial network.

2. **Scientific and Technological Cooperation**

   For the improvement of technological knowledge, participation in joint innovation processes and promotion of industrial competitiveness and productiveness.

3. **SMEs Internationalization**

   Assistance for the incorporation of technological innovation that favors the generation of quality employment and the increase and diversification of exports from SMEs.

International joint R&D activities

- JICA (Japan): KT+ Project for the Technical Assistance Network for Global Opportunities to SMES in Green Economy.

- AIST (Japan): INTI's doctoral researcher's visited at the National Institute of Advanced Industrial Science and Technology (AIST) on 2024, to pursue joint research between INTI and AIST R&D teams in Novel materials for Hydrogen conversion. Working in the document.
- Ontario Tech University (Canada): Development of new materials for energy storage and conversion, PhD Thesis.

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?

The top priority themes for collaborative research within the RD20 framework include integrating microgrids with interoperability capabilities and applied artificial intelligence, advancing hydrogen conversion technologies, and developing biorefinery technologies.

What are the best practices that your institution has been involved in so far, and possible future contributions on those critical issues/themes?

In the field of materials for hydrogen conversion and its carriers, our institution has actively pursued greater sustainability, efficiency, and cost-effectiveness. We have an expert team of professionals and PhD candidates, led by renowned PhD researchers, who are engaged in multiple projects with a network of international collaborators. This foundation positions us well for further contributions to advancing sustainable hydrogen technologies.

What do you think is an effective measure for facilitating international cooperation?

An effective measure for facilitating international cooperation is to leverage all available tools, from calls for bilateral collaborations to forming consortia of institutions. Additionally, advocating within the G20 to formally recognize RD20 as a scientific group in its activities could significantly enhance our visibility and access to funding, further supporting collaborative initiatives.

5. Future perspectives (towards carbon neutrality)

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

In accordance with the Argentina´s Third National Communication on Climate Change, our next challenges are aimed at the appropriation, generation and transfer of technology to reduce GHG emissions in two different aspects:

- Thermal Energy technologies for industrial activities:
  - **Solar Concentrators** for fluids heating or steam generation aimed at SMEs located in regions appropriated for this technology
- Transportation Energy Fuels:
  - **BioMethane for transportation**: energy recovery of the organic fraction of urban solid waste
  - **Engine Testing Laboratory**, for performance evaluation of different biofuels, evaluation of biofuels proportion in gasoline cuts.
- Electrical Transportation
  - Production and Reuse of **Lithium Batteries**: Technological assistance to local battery manufacturers. Spent batteries disposal and recycling, engine testing laboratory for different fuels and electricity.
  - **Green Hydrogen** certification and metrological quantification of Hydrogen in a mix of gases.

    - **Integration Energy Laboratory** for R&D activities related to micro and off grid systems.
- Energy efficiency in public buildings and industries through the:
    - Implementation of **energy efficiency improvement measures**
    - Introduction of **energy management criteria**
    - Staff awareness of the **rational use of resources**

Msc Ing Liliana Beatriz Molina Tirado
National Institute of Industrial Technology (INTI)

Msc Ing Liliana Beatriz Molina Tirado is a chemical engineer graduated from the National Technological University and has a master's degree in Wood, Cellulose and Paper Science from National University of Misiones (Argentina), a Specialty in Innovation and Technology Management.

She specializes in biorefinery and bioenergy from forest biomass. She has several papers published on these topics.

She was Technical Director of the Renewable Energy Technological Center at INTI. She currently oversees the Energy and Mobility Deputy from the Technological Development and Innovation Management. She represents INTI in Renewable Energy, Storage Energy and Mobility issues.

nstitute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Argentina	INTI	Storage	Development of new materials for solid oxide fuel cels and electrolyzers (2019 - 2027) Current 2019 - 2027 (R&D span)	Nex materials are prepared and caratherized for SOFC & SOEC	PhD Ana Larralde/ INTI (alarralde@inti.gob.ar), PhD Gabriel Magalhaes e Silva/INTI (gmagalhaes@inti.gob.ar)	（Domestic) CONICET & INTI	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/almacenamiento-de-la-energIa
Argentina	INTI	IoE / Smart Grids	Development of an Event Detection and Prediction System applying AI for Electrical Distribution Networks through the Use of Smart Metering Systems 2019 - 2026 (R&D span)	Creation of a system to manage a Smart Grid, capable of facilitating the management, monitoring and control of energy. In this way, the appropriate and necessary protections can be established in order to avoid accidents to people, improve the quality of service and optimize the useful life of the facilities.	Marianela Bornancin, Eng / INTI (mbornancin@inti.gob.ar)	(Domestic) Environmental Protection Agency of Buenos Aires City	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/gestion-del-sistema-integrado-de-la-energia
Argentina	INTI	Power Valorization	Power Valorization for Urban Solid Residues (2009-2019). Looking forward to investors	Industrial plant for municipal urban residues valorization	Juan Carlos Najul, Eng / INTI (jcnajul@inti.gob.ar)	San Juan Province Government, Agencia Nacional de Promocion Cientifica y Tecnologica (https://www.argentina.gob.ar/ciencia/agencia), Energia Provincial Sociedad del Estado (www.epse.com.ar), Mega Ingenieria (www.ingenieriamega.com.ar), Thala S. A. Instalar DG (www.instalardg.com), State Secretary for Environment and Sustainable Development	https://www.inti.gob.ar/noticias/21-asistencia-regional/1491-en-pocos-meses-comenzara-a-operar-la-planta-versu-en-san-juan
Argentina	INTI	Solar Thermal Energy	Performance Improvement of National Solar Thermal Collectors Industry (2020-2026) 2020 - 2026 (R span) Current	Solar Thermal Collectors lab installed.	Federico Pescio, Eng / INTI (fpescio@inti.gob.ar)	Ministry of Production Development (https://www.argentina.gob.ar/produccion)	https://www.inti.gob.ar/noticias/15-desarrollo-e-innovacion/1286-crecio-el-179-la-instalacion-de-equipos-de-energia-solar-termica-en-argentina
Argentina	INTI	PV	Simulation and characterization of thin film optoelectronic devices with computational methods (2022 - 2025). Finished 2021 - 2025 (R&D span) - Finished	Perform a systematic study with numerical simulations in optoelectronic devices with multi-junction structures based on silicon (Si)	Federico Pescio, Eng / INTI (fpescio@inti.gob.ar); Helena Ramirez Jimenez Doc/INTI (hramirez@inti.gob.ar)	National Atomic Energy Commision (CNEA)	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/gestion-del-sistema-integrado-de-la-energia
Argentina	INTI	Production	Development a photovoltaic generation system and an electrolyser for the production of green hydrogen. (2022-2024). Finished. It is used to evaluate different materials.	Development of materials for electrodes and separating membranes and integration and evaluation of the prototype photovoltaic panel-rechargeable batteries-electrolyser	PhD Jose Arroyo / INTI (jarroyo@inti.gob.ar)	Center for Research and Advanced Studies of the National Polytechnic Institute of Mexico (Cinvestav)	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/almacenamiento-de-la-energIa
Argentina	INTI	Production	Development of a roadmap for certification of origin of green and blue hydrogen (2022-2023). Finished	The main stages included in the roadmap are proposed to address the certification of origin processes for green hydrogen and low carbon hydrogen.	Liliana Molina Tirado, Eng / INTI (lmolina@inti.gob.ar)		https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/almacenamiento-de-la-energIa
Argentina	INTI	Production	Development of polymeric electrolyte anion exchange membranes (PEAEMs) (2023-2024). Finished	Develop anion exchange membranes for hydrogen conversion technologies: fuel cells and electrolyzers in alkaline medium.	PhD Jose Arroyo / INTI (jarroyo@inti.gob.ar)	Technion Israel Institute of Technology	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/almacenamiento-de-la-energIa
Argentina	INTI	PV	Floating Solar Photovoltaic Energy. Finished. Looking for partners	Float manufacturing by rotational moulding that will be used as the fixed structure of different floating photovoltaic module systems that will be installed in the near future in order to subsequently measure the mechanical properties of the system.	Marianela Bornancin, Eng / INTI (mbornancin@inti.gob.ar)		https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/generacion-de-la-energia
Argentina	INTI	PV	Degradation mechanisms in PV modules Current 2023 - 2026 (R&D span)	Development of models associated with different degradation modes is essential to adequately simulate the operational conditions of PV modules during their life cycle.	Helena Ramirez Jimenez Doc/INTI (hramirez@inti.gob.ar)	National Atomic Energy Commision (CNEA)	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/generacion-de-la-energia
Argentina	INTI	E-mobility	Retrofit of vehicles Current 2020 - 2025 (R&D span)	Create a Manual of Good Practices that governs the general guidelines for performing retrofit (electric conversion) on vans.	Diego Marino, Eng / INTI (dmarino@inti.gob.ar)	SMES	https://www.inti.gob.ar/areas/desarrollo-tecnologico-e-innovacion/energia-y-movilidad/desarrollo-para-la-industria-de-la-movilidad

The 7th RD20, Oct. 3, 2025

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 but must decrease, and 3) societies will redefine 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, hydrogen and low-carbon fuels industries emerge, and demands for decarbonised energy in the heavy industry and mobility sectors increase.

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 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 energy and industry sectors.

Australia has substantial opportunities to grow the clean energy sector, however, realising 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:

- The updated Australian Energy Market Operator (AEMO) Integrated System Plan (ISP) published in 2024 is 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 an energy system that is low-cost, 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://aemo.com.au/en/energy-systems/major-publications/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 recognise matters that are important to Australians and how Australia can uniquely

[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/wp-content/uploads/2021/06/acola-2021-australian-energy-transition-plan.pdf

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

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

The CSIRO Energy business unit strategy is focusing on three key areas of Australia's energy transition: Electricity transition, Industry and Transport Transition, and Community and Environment. In addition to the Energy business unit strategy, CSIRO is leveraging capabilities across multiple business units utilizing 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 three research topics: Electricity Transition, Decarbonised Industry and Transport and Carbon Management Technology.

3. Specific research activities

CSIRO connects 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 enabling the 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 storage solutions and systems driving energy efficiency in built environments. Another goal

we have is to improve utilisation of existing infrastructure by 50% to enhance the national economic performance of Australia.

One of our key deliverables is the 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 project costs for each of 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. CSIRO's 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.

Industry and transport transition

CSIRO's research on Advanced Solar Photovoltaics (PV) and Concentrated Solar Thermal (CST) Technologies aims to accelerate renewable energy at scale to support industry adoption and drive forward industry transition. The aspirations are high: to change how and where solar energy can be generated by developing ultra low-cost, environmentally friendly production methods, flexible materials and systems, as well as new plant deployment and operation methods. Hence, CSIRO's research is targeting commercialised, readily-available solar technologies ranging from developing printable solar cells to accelerating the perovskite solar cell production. CSIRO is also leading the Australian Solar Thermal Research Institute (ASTRI) to facilitate commercial uptake of concentrated solar thermal technologies and systems. ASTRI is providing a pathway 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 focussing on transforming the heavy industrial sector to a low-carbon future (HILT CRC). HILT CRC will enable Australian heavy industry sector to compete in the low-carbon global economy for carbon-neutral materials such as 'green' iron, alumina, cement and other processed minerals. HILT CRC will focus on developing technologies and methods that overcome barriers to the low-carbon transition, which include the unacceptable risks of untested innovations that could jeopardise equipment, production and/or worker safety. The partners will jointly develop and demonstrate the technologies needed to grow Australia's economy, unlocking potential value of $48.7 billion in annual revenue and $92 billion in investments, while mitigating carbon dioxide emissions. The industry transformation will proceed through regional hubs that have good local synergies and opportunities.

[2] https://www.csiro.au/-/media/Energy/GenCost/GenCost-2024-25-Final_20250728.pdf

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:

- 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 business to test, trial and demonstrate new and emerging hydrogen technologies to support sustainable manufacturing practices and the ability to store clean energy from renewable sources.
- 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 – like a diesel generator, but without the emissions footprint.
- 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 boost electrolysis efficiency and the produced hydrogen/syngas can be used 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 for high temperature heat industry application using falling particle technology.

Carbon Management

CSIRO's Gas Industry Social and Environmental Research Alliance (GISERA) 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 in Queensland, New South Wales, South Australia, the Northern Territory and Western Australia. This research is publicly available to support development decisions in regions where natural gas development is occurring or being proposed.

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 and ultimately to deliver viable options for Australia's low emission energy future. 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 full scale.

CSIRO is involved 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 and environmentally benign amine formulation 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 where the collected CO_2 can be placed to geological storage (producing negative emissions) or used for carbon neutral products. CSIRO is also developing solid sorbent technology, CarbonAssist™ which is a proprietary technology that allows CO_2 capture from different sources at low cost. The capture units are designed to be modular which ensures versatility and scalability.

4. International collaboration

CSIRO aims to connect Australia to the global science, technology, and innovation frontier as well as access new markets for Australian innovation. CSIRO has an extensive number of international activities and collaborations occurring around the world. These collaborations are conducted under a variety of arrangements, which are not reflected, in many cases, in formal Memoranda of Understanding (MoUs).

CSIRO has concluded MoUs in the field of energy and environment with National Renewable Energy Laboratory (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); and in early stage research with the Chinese Academy of Sciences (CAS China).

More significantly, researchers at CSIRO have and are collaborating with many institutions in the G20 country members which include innovations in clean energy technologies, research exchanges and workshops under a variety of arrangements, which are not reflected in formal MoUs.

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[3]. 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: China, Germany, India, Japan, The Republic of Korea, Singapore, The United Kingdom, The United States, The Netherlands
- 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[4].

We believe such international activities together with strategic partnerships, alliances joint projects, researcher exchanges, joint workshops and seminars are the best way to facilitate international cooperation. For us, collaborations are a fundamental way of how we work and find solutions to the greatest challenges we face on the planet.

5. Future perspectives (towards carbon neutrality)

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

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

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 energy growth areas and taking on big projects with strategic partners both in Australia and around the world.

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 driving Australian research together with international research institutes to solve the most pressing challenges to accelerate the decarbonisation of our electricity system. In 2022, CSIRO and AEMO have produced the G-PST Research Roadmap that incorporates research plans for the nine most pressing research topics. The Roadmap shows 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 2025 CSIRO released updated progress reports for the Research Roadmap[5].

Decarbonising industry through renewable heat and low-carbon liquid fuels including hydrogen

One of CSIRO's main growth initiatives in energy research is accelerating the decarbonization of industry and transport through the CSIRO Technology development aiming to build the foundations low-cost renewable energy in various forms in support of Australia's industry and transport sectors as well as for sustainable, export-focused Australian hydrogen industry, which includes the emerging natural hydrogen discovery and exploration.

CSIRO's priority focus in hydrogen is on delivering the technology investment portfolio to directly address production, storage and transport cost competitiveness as part of a domestic clean energy transition and a stepping stone to enabling Australia's clean hydrogen export industry and enabling capabilities.

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

Dr Dietmar Tourbier, Director, Energy, CSIRO

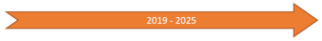
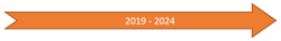
Dr Dietmar Tourbier, PhD, MBA

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.

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
			<Example> ●●●● Project Describe the summary of the project. [period of the project] Current 	Describe the target and/or goals of the project. Note the numerical purpose (if possible). e.g. Cost reduction of ■■ to ● kWh/yen in 2020	Dr. ******, ●●	(Domestic) ●● Research Institute, ▲▲ University, etc. (International) ●● (Desired collaboration) ●● field test, ▲▲ modeling, ■■ standard, etc.	https://www.●●●
CSIRO/Australia	Hydrogen	Production	Development of PEM electrolysis technology and kW class systems for distributed and off-grid a 	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, syngas and liquid fuels 	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 electricity. 	Develop various options for efficient modular design ammonia synthesis.	Dr Gurpreet Kaur / CSIRO	CSIRO Hydrogen FSP / strategic areas of research,	Relates to the development of new pathways for modular ammonia synthesis technology.
			Basic R&D for subsurface hydrogen exploration, including geogenic (natural) hydrogen. 	Understand geoscience to identify best locations for geogenic hydrogen exploration and potential for subsurface hydrogen production	Dr Ema Frery, Dr Valeria Shu	CSIRO Hydrogen FSP, ECU, Qld Govt	Geogenic hydrogen exploration attract interest from some Australian exploration companies. Qld State Govt engagement.
			Exploring the potential for ammonia recovery from wastewater with bipolar membrane electrodialysis. 	Develop processfor ammonia recovery from waste water.	Dr Sebastien Allard/ CSIRO	CSIRO Hydrogen FSP, Western Australia Water corporation	Relates to ammonia recovery from wastewater
			Development and demonstration of direct thermochemical solar reactors for production of hydrogen, syngas and liquid fuels using beam-down field configuration 	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/
			basic R&D work on elecrolysers 	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.	in progress
			Integrated hydrogen and ammonia production from organic wastes 	Integrating solar thermal into microbial digestion of biological waste for hydrogen and ammonia production	Dr Andrew Beath /CSIRO	CSIRO Hydrogen FSP	Completed
			Basic R&D for photoelectrochemical hydrogen generation using perfect photo-absorber materials 	Develop catalysts and semiconductor materials + cell design for hydrogen generation	Dr Noel Duffy / CSIRO	CSIRO Hydrogen FSP	Next stage of projects will look at new materials and larger scale systems for increased generation. Plans for demsonatratio scale prototype.
			Development of metal membrane based reactor for ammonia production at low pressures by sourcing hydrogen directly from a PEM electrolyser 	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 electric vehicles) / Fundamental research into metal hydride materials capable of compressing H2 using low grade heat sources (2018 - 2021) 	Development of a prototype solid state H2 compressor designed to deliver 350 bar H2	Dr Ashleigh Cousins / CSIRO	CSIRO Hydrogen FSP/ strategic areas of research	https://research.csiro.au/hydrogenfsp/

		Transportation / Storage	R&D in subsurface hydrogen storage 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. 2019 - 2026	Demonstrate the viability of exporting hydrogen in the form of ammonia and extracting ultra high purity hydrogen at point of use.	Dr. David Wong / CSIRO	Fortescue and partners	Pilot trials
			R&D into new carriers and pathways for hydrogen storage and distribution 2019 - 2028	develop direct production technologies for methanol and ammonia, as well as increasing our understanding of ortho-para conversion of hydrogen during liquefaction and new conversion processes for LOHCs.	Various - contact Dr Nikolai Kinaev / CSIRO	CSIRO Hydrogen FSP/ strategic areas of res	https://research.csiro.au/hydrogenfsp/
			Basic R&D for direct ammonia utilisation in a solid oxide fuel cell for power generation 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	
			Hydrogen Utilisation in industrial applications: evaluation of impact on materials and infrastructure 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 2021 - 2023	Developing modular small scale ammonia cracker	Dr John Chiefari	CSIRO Hydrogen FSP	completed
		Utilisation	Fractal Hydrogen Burner 2019 - 2024	Developing technologies to address hydrogen flame issues (stability, lack of radiant heat)	Dr Jim Patel/ CSIRO	CSIRO Hydrogen FSP	seeking commercial partners
			Iron Production Using Ammonia as a Reductant 2022 - 2025	Understand thermodynamics and kinetics of direct reduction of Australian Iron ores with Ammonia	Dr Mark Pouncby /CSIRO	CSIRO Hydrogen FSP,Swinburne University	PhD program in progress
			Hydrogen refuelling station	HRS to support local mobility projects	Dr Patrick Hartley/CSIRO		refueller installed - in operation
			Ammonia combustion in modified diesel engines 2019 - 2026	Slow-speed ammonia engines allow distributed power generation and also support decarbonisation.	Dr Louis Wibberley / CSIRO	ASLET	development engine being installed

The 7th RD20 conference, Oct. 3, 2025

National Research Council of Canada

Jean-François Houle
Vice-President, Engineering

1. Introduction

Clean energy, low-carbon technologies, GHG emissions reduction and climate change are high priorities for all levels of government in Canada. These priorities are reflected in a multitude of specific policy actions including but not limited to Canada's commitment to the Paris Agreement, Mission Innovation, the Sustainable Development Strategy, the Pan-Canadian Framework on Clean Growth and Climate Change and numerous clean energy programs administered by departments responsible for Environment and Climate Change (ECCC), Innovation, Science and Economic Development (ISED) and Natural Resources (NRCan).

As the federal government's largest research and technology organization, the NRC mandate is to provide R&D support to public policy formation, innovation in industry and knowledge development. The NRC catalyzes technology development within its own research facilities and by working alongside industry, university, and other science-based departments and laboratories at the provincial and federal levels.

The NRC is a collaboration focused science and research organization that supports partners from government, industry, and academia with over 3700 scientists, engineers, and technicians across 22 R&D sites across Canada covering a range of economically important sectors from Engineering to Life Sciences. NRC researchers work along the entire technology readiness scale, from fundamental research, to technology development and scale-up, to prototyping and field testing.

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

NRC conducts R&D activities across a wide range of clean energy technologies and applications. Activities include:

- Emissions reduction through electrification, concentrating on energy storage technologies for both stationary and transportation applications, and integration of new technologies into grid and vehicle systems
- Development of bioenergy resources through improvement of biomass and organic waste conversion, biofuel upgrading, and certification and integration of sustainable fuels
- Increasing fuel flexibility of conventional power generation technology such as gas turbines
- Increase energy efficiency, productivity and clean energy use in mines to reduce emissions and environmental impact
- Use of sustainable fuels and improving efficiency in aircraft, surface and marine vehicles
- Electrification of heavy and long-distance transportation
- Development, deployment and validation of the energy performance of retrofit technologies for commercial and institutional buildings
- Development of new technologies and associated technical guidelines for improving the

energy performance of residential buildings

3. Specific research activities

Advanced Clean Energy program

For Canada to meet its 2030 emissions reduction targets of 40 to 45% and achieve net-zero emissions by 2050, focused research is required to develop clean energy technologies and bring them from the lab to the market. The National Research Council of Canada's (NRC) Advanced Clean Energy program was developed to support the transition to a low-carbon economy with the priorities of both the Government of Canada and Canadian industry in mind.

The Advanced Clean Energy program accelerates the development of clean, renewable fuels, and energy storage materials and devices that facilitate the transition to low- and zero-carbon fuel and the electrification of our energy supply, across all sectors. To accomplish this, the program's activities are focused on the following 4 pillars:

(ア) Battery energy storage - Enable electrification in both power generation and end-use across multiple sectors.
(イ) Low-carbon fuels - Facilitate fuel switching across multiple sectors using low-carbon fuels produced from waste and negative-value feedstocks.
(ウ) Hydrogen - Advanced technologies for the production of a new generation of zero-carbon fuels and applications.
(エ) Grid integration - System-level R&D to enable higher penetration of renewable energy in off-grid and remote applications.

Platform to Decarbonize the Construction Sector at Scale

The Construction Research Centre at the National Research Council of Canada (NRC) is addressing one of the biggest challenges facing Canada's construction sector: decarbonization. The construction sector is a significant emitter of greenhouse gases (GHGs), from the production of construction materials to the heating, cooling and maintenance of existing buildings and infrastructure. To achieve Canada's emission reduction targets by 2050, new low carbon technologies and tools are needed to support further advancements in the construction sector.

Together with academia, industry and governments, the NRC is applying its R&D expertise to support the development and deployment of low carbon construction solutions through the new Platform to Decarbonize the Construction Sector at Scale. Research areas are:

Low carbon regulatory solutions

The NRC will work with stakeholders to develop new low carbon requirements and implement them through standards, specifications, guidelines and publications such as the Canadian National Master Construction Specification (NMS) and the National Model Codes through activities such as:

① Supporting the development of new language for the 2025 and 2030 National Model Codes that will enable the regulation of operational GHG emissions and embodied GHG emissions, respectively
② Developing a low carbon guideline that considers life-cycle GHG emissions in federally funded construction projects
③ Updating the NMS to include low carbon solutions
④ Supporting the development and implementation of a new suite of performance-based requirements in the National Model Codes

⑤ Enabling the digitalization of the National Model Codes and the NMS
New research and technical solutions to reduce carbon will support these requirements, including life-cycle assessment, life-cycle performance of buildings and infrastructure, digitalization, construction practices and materials.

Clean and Energy-efficient Transportation program

Transportation accounts for a quarter of Canada's greenhouse gas emissions, of which approximately 86% comes from ground vehicles. As the transportation industry undergoes major changes to reduce the environmental footprint of vehicles, the Government of Canada has committed to net-zero emissions by 2050 and has set federal targets of zero emission vehicles reaching 100% of light-duty vehicles sales by 2040.

The NRC's Clean and Energy-efficient Transportation program helps industry develop the technologies needed to be leaders in the growing supply chains associated with low-carbon mobility and sustainable transportation. The program's activities are focused on 6 research areas:

Aerodynamics – Contribute to a sustainable transportation system in Canada through the development and deployment of aerodynamic technologies and methods that meet the needs of current and emerging transportation frameworks.

Batteries – Accelerate transportation electrification supported by an innovative, sustainable, cost-competitive and world-class lithium battery ecosystem in Canada.

Electrical machines – Promote the deployment of transportation electrification by the development of innovative, cost-competitive, efficient and durable electrical machine solutions for Canadian industries.

Fleet energy efficiency – Empower fleet operators by providing tools and guidance during their transition to lower emissions and energy-efficient operations.

Hydrogen applications – Accelerate transportation electrification supported by an innovative, cost-competitive, world-class hydrogen technologies ecosystem in Canada.

4. International collaboration

The National Research Council (NRC) highly values international collaboration and actively engages with global partners through various mechanisms to advance clean technology R&D. These international partnerships are integral to building strategic platforms for future initiatives and opportunities, with NRC playing a central role in connecting key stakeholders across both domestic and international innovation ecosystems.

In 2019, NRC expanded its global presence by opening its first international offices in Japan and Germany, reflecting a growing commitment to fostering closer interactions and collaborations. This move coincided with the 2019 RD20 conference, during which NRC and the Japan-based AIST signed a Memorandum of Understanding (MOU) on research cooperation, paving the way for several collaborative projects currently in development. Additionally, NRC has established MOUs with key international partners, including UKRI in the UK, RWTH Aachen and DLR in Germany, and KIAT in Korea.

Through its associate membership in EUREKA, NRC supports Canadian companies and innovators by providing funding for co-innovation projects with European partners and beyond. Recently, NRC collaborated with NEDO on a EUREKA Globalstars consortia call for proposals to facilitate joint R&D projects between Canadian SMEs and Japanese corporations.

Further exemplifying its global engagement, NRC represents Canada on technical working groups at the International Energy Agency (IEA), including the Technology Collaboration Programmes (TCPs) on Energy Storage and Advanced Fuel Cells, as well as the World Bank's Energy Storage Partnership. NRC also maintains strong relationships with U.S. Department of Energy research laboratories, particularly ARPA-E and the National Renewable Energy Laboratory, to align efforts in advancing clean energy solutions.

Energy Diversification Research

In both the short-term and long-term, research institutions in G20 countries should work to create a resilient global market for low-carbon, cost-effective energy sources to meet the needs of developed and developing economies. As the global energy system continues its trend to increased electrification, research institutions in G20 countries should continue and expand collaborative work on technologies to integrated renewable energy sources into national electric grids, as well as technologies to reduce GHG emissions from traditional energy sources.

Green Aviation Research

In the short-term (3-5 years), NRC is prioritizing research and technology development for electrification of aircraft propulsion of up to 1-2MW class engines or smaller. Also in the shorter term, the focus of our research on hydrogen is in realizing viable, hydrogen-fueled combustion systems for aero gas turbines, and in aspects related to hydrogen safety, storage and distribution. In the medium to longer-term, electrification initiatives for larger class of aircraft, and also hydrogen employment with fuel cells are anticipated to be of greater relevance.

One of the key best practices developed by the NRC in fostering international collaboration is the use of the "3+2" format for several international calls for proposals. This innovative model has proven to be an effective way to facilitate partnerships between Canadian researchers, industry, and academia, and their counterparts in partner countries, including research institutes. NRC firmly believes that this model is a highly effective approach to international collaboration, and we are committed to pursuing it as a standard framework for future calls for proposals. By continuing to leverage the "3+2" format, NRC aims to strengthen its relationships with international partners, foster deeper collaborations across borders, and accelerate the translation of research into commercial outcomes that benefit both Canadian industry and the global marketplace.

Funding plays a critical role in enabling research and fostering international collaboration. However, when organizations from different countries collaborate, they often face the challenge of securing funding independently within their respective jurisdictions. This typically means that each partner must navigate separate funding processes, which can create significant barriers to successful collaboration. One of the key challenges is the misalignment of funding call timelines across countries. If the calls for funding in each country do not align, it can prevent collaborations from materializing, as the partners may not be able to synchronize their efforts or secure funding within the same timeframe.

Additionally, the independent funding application process can lead to disparities in how much funding each partner is able to secure. In some cases, one organization may successfully obtain

funding while the other does not, which can limit the scope of the project or, in the worst case, prevent the project from moving forward at all. This fragmentation in funding processes not only hinders the potential of international research collaborations but also diminishes the impact of the research itself.

To overcome these challenges and unlock the full potential of international cooperation, the development of joint funding mechanisms is essential. By establishing shared funding pools or coordinated funding calls, countries can align their efforts, ensure equitable participation from all partners, and provide a more streamlined pathway for cross-border research initiatives. Such mechanisms would enhance the ability of research teams to pursue larger, more ambitious projects with greater impact, driving innovation and collaboration on a global scale.

5. Future perspectives (towards carbon neutrality)

Future challenges facing G20 nations related to clean energy technologies include securing reliable, low-cost supplies of critical minerals to manufacture the energy storage systems needed to effectively integrate renewable energy sources into national electric grids and to transition transportation systems to electric power.

Dr. Jean-François Houle, Vice-President, Engineering, National Research Council Canada

Dr. Jean-François Houle's experience in the private and public sectors, portfolio of responsibilities and track record in marshalling researchers, government and business to solve problems, ideally equip him to contribute as Observer to the European Commission's Technology Council for Advanced Materials.

As Vice-President of the National Research Council Canada (NRC)'s Engineering Division since April 2022, Dr. Houle's responsibilities include oversight of NRC's Energy and Construction research centres, including programs on critical battery materials and decarbonized construction materials. Dr. Houle also provides executive oversight for the launch of NRC's self-driving materials discovery laboratories in Toronto, Canada. As the Executive Lead for Climate Innovation at the NRC, Dr. Houle is responsible for delivering a coordinated strategy to develop innovation solutions to challenges arising from the global climate crisis. As Executive Co-Sponsor for NRC's Departmental Sustainable Development Strategy, Dr. Houle is well placed to represent the Government of Canada's Federal Sustainable Development Strategy. In addition, Dr. Houle has successfully fostered international collaborations as NRC's Executive Champion for the United Kingdom and executive lead for the RD20.

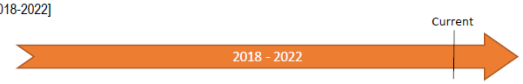
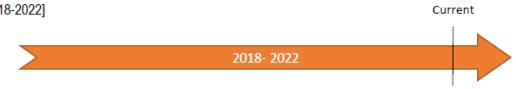
Dr. Houle joined the National Research Council (NRC) as Director of Research and Development for the Medical Devices Research Centre in June 2014. In March 2017, he was named to the position of General Manager. In March 2020, he became Vice-President of the Pandemic Response Challenge program, bringing 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.

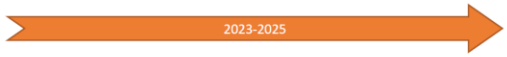
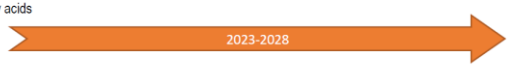
Prior to joining the NRC, Dr. Houle spent 14 years leading business, corporate and product development activities in privately-held and publicly-traded biotechnology firms at various stages of development, from university spin-offs to more established companies. These activities led to collaborative 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 people around the world.

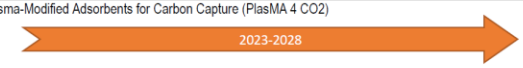
Dr. Houle holds a Ph.D. in Experimental Medicine from McGill University

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
		Materials For Clean Fuels Challenge (H2 Production Thrust)	Hydrogen and Climate Partnership (H2CliP) - A new hydrogen network between Canada and Germany as a key component of a climate-neutral energy system 2022-2025	Material acceleration pipeline for the theoretical and experimental design, synthesis, and testing of acid-stable OER catalysis. Infrastruture development (automated powder synthesis, electrode fabrication, and characterization/performance testing) and theory/simulation integration into the accelerated discovery pipeline.	Black, Robert	University of Toronto	
			Autonomous Adaptive Design & Discovery of Acid-Stable OER Catalysts 2023-2026	The objective of this project is to develop a dynamic model of a renewable electrolysis plant to inform optimal operating and design conditions for improved electrolyser efficiencies	Fatih, Khalid	Pulsenics (Canada), The Universite du Quebec a Trois-Rivieres (Canada), Segula GhbH (Germany), University of Bayreuth (Germany), the University of Victoria (Canada)	
			HYER: Modeling of electrolysis plant 2022-2025	The main goal of this project is to reduce the cost of hydrogen by enhancing the durability and performance of the PEM electrolyzer. Specifically, project will focus on identifying PEM electrolyzer degradation mechanisms, material characteristics and operating parameters that govern this degradation. This research will be carried out through a combination of electrochemical testing and synchrotron spectromicroscopy imaging.	Fatih, Khalid	University of Toronto	
			Advanced non-precious metal oxide anodes for AEM and PEM water electrolyzers 2023-2026	This work aims at development of a novel platform for development of advanced low-cost non-precious metal oxide electrocatalysts and rigorous comparative testing from half-cells to electrolysers for both PEM and AEM applications	Fatih, Khalid	University of British Columbia	
			Increasing the durability of oxygen evolution catalysts for green hydrogen and for CO2 utilization: Accelerated Testing and Modeling of Electrocatalysts at Industrially Relevant Conditions 2023-2026	This project will discover highly active and stable Ir-free acidic OER electrocatalysts with the aim of circumventing reliance on precious Ir-based OER catalysts used in polymer electrolyte membrane water electrolyzers	Fatih, Khalid	University of Toronto	
			Stand-Alone Photoelectrochemical Tandem Devices for Overall-Water Splitting 2023-2026	Converting solar energy into hydrogen fuel by utilizing a tandem photoelectrochemical (PEC) system with the main goal of generating a robust, scalable, and low cost proccessing solution of solar energy technologies. The Contribution from NRc will be delivery of feasible fabrication process for MoS2 catalyst layer on the cathode side.	Hui, Shiqiang	University of British Columbia	
			AL-H20-REAC: Germany Novel Al. Reactor 2022-2025	The goal of this project is to develop a reactor for sustainable cogeneration of hydrogen, heat and alumina from combustion of recycled aluminum with water	Kim, Keun Su	GH Power (Canada), Carleton University (Canada), ParteQ GmbH (Germany), RWTH Aachen (Germany)	
			External Field Assisted Hydrogen Production 2023-2024	This work aims to explore the acoustic assistance to achieve higher efficiency in electrochemical reactions bringing down cost that is necessary for energy transition.	Kruger, Silvio Elton		

National Research Council (NRC) / Canada	Hydrogen		INTEGRATE: Innovative alkaline membrane-electrode designs for low-cost green hydrogen at gigawatt scale 	This project involves the design and optimization of a novel AEM electrolyser designed for the GW market to minimize the cost of hydrogen production through the development of high-performance, stable electrodes based on non-noble catalysts	Qu, Wei	Ionomr (Canada), Simon Fraser University (Canada), Sunfire GmbH (Germany), Fraunhofer IFAM (Germany)	
			A self-driving laboratory for CO2 utilization 	This project is designed to accelerate the development of a reactor that converts CO2 capture solutions into valuable commodity chemicals	Song, Datong	University of British Columbia	
		Clean and Energy Efficient Transportation	Hydrail Risk Assessment, Codes & Standards [2021-2026] 	Risk Assessment of Hydrogen and Battery Power in Locomotives - Development of broad knowledge about the risks and hazards associated with hydrogen and battery technologies - Application of Risk Mitigation Research to Real-World Hydrogen Fuel Cell Rail Locomotive In-service Use	Elton Toma	(Domestic) Transport Canada, University of British Columbia, Natural Resources Canada	https://nrc.canada.ca/en/stories/towards-net-zero-emission-railway-system-hydrogen-powered-trains
		Combustion Technologies for Stationary Applications	Development of H2 combustion technology. [2018-2022] 	Supported development of a H2-fuelled gas turbine combustion system for a multi-national OEM through high-pressure rig testing.	Nanthan Ramachandran	(Domestic) Multi-national Engine OEM	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Next generation land-based gas turbine combustors [2018-2022] 	Develop and optimize a novel gas turbine fuel injection system for hydrogen-enriched fuels.	Dr. Patrizio Vena	(Domestic) Multi-national Engine OEM	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Hydrogen enriched turbulent flame behaviour [2018-2023] 	Gain a fundamental understanding of physical mechanisms that govern hydrogen-enriched flames	Dr. Patrizio Vena	(Domestic) McGill University, Multi-national Engine OEM	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Low Emission Burner development for turbine application. [2018-2021] 	Develop low emission combustion technologies for turbine application of gaseous fuels with H2 enriched blends	Dr. Sean Yun	(International) Korean Institute of Machinery and Materials	https://nrc.canada.ca/en/research-development/research-collaboration/programs/bioenergy-systems-viable-stationary-applications-program
			Life Cycle Based Methodology Development to Assess the Carbon Intensity of Hydrogen Production Pathways (2022-2026) 	Development of an LCA-based methods to assess the carbon intensity of hydrogen production pathways relevant to Canada	Dr. Giovanna Gonzales-Calienes	(Domestic) NRCan, ECCC	Advanced Clean Energy program – National Research Council Canada
			Gap Analysis in Codes and Standards Across the Hydrogen Value Chain (2022-2026) 	An analysis of existing codes and standards across the hydrogen value chain, from production to end use, will help identify gaps and address those to enable the deployment of hydrogen technologies in Canada	Mr. Manuel Hernandez	(Domestic) NRCan, Transport Canada, CSA	Advanced Clean Energy program – National Research Council Canada

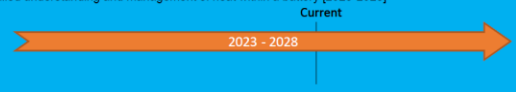
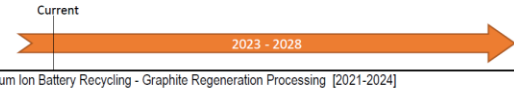
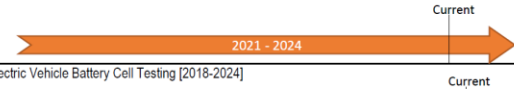
		Advanced Clean Energy	Hydrogen Distribution and Storage Infrastructure [2023-2028] Current 2019 - 2021	Investigation and testing of embrittlement of NG/H2 blends in pipelines, as well as H2 detection and coating for embrittlement mitigation	Aminul Islam	Office of Energy Research and Development, Enbridge, Dalhousie	Advanced Clean Energy program – National Research Council Canada
			Data Management and Analysis of Hydrogen Refueling Stations [2019-2024] Current 2019 - 2024	Develop core competencies in regard to the analysis of Hydrogen refueling station data, gain expertise in the applicable fueling protocols, and build data analysis template on the existing data	Cyrille Décès-Petit	(Domestic) Natural Resources Canada, Transport Canada, Measurement Canada, HTEC	Advanced Clean Energy program – National Research Council Canada
			Advanced water electrolysis for hydrogen production [2023-2028] Current 2019 - 2021	Development and investigation of various aspects of water electrolyzers including porous transport layer, PEM and AEM performance	Alison Platt	Office of Energy Research and Development, Ionomr	Advanced Clean Energy program – National Research Council Canada
			Critical Battery Materials Initiative 2023-2027	As a result of a gap identified in Canada's battery materials' midstream supply chain between critical mineral mining and battery manufacturing, the initiative will establish self-driving labs to accelerate and link discoveries in new battery materials with more economically and environmentally sustainable approaches to processing battery minerals.	Dr. Jennifer Littlejohns	Natural Resources Canada	Critical Battery Materials Initiative – National Research Council Canada
			ML-assisted discovery, optimization, and modeling of CO2 Conversion, from material innovation to system optimization, using high-throughput/automated platforms and AI-guided approaches 2023-2028	This project will demonstrate materials acceleration principles as applied to the discovery and design of CO2R catalyst materials. A combination of High Throughput Experimentation, data analytics and AI-driven material optimization will identify new candidate chemistries and process design.	Aranguren van Egmond, Derek	Natural Resources Canada	
			AI-guided High-Throughput Experimental Discovery of HEO/HEN Catalysts for the Oxygen Evolution Reaction 2023-2025	This project seeks to develop a combined high-throughput experimental and density functional theory workflow that is informed by artificial intelligence to discover novel high entropy oxide oxygen evolution reaction (OER) catalysts.	Black, Robert	University of Toronto	
			In Situ/Operando Characterization of Electrochemical CO2 Conversion Materials 22023-2026	This project will develop correlative operando spectroscopy and microscopy techniques to enable a comprehensive understanding of materials that drive sustainable energy conversion processes.	Black, Robert	McMaster University	
			Design, synthesis and characterization of organic molecules for carbon capture 2023-2025	This project is to develop a new electrochemical technology for carbon capture. We will design, and synthesize two catogries of redox materials with high solubility and stability and high oxygen torerance for electrochemical pH swing carbon capture	Chen, Shuai	University of Toronto	
			Advanced nanocomposite membranes for low-cost CO2 capture and conversion 2023-2028	The objective of this project is to developping robust polymer nanocomposite membranes and catalytic membrane for CO2 capture and conversion.	Cho, Jae-Young	Natural Resources Canada	

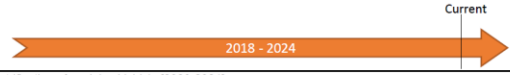
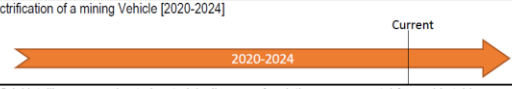
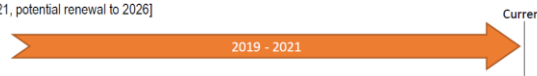
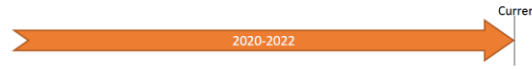
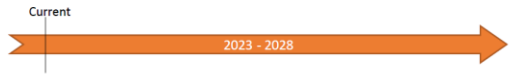
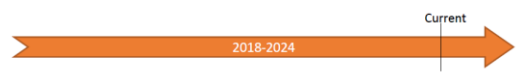
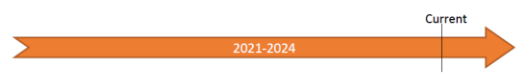
		Materials For Clean Fuels Challenge Program (CO2 Conversion Thrust)	Plasmon-enhanced CO2 Valorization for Scalable and Sustainable Electrolysis 	This work will combine high-speed manufacturing processes and catalysis to produce optically-active surfaces for plasmon-enhanced catalysis. Plasmon-enhanced CO2 reduction will be electrochemically converted into value-added products to provide a cost-effective and scalable industrial solution for reducing CO2 levels	Houache, Mohamed	Natural Resources Canada	
			Materials for In-situ Capture and Conversion of CO2 to Chemical Feedstocks 	The goal of this project is to develop innovative multifunctional composites to capture and convert CO2 to MeOH in situ. The two key objectives will be met at laboratory-scale: 1) Design, synthesize and characterize a multifunctional composite that can achieve a CO2 adsorption capacity of at least 1 mmol/g in the temperature range of 180-240 ˚C (CO2 pressure 0 - 1 atm); 2) Convert CO2 to MeOH in the temperature range of 180-240 ˚C. The third key objective will be: scale-up synthesis and demonstration of the multifunctional composite for CO2 capture and conversion it to MeOH at pilot-scale.	Hui, Shiqiang	Natural Resources Canada	
			Renewable electricity and Emissions direct Conversion to low-carbon energy 	This project aims to mature a new Power-to-X technology for the one-step conversion of flue gas into low-carbon syngas	Lotfi, Samira	University of Sherbrooke	
			In-situ studies of catalyst evolution duing thermocatalytic hydrogenation of CO2 	The project involves combination of cost-effective catalyst synthesis, advanced characterization, in-situ testing and capability development to determine optimal thermal treatment condition and improve catalyst activity/selectivity leading to optimal methanol yield. This project aims to advance the existing research on the Thermocatalytic hydrogenation for CO2 conversion and foster transformative technologies to sustainably transition Canada's energy and chemical industries to a low-carbon economy.	Patarachao, Bussaraporn		
			Development of harmonized CCU/H2 datasets and integration in NRC's Data Hub 	This project aims to identify and assess Carbon Dioxide Removal (CRD) pathways to enable Canada to achieve its long-term climate change mitigation targets. The platform to be developed will enable a continuous/seamless 3-way approach to connect laboratory data, LCI/LCCI datasets, and sustainability assessment and help refine research focus and accelerate timely decision-making for policy development and future R&D investments.	Shadbahr, Jalil		
			Development and demonstration of a microbial electrosynthesis platform for carbon dioxide conversion to medium chain fatty acids 	The goal of this project is to achieve CO2 conversion to medium chain fatty acids (MCFAs), such as caproate, through microbial electrosynthesis, which combines production of short chain fatty acids and chain elongation. Project outcomes include this novel microbial electrosynthesis platform and process scale-up evaluation.	Tartakovsky, Boris	Natural Resources Canada	

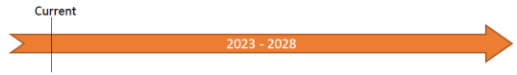
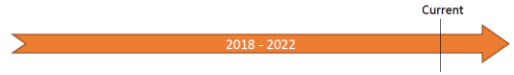
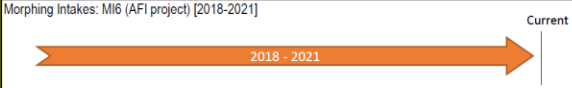
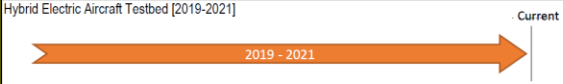
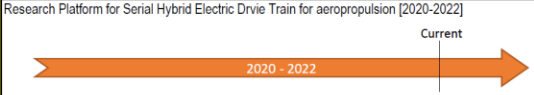
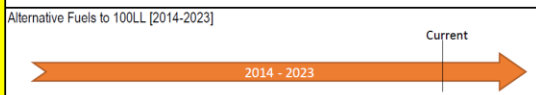
National Research Council (NRC) / Canada	CCUS		Upgrading CO2 To 1,3-Butanediol and Medium Chain Oleochemicals via Catalysis-Enhanced Microbial Electrosynthesis 	This collaboration is aimed at developing microbial consortia (wild-type and engineered co-cultures) for effective CO2 conversion to short and medium chain fatty acids and butanediols. Outcomes include microbial co-cultures suitable for high rate CO2 conversion to high value products in a microbial electrosynthesis system.	Tartakovsky, Boris	University of Toronto	
			Fundamental understanding and catalytic performance improvement of single-atom catalysts and electrode engineering for direct conversion of carbon capture solutions using a bicarbonate electrolyzer 	This project will combine single-atom catalysis (SAC) synthesis and electrode fabrication into a new, continuous, cost-effective manufacturing process, which will produce highly efficient SACs in a scalable electrode design, with continuous pore structure and high utilization. The work will generate new capabilities in cost-effective non-noble metal SACs and advanced FSE technology for directly converting carbon capture solutions into value-added chemical compounds using a bicarbonate electrolyzer.	Zhang, Lei	Natural Resources Canada	
			3D Printed Sensors for CO2 Pipeline Damage Detection & Structural Health Monitoring 	This project's objective is to demonstrate conformally 3D printed (non-planar) piezoelectric ultrasound transducers, with novel architectures directly patterned onto pipeline segments. The sensor prototypes will be geared toward detection of structural defects unique to CO2 transport pipelines, and their 3D printed architectures will be designed to match this application.	Aranguren van Egmond, Derek	Natural Resources Canada	
			Plasma-Modified Adsorbents for Carbon Capture (PlasMA 4 CO2) 	This project aims at enhancing the adsorption capacity and selectivity of carbon-based and metal-oxide solid adsorbents using non-thermal plasma treatments, followed by forming the super-adsorbents into filters via 3D printing or densification routes.	Asgarian, Ali	Natural Resources Canada, ArcelorMittal Dofasco (Canada)	
			Smart Molecule Discovery and Process Optimization for Electrochemical Carbon Capture 	This project focuses on development of an electrochemical pH-swing technique that captures and releases CO2 by shifting the pH of a working fluid between basic and acidic conditions with the goal of reducing energy consumption via new redox molecules as proton coupled electron transfer (PCET) active agents.	Chen, Shuai	Natural Resources Canada	
			Materials and System Development for Membrane-Based Direct Air Capture 	The goal of this work is to design and synthesize a series of novel polymeric materials, fabricate polymeric nanocomposite membranes, and develop an efficient membrane-based direct air capture (m-DAC) process from lab scale to a pilot scale.	Du, Naiying	Natural Resources Canada	
			CarboGeoSensing: Development of real-time sensing methods at the pre-processing, processing and post-processing phases of in-situ assessment of ex-situ carbon sequestration in geological matrices 	This work aims at filling the gaps between mineralization processes and on-site sensing for fast, accurate and low cost mineralization. The objective is to develop a new and robust global sensor solution built on an optimized combination of new, efficient leading-edge laser, optical and ultrasonic technologies.	El Haddad, Josette	Natural Resources Canada	

		Clean production Program (CO2 Capture Thrust	Capture of low concentration CO2 by advanced MOFs materials 	This project will improve the stability of MOF materials under operation conditions by design and selection of new MOFs with hydrophobic properties and chemical stability towards moisture to eliminate the adverse effect of H2O on the CO2 capture. The project will deliver enhanced capture capacity of MOFs materials for low concentration CO2-containing flue gas streams by integration of novel functional materials such as promoters and linkers into MOFs to compare with benchmark materials commonly used, such as activated carbon (AC) and MOFs without functional components. This project also is also exploring different scalable synthesis routes to reduce the cost of MOF materials	Hui, Shiqiang	Natural Resources Canada	
			Hybrid biotechnology for mineral carbonation in mine tailings 	This work aims to develop a biotechnology using microorganisms to catalyze CO2 carbonation in minerals and metallurgical wastes , forming stable metal carbonates.	Kaur, Kamalpreet	Natural Resources Canada	
			Physics Informed Machine Learning for Carbon Mineralization Prediction and Its Integrated Toolbox 	The target is to use machine learning to predict the carbon mineralization capacity in mine wastes. The carbon mineriization models will be developed and integrated into the machine learning toolbox to improve the prediction accuracy and reliability.	Ma, Liang	Natural Resources Canada	
			Accelerated ex-situ CO2 Mineralization using Industrial Solid Wastes for Production of Long-live Products 	The main objectives of this project are to develop methodologies to accelerate the reaction rate for ex-situ CO2 mineralization using different types of industrial solid wastes available in Canada as well as to estimate carbonation efficiency and capacity, evaluate the improvement on physical and chemical properties of the carbonated product as well as long-term stability of the captured CO2 and benchmark of the accelerated ex-situ CO2 mineralization technology based on scalability, economic and environmental indicators.	Patarachao, Bussaraporn	Natural Resources Canada	
			Decarbonization of pyrometallurgical routes through data-driven optimization provided by online LIBS 	This work aims at helping decarbonizing high temperature processes on heavy industry by providing real-time chemical analysis of molten material by laser-induced breakdown spectroscopy (LIBS).	Soares de Lima Filho, E	Natural Resources Canada	
			Weld overlay coating and inspection/monitoring technologies for cost-effective CO2 transportation 	The potential will be investigated to use selective and adaptive weld overlay coatings of corrosion-resistant alloys on carbon steels for localized corrosion prevention, mechanical enhancement, and/or weld repair to meet performance requirements of CO2 pipelines and ancillary equipment for safe transport of CO2. A laser ultrasonic system will be developed for pipeline hard coating inspection, and integrated ultrasonic sensors advanced for in-service monitoring of CO2 transportation pipelines.	Wang, Sheng-Hui	Natural Resources Canada	

National Research Council (NRC) / Canada	Renewable Enegy	Advanced Clean Energy Program	Integration of thermochemical and biological processes for enhanced conversion of challenging organic wastes into fungibl 	Low carbon fuel production through integrated systems of thermochemical and biochemical conversion technologies using food waste and plastic feedstocks	Dr. Laurent Spreutals	(Domestic) Ecole Polytechnique, Natural Resources Canada	Advanced Clean Energy program – National Research Council Canada
			Drop-in Sustainable Aviation Fuel (SAF) from Low Quality Waste Feedstocks [2023-2028] 	Conversion of food waste to biocrude in various blends utilizing hydrothermal liquefaction and subsequent utilization for upgrading to SAF.	Dr. Devinder Singh	(Domestic) Natural Resources Canada	Advanced Clean Energy program – National Research Council Canada
			Switching from Fossil Fuels to Hydrogen/Ammonia in Heavy Industry Power Generation Processes [2023-2028] 	Development and implementation of advanced CI for hydrogen and/or ammonia utilization to understand emissions reduce barriers to the adoption in HDVs and marine.	Dr. Hongsheng Guo	(Domestic) Environment and Climate Change Canada, Natural Resources Canada, Caterpillar Engines	Advanced Clean Energy program – National Research Council Canada
			Promising opportunity to reduce Iron and Steel industry energy/feedstock needs and CO2 emissions utilizing residual CO-rich gases [2023-2028] 	Utilizing the emissions from the steel industry to biochemically convert to natural gas to displace fossil energy and reduce emissions	Ms. Ruxandra Albu Cimpoia	(Domestic) Canadian Steel Producers Association, McMaster University, CTTEI, Natural Resources Canada	Advanced Clean Energy program – National Research Council Canada
			Harmonized and integrated data-driven LCA/TEA platform and case studies for carbon waste to fuels with carbon capture 	Integration of lifecycle analysis and technoeconomic platforms as a comprehensive decision making tool on the production of various gaseous and liquid biofuels from biomass sources, including residuals and MSW	Dr. Farid Bensebaa	(Domestic) Queen's Unviersity, Agriculture Canada, Environment and Climate Change Canada, Natural Resources Canada	Advanced Clean Energy program – National Research Council Canada
		Aerospace Research Centre	Metal fuel for energy carrier from renewable energy source [2020-2021] 	Validate the potential of using metal fuel as an energy carrier for renewable energy sources	Dr. Sean Yun	(Domestic) McGill University	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Next Generation Materials for Solid-State Batteries [2023-2028] 	To design and synthesize composite electrolyte materials and fabrication processes with greater flexibility and chemical stability along with processes	Dr. Yaser Abu-Lebdeh	Domestic (University of British Columbia), Korean Institute of Energy Research	Advanced Clean Energy program – National Research Council Canada
			Improved Vanadium Redox Flow Battery Performance [2023-2028] 	To understand and model phenomena occurring in the VRFB and their mechanisms from a fundamental perspective in order to improve specific materials and components.	Dr. Roberto Neagu		Advanced Clean Energy program – National Research Council Canada
		Advanced Clean Energy Program	Enhancing the End-Of-Life Recyclability of EV batteries [2023-2028] 	To develop testing standards and diagnostic tools for the remanufacture/repurpose of end of life batteries, investigate the potential for direct anode regeneration, develop novel elemental separation techniques of anode and cathode materials, and understand the economic and environmental impact of recycling.	Andriy Plugatyr	(Domestic) Natural Resources Canada, Various recyclers	Advanced Clean Energy program – National Research Council Canada

National Research Council (NRC) / Canada	Energy Management Systems		Detailed understanding and management of heat within a battery [2023-2028] 	Investigation and development of novel methods to manage heat within batteries	Dr. Dean MacNeil	(Domestic) Natural Resources Canada	Advanced Clean Energy program – National Research Council Canada
			2nd Life EV batteries incorporating an optimized battery management system [2023-2028] 	Investigation and development of novel diagnostic tools for the repurposing of batteries at their end of life	Dr. Yeong Yoo	(Domestic) OERD,	Advanced Clean Energy program – National Research Council Canada
		Clean and Energy Efficient Transportation	Addressing the scaling challenges for Silicon Solid State Battery [2023-2028] 	Investigate different strategies to combine silicon anodes with SSE in a battery in order to confirm if the improvements can be materialized and scaled-up to the prototype level.	Dr. Mathieu Toupin	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Quasi-Solid-State Electrolytes for EV Li-metal batteries [2023-2028] 	Study of QSSB by building on developments on polymer and composite SSBs realized at NRC during the last 12 years, as well as investigating the manufacturability potential of such technologies for scale up with NRC's prototyping line.	Dr. Alexis Laforgue	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Mitigating Non-uniform degradation in large format EV cells [2023-2028] 	Study non-uniform degradation in large-format EV cells and propose new cell designs that will mitigate the issue.	Dr. Peter Kovacik	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Green Remanufacturing of Li-ion Battery Electrodes [2023-2028] 	Recover and remanufacture with green solvents, sourced potentially from bio-feed, pristine materials used during LiB manufacturing.	Dr. Régis Chenitz	(Domestic) Natural Resources Canada, Novonix	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Novel Thermal Management Strategies in EV Battery Systems [2023-2028] 	Explore and characterize novel battery designs for electric vehicles (EVs) focused on the reduction of the thermal management system complexity.	Richard Fréchette	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Lithium Ion Battery Recycling - Graphite Regeneration Processing [2021-2024] 	Development of a graphite recycling process that is industrially scalable and can play a significant role in future production of critical minerals in Canada.	Dr. Régis Chenitz	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Electric Vehicle Battery Cell Testing [2018-2024] 	Evaulate the durability of battereis for electric vehicles	Dr. Dean MacNeil	(Domestic) Transport Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program

			Electric Vehicle Diagnostics and Propagation Testing [2018-2024] 	To evaluate the potential for thermal propagation of an unspecified thermal event with an electric vehcile and its effect on the vehicle and vehicle occupants	Dr. Dean MacNeil	(Domestic) Transport Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Electrification of a mining Vehicle [2020-2024] 	To design and develop an electric propulsion system, a battery technology and a charging infrastructure for a mining vehicle	Guillaume Imbleau Chagnon	(Domestic) Natural Resources Canada, CanMET Mines, Propulsion Québec, Nouveau-monde Graphite, TM4-Dana, Adria, Fournier & Fils, IVI	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
		Materials for Clean Fuels Challenge Program (AI-Accelerated Materails Discovery)	Artificial intelligence accelerated materials discovery for platinum-group-metal-free acid-stable oxygen evolution reaction catalysts. [2019-2021, potential renewal to 2026] 	Utilize high-throughput computational simulation and artificial intelligence to screen for new mixed metal oxides for oxygen evolution reaction	Dr. Isaac Tamblyn	(Domestic) University of Toronto (International) Carnegie Mellon University (USA) / algorithm and materials development	https://nrc.canada.ca/en/node/1616
			Automated robotics and unsupervised learning for the discovery of oxygen evolution reaction catalysts. [2019-2021, potential renewal to 2026] 	Automated robotics and deep-learning platform to iteratively discover new materials for the oxygen evolution reaction	Dr. Isaac Tamblyn	(Domestic) University of Toronto (USA) / platform and materials development	https://nrc.canada.ca/en/node/1616
		Clean and Energy Efficient Transportation	Devices for reduction of emissions from heavy duty automotive vehicles using conventional and renewable, low carbon fuels [2020-2022] 	The project aims to support broad adoption of low carbon and renewable fuels and advanced ICE solutions in HDV and rail applications by improving the exhaust treatment chain.	Dr. Roberto Neagu	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Advanced manufacturing and design solutions for electric motors [2023-2028] 	This project aims at developing electric motor solutions for the automotive and aerospace sectors via the use of advanced manufacturing and innovative designs.	Dr. Jean-Michel Lamarre	(Domestic) Natural Resources Canada, Dana-TM4, Polycontrols, Rio Tinto Metal Powders	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Advanced manufacturing of NdFeB permanent magnets [2023-2028] 	Advanced manufacturing processes to produce complex-shaped NdFeB magnets using Metal Injection Moulding (MIM) and Laser Powder Bed Fusion Additive-Subtractive Hybrid Manufacturing (LPBF-ASHM) technologies.	Dr. Roger Pelletier	(Domestic) Natural Resources Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Electric Vehicle Life Cycle GHG Analysis [2018-2024] 	Develop databases in support to public and government users looking to evaluate and compare of life cycle GHG emissions of electric (EVs) and conventional vehicles (CVs).	Dr. Miyuru Kannangara	(Domestic) Natural Resources Canada, Public Services and Procurement Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
			Aerodynamic Efficiency of Next-generation Zero-emission Heavy Duty Vehicles (ZEHDV) [2021-2024] 	Drag-reduction, energy-savings and range-extension potential using aerodynamically-optimized ZEHDV tractor concepts. Potential changes to the benefits of current trailer aerodynamic technologies when paired with ZEHDV shapes.	Dr. Brian McAuliffe	(Domestic) Transport Canada	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program

National Research Council (NRC) / Canada	Other		Energy savings from connected and autonomous vehicles [2023-2028] 	Use vehicle-mounted perception sensors and internet of vehicles (IoV) communication to obtain situational awareness of evolving on-road traffic so that the relative longitudinal and lateral positions of vehicles can be regulated to minimize their collective energy consumption.	Dr. Brian McAuliffe	(Domestic) Natural Resources Canada, Transport Canada, Ontario Tech University	https://nrc.canada.ca/en/research-development/research-collaboration/clean-energy-efficient-transportation-program
		Advanced Aircraft	Performance Improvement of small propulsor for UAV application [2021] 	Validate high altitude performance and improvement of small propulsor for the UAV application	Dr. Hamza Abo el ella	(Domestic) Carleton university, OEM	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Engine Inlet Velocity Profile Effects [2018-2022] 	Design, build and complete scaled testing of distortion-tolerant fan for a variety of flow conditions to serve as a test bed/proof of concept for future full-scale engine BLI studies.	Dr. Faezeh Rasimarzabadi	(Domestic) Bombardier Aerospace (International) GKN Aerospace Engine Systems (UK)	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Morphing Intakes: MI6 (AFI project) [2018-2021] 	Proof-of-concept of a morphing engine intake to optimize the aerodynamic performance for an aircraft operating with boundary layer ingestion.	Dr. Wajid Chishty	(Domestic) Royal Military College, University of Toronto, Queen's	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Low Order Simulation of Flying Taxis [2020-2022] 	Evaluation of key fuel properties for new Sustainable Aviation Fuels (alternative fuels) to reduce its certification time through combustion testing with international partners	Dr Francois Fortin	(Domestic) UTIAS	
		Clean Energy Sources	National Jet Fuel Combustion Project [2016-2021] 	Evaluation of key fuel properties for new biofuels (alternative fuels) to reduce its certification time through combustion testing with international partners	Mr. Pervez Canteenwalla	(International) International consortium including FAA (USA), engine OEMs, more than 10 universities from USA, UK and DLR	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Hybrid Electric Aircraft Testbed [2019-2021] 	NRC's first electric aircraft project. Involves the development of an airborne electric propulsion test-bed demonstrator that will be used to evaluate various hybrid-electric propulsion systems, configurations, and component technologies, as well as gather experimental data to inform evolving certification requirements.	Dr. Daniel Booth	(Domestic) Carleton University	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Conceptual study of new hybrid electric propulsion system architecture [2021] 	Feasibility study of a new conceptual architecture of hybrid electric propulsion system	Dr. Hamza Abo el ella		https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Research Platform for Serial Hybrid Electric Drvie Train for aeropropulsion [2020-2022] 	Build a research test platfrom for system optimization of serial hybrid electric aeropropulsion system	Dr. Osvaldo Arenas	(Domestic) Ryerson university	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Alternative Fuels to 100LL [2014-2023] 	Evaluation of candidate unleaded fuels that will replace 100 low-lead fuel that is currently used by the piston-powered General Aviation fleet	Mr. Pervez Canteenwalla Mr. Peter Earle	(Domestic) Transport Canada, Environment and Climate Change Canada, Canadian Owners and Pilot Association (International) Federal Aviation Administration (USA)	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre

			Impact of Alternative Fuels on Afterburner Performance [2020-2022] 	Evaluating the effects of Sustainable Aviation Fuels on military aircraft engines with afterburner technology to enable their use in the Royal Canadian Air Force fleet	Dr. Sean Yun	(Domestic) Department of National Defence	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
			Impact of Alternative Fuels on Hot Section Life [2020-2021] 	Evaluating the effects of Sustainable Aviation Fuels on military aircraft engines turbine component durability to enable their use in the Royal Canadian Air Force fleet	Dr. Kuiying Chen	(Domestic) Department of National Defence	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/aerospace-research-centre
		Platform to Decarbonize the Construction Sector	Low Carbon Built Environment Challenge Program 	A series of initiatives to support the development of low carbon construction tools, products and services.	Dr. Yasir Sultan		https://nrc.canada.ca/en/research-development/research-collaboration/programs/low-carbon-built-environment-challenge-program
			Low Carbon Regulatory Solutions 	The NRC will work with stakeholders to develop new low carbon requirements and implement them through standards, specifications, guidelines and publications such as the Canadian National Master Construction Specification (NMS) and the National Model Codes	Ms. Fiona Hill		https://nrc.canada.ca/en/research-development/research-collaboration/platform-decarbonize-construction-sector-scale
			Construction Digitalization and Productivity Challenge Program 	The Construction Sector Digitalization and Productivity Challenge program recognizes that digitalization can increase productivity in the construction sector and that performance-based design and building requirements help drive innovation. The program aims to apply these 2 underlying concepts to support the Government of Canada's Policy for Green Procurement and contribute to the emerging low-carbon economy.	Ahmad Sadek		https://nrc.canada.ca/en/research-development/research-collaboration/programs/construction-digitalization-productivity-challenge-program

The 7th RD20 conference, Oct. 3, 2025

JOINT RESEARCH CENTRE OF THE EUROPEAN COMMISSION

Participating in LS: Bernard Magenhann
Director-General, Joint Research Centre

- **Introduction**

Research in energy, transport, and environment/climate is vital to ensure a sustainable future of our planet in general and a low-carbon economy in particular. The aim of research in these fields is to support the European Green Deal and Clean Industrial Deal, to achieve climate neutrality by 2050, to make our energy system more efficient, secure, affordable and sustainable, and foster sustainable and efficient transport in Europe.

We have organised our work in portfolios, which allow us to better integrate our work across scientific and policy domains to provide coordinated support.

In order to face future challenges, JRC research includes experimental studies on ways to integrate renewable energy sources into the power grid. It also investigates the grid interoperability with, for example ICT and transport systems.

With its models and analyses, the JRC has contributed to the EU Climate and Energy Policy Packages that help Europe reduce its dependency on imports of gas and oil, boost its green technology industry and ensure sustainable growth.

For example, our scientists analysed the broader economic impacts of the more ambitious EU greenhouse gas emissions' reduction targets for 2030, 2040, and 2050, covering the interactions between the economy, the energy system and the environment. Research on the transport system focuses on transport electrification and decarbonisation, transport networks and mobility patterns, including impacts at urban and regional level.

The JRC has dedicated laboratories that focus on performance characterization of technologies (photovoltaics, hydrogen, batteries), emission control and related impacts on ecosystems, scientific tools that allow this research to be carried out efficiently and databases including information relevant to all aspects of energy, climate and transport.

- **R&D activities related to clean energy technology for carbon neutrality**

Please find our current workprogramme for the years 2025-27 in the link below. Portfolios 1-9 are strongly related to clean energy technology for carbon neutrality. You can find the link here: https://publications.jrc.ec.europa.eu/repository/handle/JRC140049

- **Specific research activities**

Please see here and overview of the portfolios: https://joint-research-centre.ec.europa.eu/scientific-portfolios_en

- **International collaboration**

  The Joint Research Centre is active in many international collaborations in the field of energy, transport, and climate and many others. We embrace new partnerships across Europe and internationally to broaden the knowledge base and impact of our work to ensure that science delivers for EU policy and beyond.

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- **Future perspectives (towards carbon neutrality)**

Please see the current JRC workprogramme for the years 2025-27 in the link below. Portfolios 1-9 are strongly related to clean energy technology for carbon neutrality. You can find the link here: https://publications.jrc.ec.europa.eu/repository/handle/JRC140049

Bernard Magenhann

European Commission

Director-General
Joint Research Centre

Bernard Magenhann is a Chartered Accountant and a Registered Auditor. He started his career as an external auditor working successively for Mazars and PricewaterhouseCoopers. He joined the European Commission in Brussels in 2002 where he worked in the Internal Audit Service, notably as Assistant to the Director General and Head of Unit responsible for the Internal Audit of the Regulatory Agencies (2002–2011). He was in charge of Business Process Re-engineering in DG HR between 2011 and 2013. In 2013 he was appointed Resource Director in DG DIGIT. In 2016 he returned to DG HR where he was appointed Deputy Director-general, notably in charge of Organisational Development, Talent Management and Budget and Finance. Finally, he joined the Joint Research Centre on 16 May 2020 as Deputy Director-general, in charge of Nuclear Decommissioning and Waste Management, Nuclear Safety and Security, Digital Transformation and Data, as well as Strategy and impact and Support services. Since the 1st of July 2025 he has been named Director General of the Joint Research Centre.

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
			<Example> ●●●● Project Describe the summary of the project. [period of the project] Current 20XX - 20XX (R&D span)	Describe the target and/or goals of the project. Note the numerical purpose (if possible). e.g. Cost reduction of ■■ to ● kWh/yen in 2020	Dr. ******, ●●	(Domestic) ●● Research Institute, ▲▲ University, etc. (International) ●● (Desired collaboration) ●● field test, ▲▲ modeling, ■■ standard, etc.	https://www.●●●

JRC

For the JRC we would like to direct you to our science hub (https://joint-research-centre.ec.europa.eu/index_en) which always features the latest information on the status of our activities, including data and publication repositories

The 6th RD20, Dec. 3, 2024

Advanced Research and Development of Clean Energy Technologies within CNRS

A. PETIT (CEO) and A. SLAOUI (Deputy Scientific Director – Energy)
National Scientific Research Centre (CNRS), France

1. Introduction

The prospects for sustainable development depend on a sustainable, secure and competitive energy supply with reduced environmental impact, both locally and globally. The energy problem is part of a complex framework that must respond to several major challenges: guaranteeing access to energy for all at an affordable cost, being part of climate change mitigation and adaptation, preserving human health and the environment and providing a sustainable energy mix. Thus, the strong growth of demand expected by 2030 at the global level should be satisfied by a wide diversification of energy sources, by increasing production and the integration of non-fossil energy into the network, in particular to control greenhouse gas emissions or to limit reliance on feedstocks that are irregularly distributed and inherently limited. To meet the needs of diversification of supply and major climate issues, the 21st century will therefore be that of the energy transition.

Since signature of Paris agreement of COP 21, France has adopted several policies to tackle these challenges such as the energy transition for green growth (LTECV)[1] , the National Low Carbon Strategy (SNBC) and the pluriannual program on Energy (PPE), among others. The goal is to guide technological and societal choices towards the objectives and to support the research and development effort (R & D) which is necessary for the continuous improvement of existing offers and the development of new options. This resulted in the launch in 2016 of a National Energy Research Strategy (SNRE), by the Ministries of research, Environment and Sustainability, and industry. This SNRE act aims at identifying the R & D stakes and the scientific barriers to overcome at different time scales and throughout the energy innovation chain to enable the achievement of the objectives of the LTECV policy plan in France, while at the same time inscribing this R&D in a broader international perspective. CNRS is a strong contributor to the SNRE.

Furthermore, in the frame of France 2030 Initiative, the government has launched in 2020 more than 18 National "Accelerating" Strategies and more than 25 National "prospecting" Strategies to identify the main challenges of tomorrow's socio-economic transition and to invest in an exceptional and massive way in a global approach (funding, standards, taxation, etc.). Several of those strategies have specific R&D national programs (PEPR) which are directed towards development of clean energy technologies such as low carbon hydrogen, advanced batteries, novel energy systems including photovoltaic, wind and electric networks, decarbonation of the

[1] *Among the objectives: Reduce greenhouse gas emissions by a factor 4 between 1990 and 2050 ; Reduce the primary energy consumption of fossil fuels by 30% in 2030 compared to the 2012 reference; Increase the share of renewable energies to 23% and 32% of final energy consumption in 2020 in 2030, respectively; Set the share of nuclear power in electricity production to 50% by 2025.*

industry and much more. ***CNRS is co-leading almost all the R&D (PEPR) programs dealing directly or indirectly to clean energy with a global funding of more than 800 M€.***

CNRS is also involved in several European R&D energy programs and projects *which focus on the systemic issues posed by tomorrow's energy challenges related to new routes of production of energy (variable and distributed sources of renewable energy), consumption (energy efficiency at industry and building levels...), transport (e-vehicule, smart grids…), and storage (batteries, hydrogen…).*

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

CNRS, the National Centre for Scientific Research, is the largest research organization in France and in Europe. Its mission is to develop fundamental and generic knowledge in all scientific disciplines, and to bring out concepts that are breaking down and can lead to innovative products and services. CNRS has registered the Energy Transition among the six societal challenges for the period 2019-2023. Thus, more than *4500 full time researchers working within 280 CNRS-Universities joint labs* over the whole country and abroad, are currently developing activities on topics related to energy. The main research themes of the researchers concern development of renewable energies (mainly biomass, solar and marine), flexibility of systems for the integration of renewable energies, energy storage including production and utilization of hydrogen energy carriers, decentralization and multi-scale governance of energy systems, improvement of nuclear energy production and safety, societal and economical aspects related to energy production and use, etc.

As a matter of fact, since 2021, CNRS has been appointed by the government for the scientific and financial coordination of more than 30 National Research Programs (PEPR) dealing with several topics, including energy. These Programs are chosen within the top national priorities for the coming ten years. Among those on energy, CNRS is coordinating the programs on Low Carbon Hydrogen, Batteries, Decarbonation of the Industry, and Advanced Technologies for Energy Systems (PV, wind, electric grid) as well as crosscutting ones such as Recycling and Advanced Materials by design.

CNRS has also established strong collaborations with industry through several joint R&D&I labs (+ 200), and especially with some of those involved in the energy sector such as TOTAL Energies, EDF, Schneider-electric, ENGIE, ALSTHOM, Air Liquide to mention some. Overall, the research topics concern photovoltaics, grid network and hydrogen production and much more. The main purpose is to develop new knowledge and advanced technologies and to accelerate the process from Lab to Fab.

3. Specific research activities in the next generation energy management systems, energy production, energy vectors and others.

More than 4500 full time equivalent (FTE) staff are working in the field of energy, half are PhD or postdocs. The research activities are carried out within more than 280 CNRS-universities joint labs, all over France and abroad (JAPAN, Singapore…). All fields of energy are concerned, ranging from nuclear to storage, distribution and transports, and also renewable energies (RE) topic which is at the top since a quarter of the total FTE is involved in solar energy, biomass,

bioenergy and marines and wind. To cite some, activities at CNRS labs dealing with biomass (wood, dedicated crops, vegetable waste), are mainly focusing on 2nd et 3 generation of biofuels produced by biological (ethanol) or thermochemical methods. As for solar energy, most of the R&D is concentrated on photovoltaics to develop either new materials based on abundant elements (e.g. metallic oxides …), advanced solar cells concepts (e.g. hot carrier solar cells, up/down shift converting layers…) or novel device architectures (e.g. 2T or 4T tandem cells). The aim is to develop high-efficient solar cells at low cost.

On the other hand, the energy transition requires the development of efficient energy storage and conversion technologies to manage the intermittent nature of the RES and ensure the matching between clean energy production and its consumption. Electricity and hydrogen are energy vectors particularly adapted to this task. They can be stored by electrochemical (batteries, supercapacitors) and physico-chemical (compressed gas and hydride materials) means, respectively. They have complementary discharge time-scales and energy densities and can be converted from one into another using fuel cells. Some CNRS teams have great and worldwide expertise in batteries and supercapacitors with the aim to develop new generation (Na batteries…).

As stated above, CNRS is coordinating several R&D national programs that involve most of its research labs all over France. Some examples:

- National R&D program on low Carbon Hydrogen (2021-2029)

As for hydrogen, the challenges are the development of equipment for an efficient production of hydrogen by electrolysis (preferably at high temperature using "unused" heat) using renewable energy resources (solar or wind power), breakthrough of PEM fuel cells for mobility and the understanding of their degradation and aging phenomena, innovative hydrogen storage means (hyperbare, solid as well as organic liquids), systems for hydrogen and LCA/safety/regulation aspects. This program is lasting for 8 years, and it coordinated by CNRS and CEA. For more information: https://www.pepr-hydrogen.com/

- National R&D program on Decarbonisation of industry (2023-2028)

The research program "Supporting innovation to develop new largely decarbonized industrial processes" (SPLEEN) will last for 6.5 years. It aimed at designing industrial systems that emit less greenhouse gases. Among the research activities, it is worth mentioning:

- The introduction of carbon-free energy carriers, for heat production in particular.
- Process intensification: chemical reaction, catalytic conversion, capture and separation of CO2.
- The treatment of residual CO2 by conversion into molecules of interest in fuels or for chemistry or by geological sequestration.
- The optimization of decarbonization, from processes to industrial sites (industrial ecology), based on the acquisition of data and their processing in real time, in order to feed back on the processes, in particular according to criteria based on the life cycle analysis.

For more information: https://www.pepr-spleen.fr/en/accueil-english/

- National R&D program on Batteries (2023-2029)

This program lasting for 7 years aims at the development of current and future batteries, the supply and development of materials necessary for their manufacture, and the management of their end of life by reconditioning or recycling. If the electrification of the vehicles is the first targeted application, the development of batteries intended for other markets such as aeronautics, space, stationary and the Internet of Things is also concerned.

For more information https://www.pepr-batteries.fr/en/

- National R&D program on advanced energy systems (2023-2028)

This national program aims to meet research challenges and bring out innovations in the fields of photovoltaic solar energy and flexible and resilient energy networks, while ensuring a socially appropriate, environmentally sustainable transition that strengthens national industrial sectors.
The objective is to remove the barriers associated with the two technological issues of developing energy networks and photovoltaic cells with high efficiency (tandem structures) and minimized environmental impact. In addition, some projects study human and social science issues related to these technologies.
In the topic of grid integration, CNRS is working on how connected multi-scaled grids are enable effective development and utilization of renewable-based distributed energy resources while optimizing quick energy transfer from distributed energy sources to variety of load centres (fluctuating, local and regional). The rationale behind it is a potential reduction in the need for investment in additional power generating stations.
For more information https://www.pepr-tase.fr/

4. International collaboration

4-1 International alliance/networking development

CNRS has a clear and ambitious international collaboration strategy as witnessed by the numerous international cooperation tools (see picture below) that are open to build and/or strengthen high level collaborations with leading institutes laboratories or Universities over the world. More information can be found here *https://international.cnrs.fr/en/cooperer-a-l-international/*
The most important and visible instrument for international cooperation of CNRS worldwide is probably the International Research Laboratories (IRLs) such as LIMMS in Japan. Such IRLs are located in a foreign country, and have facilities where researchers, students, postdocs, and support staff from CNRS and the foreign partner' institution are working together on well-defined topics. The Director of the IRLs is jointly named by CNRS and the foreign partner institution(s). The IRLs have a duration of five years and can be reconducted.

Other international cooperation tools are the *International Research Projects (IRP)* which are collaborative research schemes between one or more CNRS laboratories and one or two laboratories from foreign countries. The purpose is to strengthen previously-established collaboration through short- and medium-term scientific exchange, in addition to organising working meetings or seminars, developing joint research activity including field research, and supervising students. These programmes have usually a duration of five years. Another tool is the *International Research Network (IRN)* dedicated to structuring international research networks with a focus on a common theme or research infrastructure. It promotes the organisation of international workshops and seminars, as well as thematic schools organised by the network partners in France and abroad. It lasts for five years. There is also the International Emerging Actions (IEA) tool dedicated to exploring new topics and partnerships at the international level through PI-to-PI projects. The actions are usually short-term mobility of

scientists, the organisation of working meetings, and the initiation of early-stage joint research works for shared scientific projects. Such projects are funded for a duration of two years.

It should be added that around 55,000 short visits (conferences, stays…) and secondments are also carried out by the CNRS fellowships over the world each year. More important, over 200 researchers (including secondments) perform research in foreign institutions for durations of one year or more. As a result, over half of the organization's publications are joint publications with international partners witnessing the CNRS' international vitality.

CNRS is also a major player in the development of the European Research Area (ERA) and thus an important contributor to the European integration process. These last years, CNRS' researchers have participated to more than 1300 EU projects, and about the fourth of them are dealing with energy. CNRS also took an active part in the International Cooperation projects (INCO) launched by the EU commission. Last but not least, CNRS is participating to the European Interest Group (EIG) CONCERT-Japan which is a multilateral joint funding initiative between Japanese JST and European partners. In 2017, this program was focusing on "Efficient Energy Storage and Distribution" ».

Finally, researchers from the Humanities and Social Sciences department of CNRS are also involved in understanding and bringing solutions to issues which are emerging with the energy transition. Besides the commitment issue to new technologies (hydrogen for instance), they address the anthropological, sociological, political and economic aspects brought by the changes during usages: new consumption trends (consum'actor' citizens), new mobility, new markets, policies, multilevel managements, in addition to protection of privacy, availability of energy to all...

4-2 International joint R&D activities

It is worth saying that a high number of projects are carried out with European partners thanks to the bilateral and European commission on Clean and Sustainable Energy programmes. Yet, CNRS has used the tools mentioned above to fund, totally or partially, several joint projects dealing with the development of innovative clean energy technologies involving many foreign partners originating from North and Western Africa, North America (USA, Canada), Asia (Japan, Taiwan, China, India, Singapore), and Australia. Please see https://international.cnrs.fr/en/un-acteur-mondial/

To mention some of the very recent international programs dealing with energy, which are fully in line with RD20 framework:

With Japan, there is an IRP (International Joint Project) NEXTPV (2016-2024) operated by the CNRS, University of Bordeaux and the Research Centre for Advanced Science and Technology (RCAST) and the university of Tokyo. It aims at developing High efficiency solar cells concepts and devices based on III-V heterostructures, hot carriers solar cells and intermediate bands solar cells as well as Organic and Hybrid Solar cells. The next program will be directed towards the coupling of photovoltaics and hydrogen production, storage and systems integration. In 2022, an International Research Centre (IRC) was launched between CNRS and University of Tokyo and clean energy transition is part of the topics to be developed. A new IRP named Solar-X will be launched in 2025 aiming at the use of solar energy for electricity production but also for hydrogen production through the photo-electro-catalysis processes.

With Singapore: there is the French-SINgaporean network on renewable enERGIEs (SINERGIE), an international research network (IRN) resulting from a CNRS - NTU joint initiative. It has been formally established in 2017 for 5 years and now renewed till 2025, and covers a wide range of topics: Smart Grids and Power systems, Energy storage, Wind and Marine Energies, Photovoltaics and Green and smart buildings. There is an IRL CINTRA between CNRS , NTU and THALES that starts in 2024 to tackle CO2 reduction via catalysis.

With Australia, there is the IRN "French-Australian research network on Conversion and Energy Storage for stand-alone & maritime applications (FACES)" which involves several CNRS labs, UNSW, University of South Australia and Deakin University. The scientific program of this program is focusing in two main research axes, namely electrochemical storage and hydrogen conversion. For the Electrochemical storage part, it is intended to design new electrode materials and electrolytes for lithium-ion batteries to their upscale, taking into account the Australian local mining and development of new battery and supercapacitor chemistries for energy storage, and to work on Prototyping, reliability, aging, management and safety tests. As for the hydrogen conversion topic, the IRN will address the chemical hydrogen storage related to on-board hydrogen production, will study the reversible hydrogen storage aspect and End-use of hydrogen and fuel cells, and finally to set a plan for system integration which includes architecture, energy management, design methodologies, etc. More recently, a French-Australia Centre for Energy Transition (FACET) was launched to undertake joint activities in innovation, research, education and training, with a strong focus on energy transition; it combines partners from universities, research institutions and industry; CNRS and CEA are part of FACET (https://www.franceaustraliaenergy.com/).

With Africa, there is an IRP entitled ATLAS for "Associated Trans-Mediterranean Laboratories for Applications in Solar Energy," with Morocco **(2019-2024)**, which is a formal structured international laboratory collaboration created by CNRS, Georgia Tech, and Moroccan education (MESRSFC) and research (CNRST) entities for international collaborations. This lab will allow for scientific synergies in photovoltaics, energy efficiency, and provides resources for the exchange of students and researchers, and a platform for building joint projects funded by companies and by public sources. In October 2024, a French-Moroccan centre for research and innovation was launched with a focus on several topics, among them renewable energies and hydrogen (https://international.cnrs.fr/en/actualite/xd/).

CNRS has also organized on 17-20 October 2022 at University of Pretoria a CNRS-NRF-DSI Workshop on "Energy for the future : Research for Impact" with the goal to strengthen scientific collaboration between Europe and Africa in several topics dealing with renewables, hydrogen,

storage and electric grid (https://international.cnrs.fr/en/actualite/workshop-cooperation-afrique/). This resulted in the set of several research projects.

With India, an Indo-French Workshop on Clean and Sustainable Energy Technologies (INFINITE) was held between February 21 - 24, 2023, at CSIR – National Physical Laboratory (NPL), New Delhi. The event was jointly organized by CSIR – Central Institute of Mining and Fuel Research (CIMFR), Dhanbad and the French National Centre for Scientific Research (CNRS), France. The objective of the workshop was to bring together experts from both countries to exchange knowledge, ideas and best practices on the development and deployment of clean and sustainable energy technologies. These resulted in some projects as well as mobilities.

As far as seminars are concerned, CNRS has organized several meetings in 2023/2024 with colleagues from Chile (clean hydrogen), Brazil (renewables and electric grid) and Mexico (clean and sustainable energies).

To sum up this part, **CNRS considers International Collaboration as a key element towards net zero carbon emission**. With its 80 years' experience, CNRS suggest that the best measures that should be implemented at the organization levels for facilitating international cooperation are the following:

- Recruitment of outstanding researchers from all over the word,
- Encouraging mobility to other prestigious institutes and organization using specific and well identified tools (see 4.1)
- Developing strong networks on specific topics of energy (taskforces such as those already set in the frame of RD20 on LCA/H2 and photovoltaics)
- Launching international labs linked to energy sector (e.g. Africa)

5. Future perspectives (towards carbon neutrality)

Mastering the energy mix by 2050 and beyond is an important international challenge that leads to major research and specific equipment needs. The energy systems of the future, in whatever form, require large investments, major research and development (R & D) with a strong need for dedicated research infrastructures. It also involves managing uncertainties (prices, geostrategic considerations, learning curves of different technologies, behaviour of actors, etc.) to make the decisions that are the least costly in the long term.

In this context, CNRS will pursue its R&D activities in the field of clean and sustainable energy by developing renewable energies (RES) and its storage, by mobilizing bio-sourced materials (for example wood in construction), by encouraging controlled and less polluting mobility, by offering solutions for energy savings in all sectors, especially industry, buildings, transport, and by developing the circular economy, via ecodesign, reuse and recycling. Among the topics, there is the *development of new and efficient materials for energy for* which many challenges emerge (need for new generations of lighter, more insulating, more resistant materials, possibly working in extreme conditions, to cover the needs of transport, building, storage and conversion of energy, etc.). storage of electricity in electrochemical form is an important axis of future R&D at CNRS to examine the *new technologies of high-performance batteries* (stored energy density, load / discharge cycles) and *supercapacitors* with opportunities for industrialization. Other R & D topics related to storage will concern for example the *production of hydrogen* by

electrolysis but put in a broader perspective related to the multiple uses of hydrogen in several sectors, and performing materials for *thermal storage*. The numerous existing international collaborations in the different sectors of energy will be continued and strengthen and other are planned (India on photovoltaics, Australia on solar energy…)

It should be noticed that the major scientific issues, and particularly for the energy sector, pose the challenge of having experimental means and research tools at the forefront of scientific and technological knowledge. Observation, measurement, storage and sharing of data imply large instruments carrying technical capabilities beyond the existing and integrating interdisciplinary porosity source of innovation. These tools are the conditions for future discoveries as well as the product of the latest scientific and technological advances.

The existing very large infrastructures in the field of energy are five so far (ECCSEL, FR Solaris, Sophira, Theorem and West), covering different themes and all are the "French nodes" of future or existing European and international collaborations.

A. Petit is the Chairman and CEO of CNRS
A. Slaoui is Deputy Research Director, INSIS-CNRS and Coordinator of Research on Energy at CNRS

Pr Antoine PETIT, PhD
Chairman and CEO
Centre National de la Recherche Scientifique , CNRS

Antoine Petit, an exceptional grade university professor, was appointed Chairman and Chief Executive Officer of the CNRS on January 24, 2018. After earning a teaching degree and a PhD in computer science from the Université Paris Diderot, he specialized in formal methods, mostly based on transition systems, for the specification and verification of parallel systems in real time. As for academic curricula, from 1984 to 2004, he served as an assistant professor at the Université d'Orléans, a lecturer at the Université Paris-Sud and a professor at the ENS Cachan (near Paris) from 1994.

From 2001 to 2003, Antoine Petit was deputy director of the French Research Ministry's Research Department, in charge of Mathematics and Information and Communication Sciences and Technologies. In 2004, he was seconded to the CNRS, first as scientific director of the Information and Communication Science and Technologies Department, before becoming inter-regional director for South West France. In 2006, he joined the French National Institute for Computer Science and Applied Mathematics (INRIA) as head of the Paris-Rocquencourt research center. He was named Chairman and CEO of the INRIA in 2014, having been its deputy CEO.

Dr Abdelilah SLAOUI, PhD
CNRS Deputy Research Director
Head of Energy unit of CNRS
Coordinator of the National R&D program on low carbon Hydrogen
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1984 Ph.D. University Louis Pasteur , Strasbourg
1984 - 1996 Physics and Application of Semiconductors laboratory (PHASE); Strasbourg
1996 Habilitation diploma, University of Strasbourg
1996 - 2000 Institute of Solid State and Electronics (InESS), Strasbourg
2013 – Institute of Engineering, Computing and photonics (ICube), Strasbourg
2017 - Deputy Research Director in charge of Energy at the National Scientific Research Centre, CNRS-HQ, Paris
2021 – Scientific director of National Program on low carbon hydrogen

Abdelilah SLAOUI *is presently Deputy Research Director in charge of Energy at the National Scientific Research Centre, CNRS-HQ, in Paris.; Scientific director of National R&D Program on low carbon hydrogen*

He received his PhD in 1984 on laser crystallisation of implanted silicon at Laboratoire PHASE (CNRS) for optolecetronic devices. Thereafter, he continued his work on gas immersion laser doping and oxidation of silicon, laser-induced ablation of materials and laser-induced crystallisation of a-Si and a-SiGe. In 1989, he developed the activity based on lamp furnace heating for processing of solar cells and transistors. In 1992, he joined the Oregon Graduate Institute at Beaverton, Oregon, USA as a visiting scientist. His research interests include MOSFET and TFT's transistors as well as inorganic materials based solar cells. He served for 20 years as head of the photovoltaic group at PHASE, INESS and ICUBE institutes (CNRS labs). He participated/coordinated about 15 National, 10 European and 6 International projects on Energy in general and on photovoltaics in particular. He served as president of the European Material Research Society. He chaired 6 international conferences and co-organized more than 12 international symposia dealing with materials for energy. He has authored or co-authored more than 280 papers and 11 chapters in specialized books.

Since 2017, he has been appointed as a deputy research director in charge of Energy at CNRS, meaning managing all research activities on energy carried out in CNRS' labs over France. Since 2021, he is also coordinating the National Research Program on decarbonated hydrogen (PEPR-H2).

List of publications: https://orcid.org/0000-0001-8202-2833

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
CNRS/France	Renewable Energies	Photovoltaics	IRP (International Joint Project) NEXTPV (2016-2024) It aims which aims at developing High efficiency solar cells concepts and devices based on III-V heterostructures, hot carriers solar cells and intermediate bands solar cells as well as Organic and Hybrid Solar cells. The next program will be directed towards the coupling of photovoltaics and hydrogen production, storage and systems integration.[period of the project] 2016- 2024 (R&D span)	Developing and advancing knowledge in the next generation of photovoltaic devices	Dr. Eric Clouter / CNRS ; Pr. Masakazu Sugiyama (RCAST Director, University of Tokyo)	CNRS, University of Bordeaux and the Research Centre for Advanced Science and Technology (RCAST) and the university of Tokyo	https://www.●●●
CNRS/France	Energy Transition	Photovoltaics, hydrogen	In 2022, an International Research Centre (IRC) was launched between and clean energy transition is part of the topics to be developed. 2022- 2026 (R&D span)	Developing novel photovoltaic devices, and working on hydrogen production and storage	CNRS HQ	CNRS and University of Tokyo	
CNRS/France	Hydrogen	Production of hydrogen and safety	A CSIRO international programme on hydrogen ; exchange of staff 2022- 2025 (R&D span)	Mobility of researcher from CSIRO to CNRS	Dan O'Sullivan Program Manager | International Hydrogen Research Collaboration, CSIRO Energy	CSIRO and CNRS	
CNRS/France	Solar energy	Photovoltaics, photoelectrocatalysis, hydrogen	A new IRP named Solar-X : aiming at the use of solar energy for electricity production but also for hydrogen production through the photo-electro-catalysis processes. 2025- 2029 (R&D span)	electricity production ; hydrogen production by photo-electro-catalysis.	Amaury DELAMARE, CNRS (C2N); Pr. Masakazu Sugiyama (RCAST Director, University of Tokyo)	CNRS and RCAST	
CNRS/France	Energy Transition	PV and hydrogen	FACET programme: FACET | French-Australian Centre for Energy Transition 2024- 2028 (R&D span)	Call for proposals for collaboration on the Energy transition (batteries, hydrogen, renewable…)	Prune BOKHOBZA, France embassy, Australia	CNRS/CEA/UGA; French Ministery of foreign affairs	

The 7th RD20 conference, Oct. 3, 2025
(Activity Summary Template)

Fraunhofer's Contributions to Clean Energy Technologies for a Climate-Neutral Future

Prof. Christopher Hebling
Director International

1. Introduction

The Fraunhofer-Gesellschaft, headquartered in Germany, is one of the world's leading applied research organizations. Its primary mission is to drive innovation by focusing on future-oriented key technologies and translating research findings into industrial applications, thereby strengthening Germany's role as a global industrial hub and benefiting society at large.
Established in 1949, the Fraunhofer-Gesellschaft operates 76 institutes and research units across Germany. Its nearly 32,000 employees—predominantly scientists and engineers—work with an annual budget exceeding €3.4 billion. For over 75 years, Fraunhofer has collaborated with industry, research institutions, and public stakeholders to bridge the gap between scientific discovery and practical application. It remains committed to economically, ecologically, and socially sustainable development, contributing to a sovereign and resilient society.
Fraunhofer's work directly supports Germany's ambitious energy policy framework, which has evolved to address current geopolitical challenges and climate imperatives:

- 2030: 80% of electricity supply from renewable sources (already achieved 59% by 2024) and 65% reduction in greenhouse gas emissions compared to 1990 levels
- 2030: Accelerated coal phase-out timeline (advanced from 2038 following recent policy developments)
- 2040: Achieving an 88% reduction in greenhouse gas emissions
- 2045: Attaining climate neutrality

Germany's energy transition has gained additional urgency following geopolitical developments, particularly the need for energy independence and security. The country is implementing comprehensive measures including €17 billion in subsidies for hydrogen-ready gas power stations to ensure grid stability during the renewable transition.
Fraunhofer ISE remains Europe's largest solar energy research institute, with a staff of approximately 1,400 professionals. The institute is dedicated to advancing the technological foundation for a sustainable energy transition, focusing on renewable energy technologies and energy efficiency solutions. Its research and development activities encompass a comprehensive range of clean energy technologies, including photovoltaics, energy-efficient buildings, hydrogen technologies, electrical energy storage, solar thermal power plants, power electronics, and smart energy systems.
Fraunhofer ISE adopts a systemic, application-oriented approach to clean energy research. Its contributions to Germany's energy transition aim to establish a low-carbon, nuclear-free economy based predominantly on renewable energy sources. The institute actively supports global initiatives, aligning its research with the United Nations' Sustainable Development Goals, particularly Goal 7 ("Affordable and Clean Energy"), Goal 13 ("Climate Action"), and Goal 17 ("Partnerships for the Goals").
The institute plays a crucial role in addressing Germany's current energy challenges, including the need to rapidly scale renewable capacity deployment while maintaining grid stability. With

variable renewables already exceeding 60% of Germany's electricity generation in 2024, Fraunhofer ISE's expertise in energy storage, grid integration, and power electronics becomes increasingly vital for achieving the 80% renewable electricity target by 2030.
Fraunhofer ISE is actively engaged in all critical areas of R&D for carbon reduction, renewable energy deployment, hydrogen utilization, industrial and mobility electrification, and energy efficiency enhancement. Its Hydrogen Technologies division, encompassing Fuel Cells, Sustainable Synthesis Products, and Chemical Energy Storage, plays an increasingly pivotal role in advancing the clean energy transition at both national and international levels, particularly as hydrogen becomes central to Germany's strategy for achieving climate neutrality by 2045.

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

Fraunhofer ISE conducts application-oriented research and development for key clean energy technologies essential for achieving carbon neutrality. The institute adopts a holistic, systemic approach across a comprehensive range of subjects to maximize synergies between its eight core business areas:

- Photovoltaics: Materials, Cells, and Modules
- Photovoltaics: Production Technology and Transfer
- Solar Power Plants and Integrated Photovoltaics
- Power Electronics and Grids
- Electrical Energy Storage
- Climate-Neutral Heat and Buildings
- Hydrogen Technologies
- System Integration

These business areas are strategically aligned to address the complete value chain of the energy transition, from fundamental research in materials science to system-level integration and deployment. The institute's research activities directly support Germany's pathway to climate neutrality by 2045, with particular emphasis on developing scalable, cost-effective technologies for industrial implementation.
Recent breakthrough developments include advanced semiconductor technologies for next-generation photovoltaics, with innovative approaches to produce high-quality indium phosphide on gallium arsenide substrates, offering scalable pathways to reduce costs for high-efficiency solar cells. The institute has also made significant advances in building-integrated photovoltaics (BIPV), developing innovative façade elements that eliminate the need for additional substructures, thereby saving building materials while accelerating installation processes.
The institute's systemic approach enables comprehensive assessment of transformation pathways, as demonstrated by recent studies analyzing regional energy system transitions toward climate neutrality at the federal state level in Germany. This work provides essential insights for policy makers and industry stakeholders planning the implementation of renewable energy infrastructure. In addition to fundamental R&D activities, the institute offers comprehensive testing and certification services, supported by state-of-the-art laboratory infrastructure. The testing capabilities encompass performance characterization, quality assurance, aging tests, thermal analyses, and safety evaluations across all technology domains.

3. Specific research activities

Hydrogen plays a pivotal role in the global energy system transformation as a sustainable energy carrier. It stores renewable energy and enables global trade, making it one of Fraunhofer's core competencies. In 2019, the Fraunhofer Hydrogen Network was established as a dynamic platform for exchange and collaboration, bringing together 39 Fraunhofer institutes to address the entire hydrogen value chain—from production to application in industries, mobility, energy, and heating. The network, involving approximately 1,000 researchers, engineers, and students, actively contributes to the development of market-ready hydrogen technologies and supports the energy transition. Key Areas of Hydrogen Research:

Hydrogen Production

Over 14 Fraunhofer institutes are advancing hydrogen production technologies, with focus areas including:

- Development of electrolysis technologies (AEL, PEM, AEM, SOEC) at the cell, stack, and system levels.
- Exploration of alternative hydrogen production methods such as photoelectrochemical cells and thermochemical water splitting.
- Scaling production processes to enable cost-efficient mass manufacturing with resource-efficient materials.
- Comprehensive testing of materials and components to optimize performance and durability.
- Feasibility studies for innovative concepts like offshore and seawater electrolysis.

Reference Projects:

- H2Mare (2021-2025)
- H2Giga (2021-2025)
- H2 Companion: Electrolysis (2022-2027)
- SkalPro (2021-2025)
- Integrate (2019-2024)
- OffsH2ore (2021-20222)
- Neo-PEC (2020-2023)

Hydrogen Infrastructure

Nine institutes are engaged in the development of hydrogen infrastructure, focusing on:

- Advanced storage solutions such as geological storage and lightweight materials like CFRP.
- Safe transportation technologies, including pipeline materials and hydrogen refueling systems.
- Logistic modeling for hydrogen import/export and integration with existing gas networks.
- Power-to-X (PtX) technologies for efficient transport via carriers like ammonia, methanol, and LOHC.

Reference Projects:

- TransHYDE (2021-2025)
- HyPat (2021-2024)
- hyBit (2023-2026)
- H2-Sponge (2021-2025)
- KuWaTa (2020-2022)
- Power-to-MEDME (2022-2024)

Hydrogen System Modeling
Fraunhofer's system modeling expertise spans hydrogen production, conversion, and distribution. Key activities include:

- Techno-economic assessments to ensure cost-effectiveness.
- GIS-based global potential mapping for hydrogen production and logistics.
- Analysis of disruptive technologies and their impacts on the hydrogen economy.
- Development of long-term strategies and roadmaps for sustainable hydrogen deployment.

Reference Projects:

- HyPat (2021-2024)
- PtX Atlas (2020-2023)
- HySecunda (2023-2026)
- PoWerD (2022-2024)
- hyBit (2023-2026)

Hydrogen Safety, Regulation, and Reliability
Seven institutes contribute to hydrogen safety and regulatory advancements by:

- Developing international safety standards and industrial guidelines.
- Testing and qualifying materials for reliability and durability in hydrogen systems.
- Implementing advanced sensors for real-time safety diagnostics.
- Conducting scenario-based safety and reliability analyses.

Reference Projects:

- HyTrust (2023-2025)
- Long-Term Scenarios (2011-2021)

Hydrogen Applications
Fraunhofer is pioneering hydrogen applications in diverse sectors, including:

- Industry: Integrating green hydrogen into CCU processes, renewable feedstocks, and green steel production.
- Mobility: Advancing fuel cell systems and hydrogen derivatives for road, maritime, and aviation applications, including SAF production.
- Energy and Heat: Utilizing hydrogen derivatives for power and heat generation in turbines and CHP systems.

Reference Projects:

- Carbon2Chem Phase 2 (2020-2024)
- H2GO (2022-2025)
- BeWiSer (2023-2026)
- Northern Germany Real Lab (2021-2026)

Hydrogen Materials
Fraunhofer institutes develop innovative materials for electrolysis, fuel cells, and storage systems. Research includes:

- Designing durable catalysts, membranes, and coatings to enhance efficiency and reduce costs.
- Advancing recycling techniques for resource-efficient material recovery and reuse.

Reference Projects:

- POWERPASTE (2016-2024)
- ElKoHEL (2021-2024)
- SOC Degradation 2.0 (2021-2024)

4. International collaboration

The Fraunhofer-Gesellschaft operates through legally independent Fraunhofer affiliates across Europe, North and South America, and Singapore. Representative Offices and Senior Advisors worldwide serve as bridges between local markets and Fraunhofer Institutes, focusing on marketing and business expansion. The Fraunhofer Brussels office provides a platform for dialogue with European policy makers, issuing official statements and delivering information services. Fraunhofer maintains comprehensive Memoranda of Understanding with a diverse range of research institutes, companies, and organizations worldwide. Recent developments include the landmark partnership between the Israel Innovation Authority and Germany's Fraunhofer-Gesellschaft, forged in March 2025, which aims to foster cooperation in key technological sectors and promote joint research and development initiatives benefiting both nations.

Selected international collaborations of Fraunhofer ISE:

- Global Alliance for Solar Energy Institutes (GA-SERI): As a founding member alongside AIST (Japan) and the National Renewable Energy Laboratory NREL (USA), Fraunhofer ISE participates in this international consortium of scientific experts. Since 2016, GA-SERI has addressed global challenges related to photovoltaics and key technologies such as hydrogen to achieve international climate goals.
- Fraunhofer Innovation Platform for the Water-Energy-Food Nexus at Stellenbosch University: This strategic partnership between Stellenbosch University and the Fraunhofer-Gesellschaft develops tailored technological and cross-sectoral solutions for water, energy, and food security, contributing to sustainable development across the African continent.
- Fraunhofer Chile Research – Centro para Tecnologías en Energía Solar (FCR-CSET), Santiago, Chile: Conducting research in solar electricity generation, thermal solar energy, water purification, and process heat applications, specifically adapted to South American conditions and requirements.
- European Research Collaborations: Fraunhofer ISE maintains active membership in the European Research Alliance (EERA), the European Technology and Innovation Platform (ETIP), and the Association of European Renewable Energy Research Centers (EUREC), facilitating coordinated research efforts across the European Union

International collaboration has proven essential for accelerating clean energy technology development and deployment. Key successes include breakthrough achievements in organic solar PV technology, where Fraunhofer ISE and international partners set a world record with 14.5% efficiency in 2024. However, challenges persist in coordinating research timelines, harmonizing technical standards, and navigating different regulatory frameworks across countries. The institute has observed that effective international partnerships require sustained commitment, clear intellectual property frameworks, and aligned research priorities. Cultural and linguistic differences, while manageable, require dedicated effort to maintain effective communication and collaboration protocols.
Fraunhofer ISE's most successful international collaborations have involved:

- Joint Laboratory Concepts: Establishing shared research facilities that enable continuous collaboration
- Researcher Exchange Programs: Facilitating long-term exchanges that build lasting partnerships
- Coordinated Technology Roadmaps: Developing shared visions for technology development pathways
- Industry Integration: Involving industrial partners from multiple countries in research initiatives

The institute believes that the current geopolitical climate necessitates strengthened international cooperation in clean energy research, particularly within frameworks like RD20, to accelerate the global energy transition and achieve climate neutrality targets.

Selected international collaborations of Fraunhofer ISE through Prof. Dr. Christopher Hebling (Director International):

- Honorary Professor at the University of Cape Town
- Executive Board Member of the Gigaton Hydrogen Workshop (AIST Japan, NREL USA, Fraunhofer ISE Germany)
- Member of the National Academy of Science and Engineering (acatech), Germany
- Speaker of the Hydrogen Network of the Fraunhofer Society (39 member institutes)
- German Delegate in the IEA Technology Collaboration Program for Hydrogen Generation and Utilization
- Member of the Sasol Research Council, South Africa
- Co-Founder and Organizer of the annual Freiburg Energy Talks, which is an international platform for networking and Collaborations

5. Future perspectives (towards carbon neutrality)

Future challenges in clean energy technologies revolve around achieving large-scale decarbonization while ensuring energy security, affordability, and sustainability. As we approach critical climate targets, key challenges have evolved to address more sophisticated integration requirements and emerging technological opportunities.

1. Advanced Hydrogen Economy Development

Hydrogen continues to play a central role in transforming energy systems, particularly for applications difficult to electrify. Current challenges have intensified:

- **Next-Generation Production Technologies**: Overcoming infrastructure, safety, and production cost barriers remains critical, as conventional hydrogen production still generates around 843 million tonnes of CO_2 emissions annually
- **Geologic Hydrogen Exploration**: Emerging focus on natural hydrogen resources, with significant engineering efforts to bring this budding energy resource from underground to surface applications
- **Global Supply Chain Optimization**: Developing secure and sustainable hydrogen import strategies, with detailed analysis of potential partner countries for Germany's hydrogen supply security
- **Hydrogen Derivatives Integration**: Advancing ammonia, methanol, and synthetic fuel production pathways for international transport and storage

2. Revolutionary Energy Storage and Grid Intelligence
The strategic deployment of electrical energy storage technologies enables a new power system with higher renewable integration, spanning from ultrashort-term options like flywheels to ultralong-term solutions like hydrogen storage. Critical challenges include:

- **Multi-Scale Storage Systems**: Integrating storage solutions across temporal scales from seconds to seasons
- **AI-Enhanced Grid Management**: Leveraging artificial intelligence to support the digital transformation of Europe's energy system and accelerate the transition to climate neutrality
- **Levelized Cost Optimization**: Achieving competitive costs across diverse storage technologies while maintaining system reliability
- **Grid Flexibility and Resilience**: Developing adaptive systems capable of handling increasing renewable variability

3. Next-Generation Photovoltaic Technologies
Fraunhofer ISE is advancing highly efficient III-V multi-junction solar cells with the Werner Siemens Foundation funding the "Sustainable Energy Transition through High Efficiency Tandem Photovoltaics" project with 14 million euros until 2032. Key focus areas include:

- **Tandem Solar Cell Commercialization**: Scaling perovskite-silicon tandems and III-V multi-junction technologies
- **Building Integration Advancement**: Developing architecturally integrated solutions with enhanced functionality
- **Manufacturing Process Innovation**: Reducing costs while maintaining ultra-high efficiency standards
- **Material Sustainability**: Developing recycling pathways and alternative materials for critical components

4. Artificial Intelligence and Energy System Convergence
AI that promises to solve huge global challenges while consuming vast amounts of energy necessitates a fundamental shift in our approach to a greener AI. Challenges include:

- **Energy-Efficient AI Computing**: Developing AI systems that minimize energy consumption while maximizing clean energy optimization
- **Predictive System Management**: Implementing AI for predictive maintenance, demand forecasting, and system optimization
- **Digital Twin Technologies**: Creating comprehensive virtual models of energy systems for optimization and planning
- **Cybersecurity Integration**: Ensuring secure, resilient AI-enabled energy infrastructure

5. Cross-Sector Decarbonization Integration
Addressing the complexity of system-wide carbon neutrality requires:

- **Industrial Process Transformation**: Developing clean heat technologies and process electrification strategies
- **Transport Sector Integration**: Advancing sustainable aviation fuels, maritime hydrogen applications, and heavy-duty transport solutions
- **Carbon Utilization Technologies**: Converting CO_2 into valuable products and establishing circular carbon economies
- **Regional Energy Independence**: Building resilient local energy systems while maintaining international cooperation

Expected International Collaborative Framework at Fraunhofer ISE
Fraunhofer ISE's enhanced collaborative framework addresses these evolving challenges

through:

Advanced Joint Research Initiatives

- **Multinational Technology Platforms**: Establishing shared research infrastructures for hydrogen, advanced PV, and energy storage technologies
- **Climate Diplomacy Integration**: Aligning research priorities with international climate agreements and geopolitical considerations
- **Digital Collaboration Networks**: Implementing AI-enhanced platforms for real-time international research coordination

Strategic Knowledge Transfer Programs

- **Global Capacity Building**: Expanding training programs to include emerging economies and technology transfer partnerships
- **Innovation Ecosystems**: Creating international innovation hubs that foster public-private partnerships
- **Talent Mobility Initiatives**: Facilitating long-term researcher exchanges and joint PhD programs

Next-Generation Standardization Efforts

- **Global Technology Standards**: Leading the development of international standards for hydrogen technologies, advanced PV systems, and energy storage
- **Digital Integration Protocols**: Establishing cybersecurity and interoperability standards for smart energy systems
- **Sustainability Certification**: Creating transparent lifecycle assessment frameworks for clean energy technologies

Demonstration and Scaling Partnerships

- **Living Laboratory Concepts**: Implementing real-world demonstration projects across diverse geographic and economic contexts
- **Technology Validation Networks**: Establishing international testing and certification networks
- **Market Acceleration Programs**: Supporting policy frameworks that enable rapid technology deployment

Regional Specialization and Global Integration

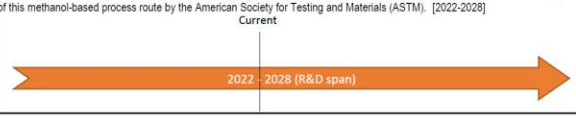
Building on successes like the 10-year anniversary of Fraunhofer Chile's Center for Solar Energy Technologies, the institute will:

- **Regional Excellence Centers**: Developing specialized competencies adapted to local conditions and resources
- **Global Challenge Coordination**: Addressing interconnected challenges like the water-energy-food nexus through integrated solutions
- **Technology Transfer Optimization**: Ensuring appropriate technology adaptation for diverse market conditions

Prof. Dr. Christopher Hebling

Director International, Fraunhofer Institute for Solar Energy Systems (Fh-ISE), Germany

1992 Diploma, University Freiburg/ Fraunhofer ISE
1998 Ph.D. University of Konstanz and Fraunhofer ISE

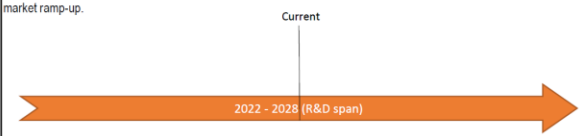
Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer ISE	Hydrogen	Synthetic Fuels	SAFari In the research project »Sustainable Aviation Fuels based on Advanced Reaction and Process Intensification« (SAFari), a consortium of research institutes and industrial partners under the project leadership of the Fraunhofer Institute for Solar Energy Systems ISE will produce and test sustainable kerosene from methanol in a pilot plant. The project is expected to contribute to the full market approval of this methanol-based process route by the American Society for Testing and Materials (ASTM). [2022-2028] 	This pilot plant for the production of Sustainable Aviation Fuel (SAF) will be designed and operated with all functionalities required for the eventual engineered process. It will be equipped to demonstrate feasibility of high yield methanol-based SAF production in an industrially relevant area.	Dr. Malte Gierse Fraunhofer ISE	ASG Analytik-Service AG BP Europe SE Clariant Produkte (Deutschland) GmbH Deutsches Zentrum für Luft- und Raumfahrt e.V. DLR Südzucker AG Bundesverband der Deutschen Luftverkehrswirtschaft (BDL) e.V.	https://www.ise.fraunhofer.de/en/research-projects/safari.html

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer	Hydrogen	Fuel Cells	GIRAFFE – PFAS-Free Electrolytes for PEM Fuel Cells 	research and sourcing of available hydrocarbon ionomers and membranes for fuel cells -development of lab-scale manufacturing methods for CCMs and Membrane Electrode Assemblies (MEA) -characterisation of hydrocarbon-based CCMs and MEAs in fuel cells will be compared with PFSA-based reference materials -ex-situ analysis of the microstructures to gain insight into the materials and identify potential for improvement in material and production processes -development of models to predict performance	Sophia Gierse Fraunhofer ISE	Hahn-Schickard ionysis GmbH Kempten University of Applied Sciences	https://www.ise.fraunhofer.de/en/research-projects/giraffe.html

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer ISE	Key Energy Transition Technologies	Resource Efficiency and Circular Economy	SOUVERÄN Project examines how the European energy transition impacts resource demand, supply chain security, and environmental performance. It focuses on photovoltaics, wind power, batteries, and electrolysis due to their strategic role and reliance on critical raw materials. The project maps value chains and life cycles of these technologies and integrates them into energy system and material flow models. Transformation pathways for the EU energy system up to 2050 are developed, considering sustainability, circularity, and costs. Industry stakeholders are involved to ensure robust and relevant data. The results support EU strategies such as the Critical Raw Materials Act and strengthen technological sovereignty. 	The project delivers assessments of material needs, energy demand, and CO_2 impacts of key energy technologies. It evaluates circular economy, substitution, and supply chain strategies to identify sustainable and secure pathways. A modelling tool will support location decisions for production sites and provide actionable guidance for policymakers and companies.	Dr. Charlotte Senkpiel Fraunhofer ISE	Albert-Ludwigs-Universität Freiburg, Lehrstuhl für nachhaltiges Energie- und Stoffstrommanagement, Universität Bayreuth, Lehrstuhl für ökologische Ressourcentechnologie	SOUVERÄN – Fraunhofer ISE

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer IEG	Hydrogen	Ammonia	PICASO The project develops a novel power-to-ammonia process to enable sustainable and efficient ammonia synthesis. It addresses the limitations of the conventional Haber-Bosch process, where incomplete conversion of hydrogen and nitrogen leads to losses and costly recycling. The new approach integrates reaction and separation in a single reactor through in-situ adsorption, enabling lower pressures and temperatures. This concept improves material and energy efficiency while reducing investment costs. The technology could be deployed economically in decentralized settings, including remote regions with high renewable energy potential. The project is conducted by Fraunhofer ISE together with the University of Ulm and the Fukushima Renewable Energy Institute until 2025. 	PICASO aims to develop integrated reactor technology and operating strategies for efficient, low-cost ammonia synthesis. It will deliver reaction engineering models, suitable adsorbent materials, and experimental validation at relevant scale. The outcomes will be assessed through techno-economic and life cycle analyses to quantify cost and resource savings.	Dr.-Ing. Malte Gierse Fraunhofer ISE	University Ulm; Associated: Fukushima Renewable Energy Institute, AIST (FREA), Clariant Produkte (Deutschland) GmbH	PICASO – Novel power-to-ammonia process for sustainable ammonia synthesis – Fraunhofer ISE

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer ISE	Hydrogen	DME production	Power-to-Medme 	This project involves examining the »Power-to-MEDME« project along the entire process chain – from green hydrogen production to CO2 capture to dimethyl ether (DME) production – in order to reduce costs and increase efficiency. Research accompanying the construction of a pilot plant for green methanol and DME production in the megawatt range by Linde GmbH in northern Chile will simulate processes and investigate and develop materials for the individual steps in the chain, as well as assessing markets in Chile and globally, and carrying out a scale-up of the plant. Also important is the sustainable development and transfer of know-how on site, including the education and training	Robert Szolak (Fraunhofer ISE)	Fraunhofer Institute for Energy Economics and Energy System Technology IEE Fraunhofer Chile Research Fraunhofer Institute for Microengineering and Microsystems IMM Fraunhofer Institute for Silicate Research ISC, Fraunhofer-Center for High Temperature Materials and Design HTL Fraunhofer Institute for Applied Polymer Research IAP, Center for Applied Nanotechnology CAN Chair of Thermodynamics of Mobile Energy Conversion Systems RWTH Aachen Research Institute for the Economics of Education and Social Affairs FiBS	Power-to-MEDME – Applied research for large-scale production of green hydrogen carriers in Chile – Fraunhofer ISE

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer ISE	Hydrogen		SynAgri-PV: The SynAgri-PV project investigates how agrivoltaics can contribute to the energy transition while strengthening sustainable agriculture in Germany. Coordinated by Fraunhofer ISE and ZALF, nine partners from research, industry, and practice collaborate to develop a roadmap for broad agrivoltaic deployment. Agrivoltaics enables dual land use for food production and solar energy generation, offering protection against extreme weather and providing farmers with new income opportunities. At the same time, it reduces pressure on land resources and supports renewable expansion. Despite its potential, only a few small-scale projects exist in Germany due to legal and regulatory barriers. SynAgri-PV addresses these challenges by combining technical, legal, economic, and social perspectives to support market ramp-up. 	The project will provide an evidence-based model for agrivoltaic expansion in Germany, identifying needs for action and possible solutions. It supports and connects pilot plants, creates participation formats, and develops guidelines and a digital platform. The outcomes will inform policymakers, farmers, and the public to accelerate agrivoltaic market uptake.	Andreas Steinhüser (Fraunhofer ISE)	Leibniz-Zentrum für Agrarlandschaftsforschung (ZALF), Universität Hohenheim - Institut für Landschafts- und Pflanzenökologie, Elysium Solar GmbH, Becker Büttner Held Rechtsanwälte Wirtschaftsprüfer Steuerberater PartGmbB, Stiftung Umweltenergierecht, Bosch & Partner GmbH, Hochschule Kehl.	SynAgri-PV – Synergetic Integration of Photovoltaics in Agriculture as a Contribution to a successful Energy Transition – Fraunhofer ISE

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer ISE	Solar Energy	PV	AtaMoS-TeC: Photovoltaic Technologies for Harsh Conditions 	Develop photovoltaic technologies that adapt to the exceptional conditions of the Atacama Desert (high radiaton; high average hours of sunshine, an arid climate; skies almost cloudless; low ambient temperature). Energy cost will be reduced to a target of 25 US$/MWh by the year 2025	Sophia Köhler Fraunhofer Chile Research	SERC Chile (Solar Energy Research Center)	https://www.fraunhofer.cl/en/press/news/cset-news/atamos-tec-starts-construction-for-applied-research-outdoor.html

Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Fraunhofer IMWS	Hydrogen	Import	HySecunda: Achieving climate neutrality in Germany will require large quantities of green hydrogen and its derivatives, which will have to be imported to a large extent. To this end, production opportunities are to be systematically developed in partner countries.The HyShiFT project (Module 1) is an important milestone in this respect, with the construction of a 40 MW electrolysis plant for the generation of green hydrogen for the production of green kerosene in South Africa. As part of the accompanying research project "HySecunda", scientific monitoring and extensive support for this large-scale project is planned. The main objective of the HySecunda project in South Africa is to develop practical, scalable technological and capacity solutions for the market ramp-up along the entire value chain of green hydrogen and its derivatives for the entire SADC region (SADC stands for "South Africa Development Community"), which will lead to a significant reduction in the costs of hydrogen production. 	Technology development, certification and capacity building for the international market ramp-up of green hydrogen and its derivatives in the SADC region using the example of the HyShiFT project in South Africa	Dr. Klemens Ilse	Fraunhofer Institute for Microstructure of Microstructure and Systems IMWS Fraunhofer Institute for Energy Economics and Energy System Technology IEE Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems IEG Fraunhofer Institute for Ceramic Technologies and Systems IKTS Fraunhofer Institute for Silicate Research ISC Fraunhofer Institute for Surface Engineering and Thin Films IST Fraunhofer Institute for Wind Energy Systems IWES Fraunhofer Institute for System and Innovation Research ISI	https://www.hysecunda.fraunhofer.de/en/project.html

The 7th RD20 conference, Oct. 3, 2025

(Activity Summary Template)

National Energy Policy in Indonesia

Arfie Ikhsan Firmansyah, Joko Santosa, Alfian Yudha Prihatmoko, Ratih Damayanti, Tata Sutardi, Euis Djubaedah

National Research and Innovation Agency (BRIN), Indonesia

1. Introduction

The National Research and Innovation Agency (BRIN) conducts research and develops clean energy technologies in accordance with Indonesia's national energy policy and sustainable development agenda. The government has prioritized diversification of the energy mix, a gradual shift away from fossil fuels, and accelerated deployment of renewable and low-carbon alternatives.

According to the National Energy Policy (KEN) and the National Energy General Plan (RUEN), Indonesia aims to raise the share of renewable energy in its primary energy mix to a minimum of 23% by 2025 and 31% by 2050 [1]. These strategic documents serve as a foundation for advancing innovation and technological progress in solar, wind, biomass, geothermal, and ocean energy, as well as in clean fuel alternatives such as green hydrogen and biofuels. Within this framework, BRIN implements research and development initiatives in several key areas:

- **Renewable Energy Technologies** – enhancing the performance, dependability, and scalability of solar, wind, geothermal, and ocean-based energy systems.
- **Energy Conversion, Conservation and Storage** – developing efficient conversion systems, batteries, hydrogen, and other storage technologies to improve grid reliability.
- **Carbon Mitigation and Clean Fuels** – advancing cleaner combustion methods, carbon capture, utilization, and storage (CCUS), and producing green hydrogen and synthetic fuels.
- **Policy and Socioeconomic Analysis** – ensuring that innovations are aligned with national priorities, economically viable, and socially acceptable.

BRIN seeks to accelerate the shift toward clean, reliable, and affordable energy by engaging with government bodies, industry stakeholders, and international collaborators. These R&D efforts contribute to Indonesia's national energy goals and reinforce the country's role in achieving global climate objectives under the Paris Agreement and the Net Zero Emission (NZE) 2060 agenda [2],[3].

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

The focus areas of research and development activities are:

- **Hydrogen & the Hydrogen Ecosystem**
  BRIN is researching to map Indonesia's hydrogen landscape, focusing on green hydrogen production, storage technologies, and applications in transportation. There is also a broader vision for Indonesia to position itself as a global supplier of hydrogen.

- **Biofuels & Biomass-Based Clean Fuels**
  Research at BRIN includes the development of bioethanol and hydrogen as clean energy carriers. A notable collaboration has been established to explore green fuel derived from sorghum biomass (a non-food feedstock), covering feasibility studies, emissions analysis, and generator system design.

- **Renewable Energy & Expansion of the Clean Energy Mix**
  BRIN is enhancing research in solar, wind, and other renewable sources to expand the share of green electricity in Indonesia's energy mix. For instance, BRIN has projected that more than 20% of the national electricity supply could come from renewable sources. In addition, BRIN is engaged in projects that strengthen the energy transition ecosystem, including domestic and international collaborations to exchange technology and innovation.

- **Low-Carbon and Emission Reduction Technologies**
  Ongoing work at the Energy Conversion and Conservation Research Center focuses on low-carbon technological solutions. Plans also include alternative energy pathways to reduce dependence on coal-fired power plants, such as integrating biomass and other cleaner sources into the system.

- **Nuclear Energy**
  BRIN contributes to discussions and strategic planning regarding nuclear power's potential role as part of Indonesia's clean energy portfolio through its nuclear research division. The research includes examining institutional frameworks and regulatory challenges accompanying atomic development.

- **Waste-to-Energy and Resource Conversion**
  BRIN is conducting R&D on converting organic waste streams, including food waste and wastewater, into energy or other usable products. For example, a partnership with KOICA is exploring food waste-to-energy conversion. Additional studies are being carried out on clean air zones and identifying pollutant sources linked to energy emissions.

- **Policy, Planning, and Roadmaps**
  BRIN is drafting frameworks for Indonesia's energy transition, such as the Energy Transition Preparedness Framework Towards 2060. BRIN also ensures that its R&D activities align with national commitments, including the target of Net Zero Emissions by 2060, while strengthening cooperation with international partners.

3. **Specific research activities**
   Related programs/projects conducted by BRIN
   - **Non-Standard Coconut Sorting Manual Development,** the project aims to make manual development of non-standard coconut as feedstock for ICAO CORSIA Sustainable Aviation Fuels (SAF) (2025-2027)
   - **The Regional Energy General Plan (RUED)**, a research project that aims to be an energy planning document at the provincial level that serves as a derivative of the National Energy General Plan (RUEN) (2025-2026)
   - **Economic Impact of Carbon Tax Implementation in the Energy Sector,** a research project that aims to provide policy recommendations to assess the impact of carbon tax implementation in the energy sector and its sub-sectors on the national economy (2024-2026)

4. **International collaboration**

Science-based diplomacy constitutes one of BRIN's strategic approaches to fostering international partnerships in research and innovation. Through this diplomacy, BRIN seeks to contribute to Indonesia's efforts in addressing global challenges, particularly in advancing green energy technologies and formulating long-term strategies and policies to achieve Net Zero Emissions by 2060. In line with this objective, BRIN has established a range of international

collaborations in research and innovation under various schemes, including government-to-government (G-to-G), business-to-business (B-to-B), and university-to-university (U-to-U) cooperation. Several cooperation agreements in the form of Memorandum of Understanding (MoUs) concluded by BRIN are as follows:

a. An MoU concerning research and innovation collaboration exists between BRIN and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. Within this MoU, one of the designated areas of cooperation covers energy and manufacturing, with particular emphasis on advancing low-carbon clean energy technologies as a central focus of the collaboration.
b. An MoU concerning accelerator-based science and technology for material research between BRIN and Riken Nishina Center for Accelerator-Based Science of Japan (RNC), Japan. The scope of cooperation under this MoU includes Advanced Materials, Quantum Matter, and Computational Physics. Research on Advanced Materials and Quantum Matter is essential in the energy sector, particularly in energy storage or battery studies. In addition, Computational Physics is required for research and innovation in magnetic and semiconductor materials, which can subsequently be utilized as generators or control devices for renewable energy power plants.
c. BRIN and the Center National De La Recherche Scientifique (CNRS), France, have an MoU concerning research and innovation cooperation. This cooperation agreement covers a wide range of areas beyond energy, providing access to information exchange, the use of research facilities, and joint research funding schemes.
d. BRIN and the Scientific and Technological Research Council of Turkiye have an MoU concerning cooperation in science and technology. Within this MoU, one of the designated areas of cooperation covers energy and manufacturing, with particular emphasis on advancing low-carbon clean energy technologies as a central focus of the collaboration.
e. An MoU concerning the Sustainable Aviation Fuel (SAF) project between BRIN and Green Power Development Corporation, Japan. Undertaking research aimed at formulating policy frameworks and mechanisms for utilizing non-edible coconuts as a strategic feedstock for Sustainable Aviation Fuel (SAF).

Prospects for Future Collaboration with RD20

Indonesia is the largest archipelagic country in the world, with approximately 63% of its territory consisting of marine areas [4]. The Indonesian seas hold a vast energy potential, estimated at around 17,989 MW [1]. Ocean resource potential would be converted into primary electricity generation by utilizing potential energy, kinetic energy, and temperature differences within ocean water layers [5],[6],[7].[8].

Presidential Regulation No. 22 of 2017 on the National Energy Plan has designated ocean energy as a source in the national energy mix. However, domestic research and innovation related to ocean energy utilization have not yet been fully integrated from upstream to downstream.

Therefore, a well-directed strategy of collaboration among research institutions, universities, industries, and policymakers at national and international levels is needed to promote the integration of national research and innovation while strengthening learning from global best practices.

Indonesia's participation in the RD20 forum is expected to lead to concrete cooperation in the field of ocean energy. The short—and medium-term targets focus on knowledge exchange and technology transfer, as well as the implementation of pilot projects for ocean energy-based power generation as an initial step towards large-scale deployment in the future.

5. Future perspectives (towards carbon neutrality)

Indonesia has abundant renewable energy potential. Therefore, energy diversification is needed

so that the national energy mix, which is currently still dominated by fossil fuels, can gradually and systematically be replaced with clean energy.

Through research and innovation, the National Research and Innovation Agency (BRIN) seeks to utilize renewable energy sources sustainably while upholding the principles of energy security. These principles encompass four key aspects: Availability, Affordability, Accessibility, and Acceptability [9].

To achieve these objectives, in addition to developing pilot projects and the marine energy industry, upcoming initiatives will include joint research and collaboration on the Food and Energy Nexus in Indonesia's Tropical Coastal Areas: Sustainable Hydrogen Small Bay City. Furthermore, BRIN and Sumatera Utara University (USU) have initiated the Project for the Development of an Advanced Palm Oil Mill through Next-Generation Anaerobic Digestion, Wastewater Treatment System, and Start-up Company Establishment, in collaboration with several universities in Indonesia and Japan, and submitted to the Science and Technology Research Partnership for Sustainable Development (SATREPS) scheme.

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Director of Environment, Maritime, Natural Resources, and Nuclear Policy,
the National Research and Innovation Agency (BRIN), Indonesia.

Ratih was Research Professor at Ministry of Environment and Forestry. In 2022, when all researchers in Indonesia were integrated into National Research and Innovation Agency (BRIN), she continued focusing her scientific interests in the Anatomy and quality of lignocellulose materials, timber forensic, and Non-Destructive Testing (NDT).
Ratih got her Ph.D. in Wood Science from the University of Melbourne, Australia, and Bachelor's and Master's Degrees from IPB University, Indonesia. More than 130 national and international publications and 20 Patents and Copyrights have been produced during her career as research scientist from 2007 to the present. In 2021, she was selected as a member of IAWA (International Association of Wood Anatomist) Council based in Leiden, Netherlands, until present.

2019 Published in TEMPO Magazine in a special report entitled
"The 'Eureka' Moment of Female Inventors"
Awarded the Top Ten Most Inspiring Civil Servants
2021 Awarded the 113 Indonesia Innovations from Business Innovation Center
Awarded the HIMPENINDO AWARD: Outstanding Young Researchers in Life Sciences
2022 The 1st Winner of the JAAI Innovation Award
(JSPS Alumni Association of Indonesia)
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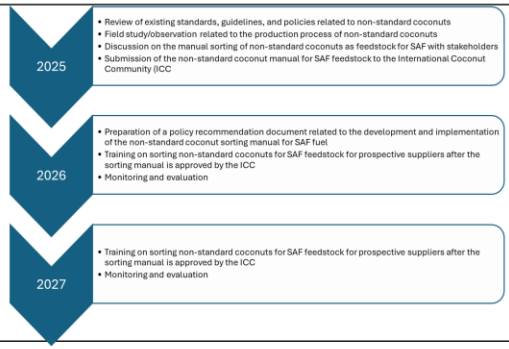
Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
Green Power Development Coorperation Japan	Sustainable Aviation Fuel (SAF) project	Sorting Manual Development of Non-Standard Coconuts as raw material for ICAO CORSIA Sustainable Aviation Fuel (SAF)		1. The manual sorting of non-standard coconuts as feedstock for SAF 2. Policy Recommendations on the Development and Implementation of the Non-Standard Coconut Sorting Manual for SAF Feedstock 3. Training on sorting non-standard coconuts for SAF feedstock for prospective suppliers	Dr. Ratih Damayanti, S.Hut, M.Si.	(Domestic) : 1. Research Center for Testing and Standards ■■ 2. PT. Green Power Palembang ●● 3. PT. ABE Indonesia Berjaya ●● 4. Yayasan Indonesia Jepang Bersama▲▲ （International) : Green Power Development Corporation Japan ▲▲ (Desired collaboration) ●● field test, ▲▲ modeling, ■■ standard, etc.	https://brin.go.id/dkp/DKPLHKSDAK/page/kajian-tahun-2024

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R&D activities in ENEA on the Clean Energy Technologies

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1. Introduction

ENEA is a public body with the aim of pursuing research and technological innovation, as well as providing enterprises, public administration and citizens with advanced services in the sectors of energy, environment and sustainable economic development.

ENEA activities in the field of renewable energy sources are mainly centered upon research, innovation, and technology transfer. The Agency also provides advanced services contributing to both decreasing CO_2 emissions and the national energy dependence on fossil sources and increasing Italy's economic competitiveness.

ENEA is present with numerous Research Centers distributed throughout the Italian national territory (Bologna, Brasimone, Brindisi, Casaccia, Frascati, Ispra, Portici, Trisaia and Brindisi). Enabled by high-quality equipment and long-standing experience, ENEA plays a key role in managing complex projects at national, European, and international levels. It provides testing, research, and measurement services aimed at improving the quality, sustainability, and competitiveness of products, services, and processes.

ENEA, through the Department of Energy Technologies and Renewable Sources (TERIN), operates in the energy sector with particular reference to energy renewable sources and vectors (photovoltaic and agrivoltaic, concentrated solar, biomass and biofuels, hydrogen and e-fuels), to technologies and systems for energy storage, transport and distribution (Smart Grid, power to gas/liquid, electrochemical and thermal storage), to technologies and new models to decarbonize energy final uses (Renewable Energy Communities, smart industry, smart cities, smart communities, sustainable mobility, fuel cells, heat pumps, advanced thermal cycles), to enabling technologies and supporting digital transition (Cloud Computing, Big Data, Blockchain, IoT, AI, HPC, , machine learning, etc.). In these sectors it is a national and European reference point in applied research, supported by advanced equipment, a strong background and long-standing experience in technological innovation.

In such context, ENEA coordinates the National Technological Energy Cluster, which aims to promote scientific and technological research to foster participation, coordination and launching of national and international initiatives and projects concerning the energy sector, by giving particular attention to clean energy solutions.

The priorities of ENEA activities take into account the National Resilience and Recovery Plan (PNRR) and the Integrated National Energy and Climate Plan (PNIEC).

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

ENEA, through the Department for Energy Technologies and Renewables Sources (500 researchers and technicians organized in six Divisions), fosters innovation in the development of new technologies in the sectors of renewable energy. All R&D activities in the field of clean energies, supported by testing and validation on relevant scale experimental platforms (some

examples in Fig. 1) aim at the reduction of greenhouse gas emissions and fossil-sourced energy dependency, development of a low-carbon economy, also by optimizing energy use, medium-to-long-term diversification of energy sources, enhancement of the competitiveness of the Italian industry by reducing energy costs. ENEA activities also focus on research in the field of energy management systems (smart grid, grid integration with variable renewable energy, HEMS/BEMS with H_2, vehicle to X). Additionally, life cycle assessment and social acceptability aspects related to the energy sector, are also considered.

Figure 1: ENEA Research Test Facilities

The priorities of research activities refer to the targets of the National Resilience and Recovery Plan (PNRR) and of the Integrated National Energy and Climate Plan (PNIEC) as well to the Program Agreements with the Italian Ministry of Environment and Energy Security (Electric System Research and Mission Innovation) and the Ministry of Made in Italy and Enterprises. Moreover, research activities consider the vision embodied by the European SET Plan, EERA (European Energy Research Alliance), IEA (International Energy Agency), BIC (Bio-based Industries Consortium), SERIT (Security Energy in Italy) and the Horizon 2020 and Horizon Europe programs.

3. Specific research activities in the next generation energy management systems, hydrogen and others

ENEA has been conducting experimental studies and field research on Concentrating Solar Thermal (**CST) technology** for 20 years. The core of the innovation introduced during the past years by ENEA consists in the use of molten salt mixtures both as heat transfer fluid and thermal storage material, replacing the conventional diathermic oil, and in the development of high-performance selective coatings for the Parabolic Trough (PT) receiver, producing a series of patents whose licenses have been acquired by a national industry in the sector. Currently, main activities, characterized by medium-high technological maturity, aim at the development and construction of new prototypes and demonstration systems. In particular, the research is mainly focused on the development of new materials for reliable and costly effective components (high performance spectrally selective coatings with reduced emissivity and enhanced stability up to 600°C, self-cleaning and smart coatings for low maintenance mirrors alternative molten salts mixtures) and new system configurations for multipurpose CST plants, able to generate heat/power for distributed or centralized applications, and possibly integrated with different renewable energy sources locally available (photovoltaic/wind or biomass) to reduce the costs and increase the dispatchability of heat/electricity produced. In this respect, the development of versatile thermal energy storages (TES), flexibly powered by heat and renewable electricity (wind/PV) is a key asset for ENEA, which is also considering and analyzing the transversal application of thermal energy storage for the coupling of the power and heating sectors, beyond the waste heat recovery in industrial processes. To this end, different heat storage systems (sensible/latent/ thermochemical) in the medium-high temperature range are currently being developed by ENEA, with the realization of pilots and demonstrators to validate technical solutions and facilitate the technological transfer to the industry. A specific research activity is also focused on the development of CST solutions for the provision of medium/high temperature heat to the industrial processes (SHIP), whit the aim of promoting the decarbonization of the industrial sector. Finally, a promising perspective for the application of CST technology is the thermal supply of "green" fuel production processes (in particular, hydrogen) starting from biogas/biomass or water. In this regard, both the hydrogen generation processes that use water as a primary source and those that use a carbon source (fossil or biological) can be powered by high-temperature heat and/or by the electricity produced by CST plants, depending on the type of process considered. ENEA is actively involved in this field, with R&D activities ranging from new materials development to process design, realization, and testing.

Regarding the development of **photovoltaics (PV)** as key technology to build a secure and sustainable energy system for the future and to favor the energetic transition, ENEA is developing materials and device architecture for highly efficient solar cells. In particular, the research is focused on tandem solar cells realized by a silicon heterojunction bottom cell and a perovskite front cell. Perovskite/Silicon solar cell mechanically stacked two terminal tandem cells, having maximum efficiency of 31%, have been obtained with the research efforts in cooperation with Rome University “Tor Vergata”, while efficiencies higher than 20% have been obtained on perovskite single junction solar cells.

ENEA is giving great boost to the development of Agri-PV, while finalizing its studies to several demonstration sites, to show how to convert simple agricultural sites into possible resources of open space for communities, adding to the productive values (electricity and food) the recreational one, with maximum landscape integration to favor the social acceptability of agrivoltaic systems. ENEA has promoted the creation of the Italian network for Sustainable Agrivoltaics and coordinates this network with the aim to provide guidelines to support decision makers, as well as methodologies for impact assessments. ENEA has also designed

new/renovated greenhouses with the roofs equipped with different customized photovoltaic glasses and is also realizing spectrally selective solar cells in order to study the effects on test species (plants and microalgae).

Furthermore, research activities on PV module eco-design have been started based on the utilization of new polymers alternative to conventional encapsulants and backsheets, looking also to the possibility to recover valuable materials, such as glass, metals and polymers introduced into the eco-designed panels.

ENEA is also implementing efforts on Digital-PV, a meeting place between artificial intelligence (AI) techniques and those characterizing the energy sector. Priority is being given to the needs for monitoring, management and operation of photovoltaic systems. New methods for anomalies detection, predictive O&M and the assessment of solar suitability, also with the creation of tools for the public decision-makers aimed at optimal energy planning including photovoltaics, are the research targets.

Paying now attention to the topic of **hydrogen**, it is necessary to emphasize that the R&D activities in ENEA began before the 2000s and have never stopped. Over the years, various pathways and methods for the production of clean and green hydrogen have been explored, both thermochemical and electrochemical, with carbonaceous matter and/or water as feedstock. Hydrogen conversion, storage, distribution and utilization have been investigated too.

Currently in the field of hydrogen production, the research activities at ENEA are mainly focused on advanced low temperature electrolysis and high temperature electrolysis. ENEA's activities on low temperature electrolysis concern both the development and optimization of the electrochemical aspects and materials of devices (electrolysers) based on "polymeric ion-exchange membrane", as far as both the optimization at system level, including the possibility to operate at higher pressure and temperature. For what concerns the research activities in the field of high temperature electrolysis ENEA's expertise mainly lays in a structured and well proven methodology for testing and characterization of solid oxide electrolysis (SOEC) and molten carbonate electrolysis (MCEC). Particularly advanced electrochemical diagnostic tools have been developed and improved in years of activities, enabling not only a more accurate quality assessment of specific systems but also the development of ad hoc accelerated stress tests able to predict the degradation phenomena occurring inside high temperature electrolysis in a shorter time. The optimal integration of electrolysers operating at low and high temperatures with renewable sources is investigated too.

Besides electrolysis, non-electrochemical (clean and green) hydrogen production pathways are also explored. These include solar thermochemical water-splitting, biotechnologies and the thermochemical conversion of (bio)wastes. Of these, some emerging technologies with relatively low Technology Readiness Levels (TRL from 2 to 4) are studied in the lab, while R&D is also carried out at higher TRL (from 4 to 7) in the case of biogas reforming and solid biomass gasification.

In the field of **hydrogen utilization**, different approaches are followed: **fuel cell** applications, **H_2 combustion** and hydrogen conversion to synthetic fuels (or e-fuels) or commodities such as green ammonia. ENEA attention gradually turned to the study and development of different types of fuel cells, such as polymeric fuel cells, molten carbonate fuel cells or solid oxide fuel cells. In the last years, from a research and development prospective, most of the efforts were focused on two main topics regarding SOFC technology: extending systems lifetime and improving the reliability and automation of mass manufacturing. The main activity carried out in ENEA related to Solid Oxide technology has always been the testing and characterization of solid oxide cells (SOC) on a laboratory scale, conducted in the framework of European and National research projects.

Testing and characterization of solid oxide cells samples, supplied by the leading

manufacturers in Europe, are carried on at the level of button cells (1-10 cm^2), single cells (up to 100 cm2) and laboratory scale power modules (short stacks, 5-6 single cells connected in series). The main studies are focused on: (i) the evaluation and quantification of the electrochemical performance by simulating the different operating conditions with respect to the scope of a specific project, (ii) the study of the material degradation phenomena, induced by particular operating conditions or by the presence of contaminants in the fuel gas, (iii) the definition of experimental procedures for the qualification of the performance of commercial cells and modules.

ENEA is also testing high-temperature cells (Molten Carbonate and Solid Oxide) in reversible electrolysis/fuel cell mode for different applications of practical interest.

More recently, ENEA started new research lines on polymeric fuel cells (PEMFC) dealing with the manufacturing and characterization of PEMFC, system integration and Balance of Plant (BoP) optimization.

Regarding combustion applications, hydrogen will contribute to decarbonise the power and transport sectors as well as the hard-to-abate industrial sector. Although in the power generation sector most of the attention is focused on renewable energies, gas turbines still play a crucial role: they are asked to operate as a back-up service to sustain variable renewable energy sources and to stabilize the electric grid, with a contribution to the electric system flexibility. It is fundamental to have fuel-flexible gas turbines running with hydrogen blends as fuel (from hydrogen-enriched natural gas, HENG, to ammonia, a promising H_2-carrier) in a stable, safe and reliable way when the H_2 content in the fuel mix, unpredictably varies in time due to intermittent production from renewables.

ENEA is investigating combustion technologies for burning HENG with high hydrogen content and low NOx emissions, mainly applicable for fuel-flexible gas turbines. Positive feedback were collected for burners and furnaces in the hard-to-abate industry. Activities will aim to investigate flame topology (wrinkles, length) and burning rate changes while increasing hydrogen content, to define strategies for real-time combustion stability monitoring, to develop new fuel-flexible low-NOx combustors for turbines. A couple of fuel-flexible and low-NOx burner prototypes for a micro-gas turbine were designed, built and experimentally tested in a laboratory-scale facility, reaching interesting KPIs from which future activities will start in 2025.

Important R&D programs concerning the valorization of **biomass for bioenergy** and integrated biorefineries applications are also underway at ENEA. On December 2023, COP28 recognized the crucial needs to accelerate the reduction of emissions from road transport on a through development of infrastructure and rapid deployment of zero and low-emission vehicles by utilizing zero- and low-carbon fuels. According to the IEA scenario for net zero, biofuels will play a major role to decarbonize the road transport to 2030. Thereafter, electrification will be the prominent lever while biofuels and hydrogen-based fuels will be mainly used for shifting to aviation and shipping. Sustainable fuels provide more than 75% of energy for aviation and shipping, and more than 25% of industry supply by 2050. On the whole the IEA report issued on January 2024 indicated that biofuels demand is set to expand 38 billion liters over 2023-2028 corresponding to near 30% increase compared to the last five-years period. In fact, the total biofuel demand will rise by 23% by 2028 with respect to 2022 corresponding to 200 billion liters with an internal distribution of 26,4 bl renewable diesel, 117,5 bl ethanol, 52,9 bl biodiesel, 5,2 bl liters and biojet fuels. ENEA R&D on advanced biofuels is focused on both thermochemical and biotechnological conversion processes of different biomass resources. More precisely, biotechnological processes mainly consist in fermentation of biomass derived carbohydrates into alcohol fuels and microbial oils, syngas fermentation, anaerobic digestion of humid biomass to biogas/biohydrogen. Production of advanced biofuels to be used in the transport sector has been demonstrated over a number of feedstocks, namely agroforestry

biomass, poliannual and grass biomass crops. The process steps consist in the biomass pre-treatment, enzymatic hydrolysis, fermentation. An application area is the microbial oil production as intermediate for biodiesel and HVO (hydrotreated vegetable oil). These oils are produced through the cultivation of specific microorganisms capable of accumulating lipids, which can then be refined into fuels. The production of biofuels is seen as an important step towards reducing reliance on fossil fuels and lowering carbon emissions in the transportation sector.

The R&D activities also explore promising approaches for the cascading biomass valorization for the integrated production of green intermediates and bioenergy. In this regard it is worth mentioning ENEA's participation in the SPRING cluster, i.e. the national network for the Circular Bioeconomy, and the realization of the innovative "Biolube" platform including an exclusive hydrotretament facility operating at pilot scale for the production of advanced biofuels and biolubricants. The platform is a versatile technological unit which can be used for the production of a number of hydrotreated biobased products such as bio-LPG and upgraded biocrudes from biomass.

Thermochemical processes mainly rely on biomass gasification to carbon monoxide and hydrogen which represent a versatile platform for the production of energy and liquid and gaseous biofuels. Biomass pyrolysis produces three main products, bio-crudes syngas and biochar, a carbon-rich material which can be used for many applications (soil amendment, water retention, and nutrient availability and advanced materials). Several ENEA gasification reactors are included in the Pilots4U European database and belong to the European Research Infrastructure. They have been developed in order to allow the highest performance in relation to the feedstock to be exploited and the final application such as H_2 productions and gaseous liquid biofuels, as well as combined heat and power.

Thanks to the availability of a technological park provided with facility of different size, from bench to pilot scale, based on different reactor technologies (e.g. fixed bed, rotary kiln, fluidized bed and stage reactors) and the availability of well-equipped analytical labs for chemical characterizations, on this field it is possible to carry out studies focused on the chemistry and the technology of the conversion process of solid fuels into combustible hydrogen rich gaseous stream, as well as on its purification, subsequent conditioning and use. The overall aim is to develop the most effective solutions based on the chemical and physical characteristics of the feedstocks, their availability, and their potential final applications. At the same time, attention is given to reduce the environmental impact, sustainability issues and cost-effectiveness of the approach. The specific items regard:

- Gasification reactor design, with particular attention to fixed and fluidized bed reactor.
- Process intensification for N_2-free producer gas via steam/oxygen gasification agent to make available a producer gaseous stream useful for H_2 production or to be directed to chemical conversion.
- Simultaneous gas cleaning and conditioning via in-bed catalysts and sorbents, or standalone hot gas cleaning units.
- Producer gas exploitation for power production via ICE and SOFC.
- Producer gas exploitation for conversion in advanced energy carrier, with focus on bioSNG, eventually integrated with use of H_2 from water electrolysis for electrical RES storage and grid stabilization, as well as for chemical storage of the hydrogen itself.
- Valorization of process byproducts with particular attention to biochar and its possible uses, including emerging applications of biochar-based materials for energy storage and conversion.

CCUS technologies represent a broad class of technological options for the decarbonisation of industries and of the power sector at a large scale, favouring a growing share of renewable

energy and industrial processes. CO2 capture, transport, and storage technologies have been demonstrated and shown to be technological feasible. However, high-priority research gaps exist to address barriers such as investment and operating costs, robustness, risk mitigation and flexibility.

ENEA oversees the European ECCSEL (European Carbon Dioxide Capture and Storage Laboratory Infrastructure) research infrastructure ZECOMIX (IT3.1) centered on the decarbonisation of fuel gas (syngas) and flue gas on prototype plants and reactors. Different sustainable technologies are being investigated in this plant. The key objective is the hydrogen production from syngas and methane with simultaneous capture of CO_2 via calcium-based solid sorbents. Being a member of the ECCSEL consortium is a label of quality: it has been evaluated via a European process based on commonly agreed criteria and recognized as being of the highest standards and relevance to European research. As a member of the ECCSEL consortium, ZECOMIX offers (i) top-quality scientific and technological performance and support recognized as being of European relevance; (ii) access to visiting scientists from Europe and beyond through a transparent selection and admission process based on scientific merit, already some secondments were made in the framework of different projects with the exchange of personnel; (iii) training for PhD and Master students.

ENEA is, also in charge of projects, programmes and research infrastructures where operational conditions will be provided along with the cost-effectiveness of CCUS processes. The activities of ENEA on CCUS utilize credible and key performance indicators (KPIs) that emerged in the framework of the international collaboration and groups where ENEA is involved (IEA and EERA alliance), which are for the reduction of the energy penalty, the capture rate and the related capital and operational costs of the CO_2 capture processes and thermochemical conversion of biogenic feedstocks and reforming of methane. CO_2 capturing materials developed in the ENEA laboratories and infrastructures are advanced solid sorbents that permit cheaper and greener CO_2 removal than state-of-the-art solutions proposed for pre-combustion capture, such as amines. Furthermore, ENEA promotes next-generation CO_2 capture with higher efficiencies (8-10% increase in carbon removal efficiency), lower energy consumption and heat recovery for power generation (20-30% decrease) and lower capture costs (20-40% decrease) than conventional pre-commercialized and existing CO_2 capture technologies (e.g., amines).

ENEA is actively developing thermochemical conversion of methane and biomass residue feedstocks to couple with CO_2 capture and H_2 production in the so-called Sorption Enhanced Processes (SEP), both in atmospheric conditions and under pressure. ENEA is also studying the conversion of CO_2 (from CCUS or biogenic CO_2) and hydrogen to synthetic gas or liquid fuels (e-fuels). And is developing technologies for the production of synthetic methane from CO_2 and hydrogen, called “methanation”, both by means of thermochemical or biochemical processes. This approach enhances CCUS's effectiveness and field of application and supports the broader goals of carbon neutrality and sustainable energy production.

The use of the chemical process **methanation** to convert CO_2 into CH_4 by reaction with a H_2 flow electrically generated can be a solution for energy storage: the discontinuous nature of most renewable sources, candidate to supply increasingly part of the world energy needs, could be remedied by an appropriate energetic high value storage medium. The ENEA MENHIR Plant (MEthaNe and Hydrogen Infrastructured with Renewable) is an infrastructure dedicated to the study of this Power to Gas technologies. The plant consists in a modular, moveable and containerized facility composed by two shippable containers equipped with an electrolyser and a methanation unit. The methanation unit is composed of a tubular fixed bed reactor with different stages of catalytic beds, able to work in cooled or adiabatic conditions. The facility is suitable for evaluating the dynamic environment of the individual units and of the integrated system start up, shut-down, stand-by e idle condition (plant able to work at load between 20 %

and 100%); testing different methanation catalysts and intensified reactor; testing different process methanation configuration (e.g. cooled or adiabatic reactor condition); testing methanation unit performance in different operating conditions of temperature, pressure, inlet flows, typical of the implementation in Power To Gas (start up, shut-down, stand-by e idle); testing of upgrading methodologies (e.g. membranes); evaluating hybrid systems of energy storage. Besides the MENHIR plant, ENEA has developed a biomethanation facility with 1 m3 bioreactor.

Furthermore, in the framework of national projects, ENEA is developing technologies to produce liquid e-fuels from CO2 and hydrogen, such as liquid hydrocarbons (e.g. to produce Sustainable Aviation Fuels) methanol and dimethyl ether.

A new research activity also deals with the chemical treatment of solid carbon-rich wastes with hydrogen to produce light gas fuels (mainly methane) with a process named hydrogasification and a technology patented by ENEA.

ENEA is also studying the production of green ammonia and its use as hydrogen carrier.

The energy storage will guarantee the balancing of the grid, a greater seasonal storage capacity and, at the same time, will encourage the penetration of RES in energy-intensive sectors, including transport and industrial sectors.

Batteries are a key enabler for renewable energy sources full deployment and for decarbonization. Among all electrochemical energy storage technologies, Li-ion batteries (LIB) are the more advanced and commercially available option; they already have been a game changer in the portable electronic market, and they have a pivotal role in the "full-electrification revolution". Yet, the technological developments are still unfolding to address the increase in demand and their sustainability. As European ETIP Batteries Europe claims[1]: "within this decade, where it is technologically and economically viable, everything that can be electrified will be electrified**,** thus making battery technology one of the most important key enablers for the green energy transition facilitating existing and new technologies"

The main contributor to the rising demand for Li-ion batteries is the electric vehicle (EV) market. The stationary storage market is also expected to experience significant growth in the next decades. The total global battery demand is expected to reach nearly 1,000 GWh per year by 2025 and exceed 2,600 GWh by 2030.[2] In Europe, the demand for EV batteries was expected to surpass 200 GWh per year by 2023 and reach around 400 GWh by 2028, creating at least 3-4 million jobs in the process.[3] From a manufacturing standpoint, "*in 2023, battery manufacturing reached 2.5 TWh, adding 780 GWh of capacity relative to 2022. The capacity added in 2023 was over 25% higher than in 2022*"[4]. Future trends are extremely challenging, also considering the amount of "spent EV batteries" that will reach end-of-life (first) life and will need to be replaced, as shown in the figure below:

1 https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications/sra_en

2 World Economic Forum, M. analysis. A Vision for a Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation. http://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf (2019)

3 https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/strategic-action-plan-batteries-report

4 Global EV outlook 2024 - https://www.iea.org/reports/global-ev-outlook-2024/outlook-for-battery-and-energy-demand

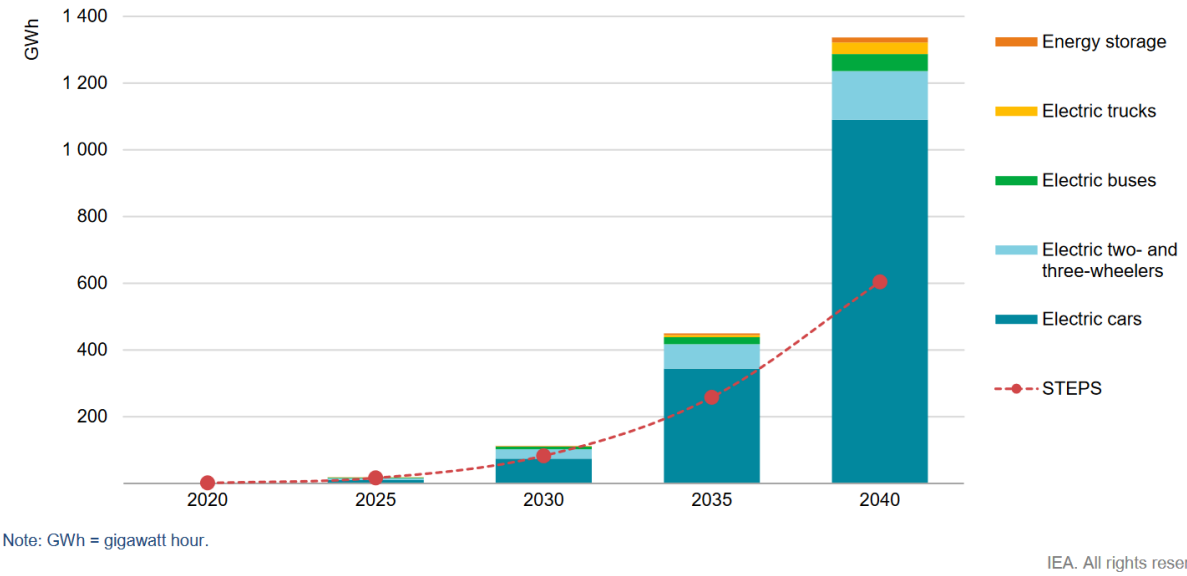


Figure 2. *Amount of spent EV and storage batteries reaching the end of their first life by application until 2040.*

Battery technologies have indeed a wide range of solutions at different readiness level (TRL), often called "generations", an outlook of which is provide following table[5].

Battery Generation	**Electrodes active materials**	**Cell Chemistry / Type**	**Forecast market deployment**
Gen 1	• Cathode: LFP, NCA • Anode: 100% carbon	Li-ion Cell	current
Gen 2a	• Cathode: NMC111 • Anode: 100% carbon	Li-ion Cell	current
Gen 2b	• Cathode: NMC523 to NMC 622 • Anode: 100% carbon	Li-ion Cell	current
Gen 3a	• Cathode: NMC622 to NMC 811 • Anode: carbon (graphite) + silicon content (5-10%)	Optimised Li-ion	2020
Gen 3b	• Cathode: HE-NMC, HVS (high-voltage spinel) • Anode: silicon/carbon	Optimised Li-ion	2025
Gen 4a	• Cathode NMC • Anode Si/C • Solid electrolyte	Solid state Li-ion	2025
Gen 4b	• Cathode NMC • Anode: lithium metal • Solid electrolyte	Solid state Li metal	>2025
Gen 4c	• Cathode: HE-NMC, HVS (high-voltage spinel) • Anode: lithium metal • Solid electrolyte	Advanced solid state	2030
Gen 5	• $Li\|O_2$ – lithium air / metal air • Conversion materials (primarily Li|S) • new ion-based systems (Na, Mg or Al)	Beyond Lithium New cell gen: metal-air/ conversion chemistries / new ion-based insertion chemistries	>2030

R&D activities are carried out on all the different generations: from the next-to-market generations to the already well positioned or the far in the future ones. Improvements can be aimed in many aspects of the battery value chain and on the sustainability or performances sides.

ENEA activities on storage systems are focused on innovative batteries development: research program intends to pursue the entire battery value chain, from the development of new battery materials to new battery systems, from cradle to grave. ENEA's research on advanced materials for batteries aims at having more sustainable, performing, and safer materials.

5 Drafted after ETIP roadmap: https://energy.ec.europa.eu/system/files/2021-12/vol-3-008-2.pdf

Throughout Italian and European funded projects, ENEA's research laboratories work on parallel topics:

- Lithium-rich cathode materials
- Intrinsically safer electrolytes, such as ionic liquid based or solid polymer electrolytes
- More eco-friendly components as water-soluble binders
- Fluorine-free separators
- Nanostructured silicon-based and graphene-based anodes
- Material synthesis optimization and scaling-up at a pre-industrial scale
- New battery chemistries, such as Na-ion or Li|S or multivalent ion batteries.
- Smart sensors development and their integration within the battery system.

In addition to the study and design of specific technologies (e.g., CSP, PV, etc.), ENEA is involved in R&D activities related to the development of technological application for supporting integration of RES into the energy systems and maximizing their penetration thanks to an increased efficiency in energy resources use. In this scope, ENEA designs and implements innovative **Energy Management Systems** (EMSs) in the context of local multi-carrier energy systems - in presence of a variety of heat and power technologies as generation, conversion, and storage systems, and/or in presence of plug-in EVs, which can operate in both G2V and V2G modes - with the aim of satisfying the multi-energy demand of a user or group of users in dynamic conditions. Thanks to advanced programming techniques AI based, these EMSs may not only smartly manage local assets, according to multi-objective functions aiming at enabling the optimal operating conditions into a specific network (e.g., electrical, gas, etc.), but also smartly coordinate, as a unique energy system, the several networks and multiple energy carriers integrated into the system. Therefore, going beyond the smart grid concept, these new generation of EMSs enable the smart energy networks, complex energy infrastructures characterized by a high level of integration between all networks of energy carriers, coupling electrical networks with gas networks, heating, and cooling, supported by energy storage and conversion processes. In addition to EMSs solutions, ENEA is fully committed within research activities regarding **Smart Grids and Smart Energy Networks** by designing and developing innovative technologies and applications for the smart management and control of power grids and energy networks, and **local and renewable energy communities**.

It is worth mentioning that the strength of ENEA stands in its ability to develop technologies, processes, components, and systems for the safe and efficient exploitation of RES by the view of carbon neutrality of the energy system.

ENEA operates a multidisciplinary centre of competence dedicated to assessing the broad sustainability profiles of energy technologies, including socioeconomic impact assessment and environmental ones, with a neutral technological approach not confined to specific energy or transport technologies but open to all the technologies and their integration in energy systems. Recent works of sustainability assessment include agrivoltaics, concentrated solar power (CSP), biofuels, solid bioenergy, cement and steel (with a strong focus on carbon capture), biogas, biomethane, hydrogen storage, fuel cells, and batteries, renewable integration technologies. ENEA primary goal is to assess the potential of these technologies to meet sustainability targets set by policies and research programs, while promoting their advancement through an eco-design approach. ENEA's research focuses on developing a comprehensive methodology that integrates economic, social, and environmental dimensions for assessing energy and transport technologies, along with creating a comprehensive system of knowledge and modelling tools for **technoeconomic (aspen), social LCA (PSILCA), and environmental life cycle assessments** (**Sphera for expert**).

ENEA is also equipped to conduct in-depth analyses to identify the technical, organizational, social, policy and financial barriers faced by various stakeholders, providing valuable insights to enhance and support energy programs. Additionally, ENEA engages in a range of interdisciplinary research activities focused on socio-technical aspects of achieving carbon neutrality, with particular emphasis on social impacts and public acceptance of energy related technologies (**social acceptability**).

4. Specific projects

Some of the main national and international programs/projects conducted by ENEA on the topics addressed in the previous section are reported below:

- **National Recovery and Resilience Plan: Hydrogen R&D - Ministry of Environment and Energy Security** (2022-2025, National Project): research activities on hydrogen to promote interdisciplinary and multidisciplinary interactions through the sharing of knowledge, skills, experiences, infrastructures and networks of laboratories in order to contribute to the increase of qualified critical mass and to the pursuit of objectives challenges. This project is organized into the following thematic areas:
    1) Production of green and clean hydrogen
    2) Innovative technologies for the hydrogen storage and distribution and its transformation into derivatives and e-fuels
    3) Fuel Cells
    4) Digitalization of Hydrogen-based infrastructures.

  ENEA funding 75 M€
- **National Recovery and Resilience Plan (**2023-2026**), From research to business - Ministry of University and Research:** aims to strengthen the conditions for the development of an economy with a high intensity of knowledge, competitiveness and resilience, starting from the recognition of the criticalities of our education, training and research system. ENEA is involved in several projects for a total funding of 240 M€. The main topics of the projects are: energy transition, climate, sustainable mobility, advanced materials, artificial intelligence and smart energy systems. As an example, three projects are listed below.
    1. **ICSC - Italian Research Center on High Performance Computing, Big Data and Quantum Computing**. The main objective of the ICSC national center is to create a powerful national infrastructure for HPC and data at the national level, with cloud services, data lakes, and supercomputers available for research, industry, and public administration. The national center will be a center of excellence where technology transfer and the creation of synergies between public bodies, universities, and industry will be encouraged, and the development of new hardware/software technologies in the fields of HPC, Big Data, and quantum computing will be promoted. In parallel with infrastructure activities, vertical communities and expertise have been created to address major challenges in scientific and industrial domains (climate, environment, space, medicine, materials, etc.) through complex simulations, data analysis, and advanced applications.
    2. **Rome Technopole**. The main objective is to create a regional innovation ecosystem, transform the Lazio Region into a European technology hub, foster the competitive growth of local industry, and promote sustainable development

in key sectors such as energy transition, digitalization, and health.

3. **NEST - NETWORK 4 ENERGY SUSTAINABLE TRANSITION**. The goal of the NEST project is to support Italy's sustainable energy transition by fostering the development of innovative technologies for the production, conversion, storage, and distribution of energy from renewable sources. It aims to strengthen collaboration between universities, research centers, and industry, while promoting the training of new professionals and the emergence of advanced industrial solutions aligned with European decarbonization and sustainability targets.

- **National Fund for Electric System Research (RdS) ENEA - Ministry of Environment and Energy Security** (2025-2027, National Project): development of innovative hydrogen technologies with impact on the electric national grid (i.e. power to gas for network and micro-gas turbine operated in blending H_2/natural gas, for grid flexibility); renewable technologies to increase the flexibility of the grid (CSP); technologies and system for energy storage (electrochemical and thermal) focusing on advanced battery materials development; high-efficiency solar cells and innovative materials for PV applications; development of smart grids, CCUS, energy communities, Cyber Security, etc. ENEA funding 85 M€.
- **HYSELECT (**2022-2026, Horizon Europe Project**)** "Efficient water splitting via a flexible solar-powered Hybrid thermochemical-Sulphur dioxide depolarized Electrolysis Cycle". The project will demonstrate the production of hydrogen (H2) by splitting water via concentrated solar technologies (CST) with an attractive efficiency and cost, through the hybrid sulphur cycle (HyS). Funding: 3.9 M€ - ENEA Funding: 314.1 k€
- **IPCEI Hy2Tech** (2023-2028, EU Project) development of four pilot lines (electrolizers, fuel cells, hydrogen storage and system for mobility sector) and innovative laboratories and experimental facilities to support research and innovation and first industrial deployment in the hydrogen technology value chain. ENEA funding 52 M€.
- **TANDEM** (2022-2025, National Project), funded by Italian Ministry of Ecological Transition: The target of the project is the creation of production systems for the fabrication of tandem solar cells - Project Funding:1,745 M€ - ENEA 337.5 k€.
- **GoPV** (2022-2025, National Project), funded by Italian Ministry of Ecological Transition**:** The project aims to study innovative materials that can contribute to the development of a high-efficiency, tandem PV technology, reliable over time and that uses sustainable raw materials free from availability problems. Project Funding: 5 M€ - ENEA Funding: 1.6 M€.
- **SYMBIOSYST** (2022-2025, EU Project): the project will fully exploit all the degrees of freedom and potential provided by the synergy between land & crop and open or closed agri-PV systems. The ambition is to create a fully integrated solution, from the design to the implementation, a symbiosis where PV and agriculture can have a mutually beneficial relationship. Project Funding: 5 M€ - ENEA Funding: 242 k€.
- **MARTA** (2022-2025, National Project), funded by Italian Ministry of Economic Development: The target of the project is the monitoring and advanced management of photovoltaic systems. Project Funding: M€ 7 - ENEA Funding: 2.1 M€.
- **SALTOPower** (2022-2025 EU Project): creation of a Reference European Facility for the development and testing of molten salt based technologies solutions for the energy storage and dispatchable power generation - Project funding 1,499 M€ - ENEA funding 447 k€.

- **EU-DREAM** (2024-2027, EU Project). The project aims at accelerating innovation in digital tools for the energy sector. A key feature is the introduction of an AI-based assistant and a Natural Language Processing (NLP) intermediary, which will translate complex energy market details into everyday language, making it easier for users to manage their energy consumption. The project will validate its solutions in six Living Labs Project funding 4,54 M€ - ENEA funding 165,6 k€.
- **CST4ALL** (2022-2025 EU Project): supporting the creation of strong and sustainable networks between CSP and other relevant technology areas covered through the SET Plan to enable efficient and direct cooperation among stakeholders. Project funding 559.529 k€, ENEA funding 50.625 k€.
- **EMERA** (2022-2025, Regional project): development of an efficient micro energy networks powered by only RES for the autonomy and independence of rural areas from the centralized system. Project funding 3.57 M€ – ENEA funding: 392 k€.
- **RECOVERY** (2022-2025, National project): energy valorization of residual materials coming from the agro-food industry (e.g., sewage sludge, digestate, and putrescible surplus materials) through syngas from gasification for self-production and self-consumption of electricity. Project funding € 1.38 M€ - ENEA funding: 570 k€;
- **WW-Green Fuel** (2022-2025, National project): development of gasification process (dry and SCWG) for the exploitation of large-scale biomass and production of liquefied SNG. Project funding € 8.8 M€ - ENEA funding: 1.62 M€.
- **PERCIVAL** (2023-2025, National project): Extraction processes of bioproducts from agro-industrial wastes and cascade valorization to bioproducts and bioenergy. Project funding 7.8 M€ – ENEA funding 1.6 M€.
- **Joint Cooperation ENI-ENEA** (2022-2025 National Project): Biomass project n. 2, biomethane, microbial oils, and biochar production – ENEA funding 1 M€.
- **REVINE** (2021-2025 EU Project): Regenerative agricultural approaches to enhance ecosystem services in Mediterranean vineyards. Project funding 1.5 M€ – ENEA funding 165 k€.
- **MECCA Green H2 from bioMEthane cracking,** (PNRR national project 2022-2025 Project funding: 3M€, ENEA funding: 600k €.
- **CALIPSO** (PNRR national project 2022-2026 Project funding: 3.8M€, ENEA funding: 430k €.
- **KijaniBox** (2024 – 2028; HORIZON-IA Program): Transforming African Organic Waste into Green Energy for Cooling. The project aims to demonstrate anaerobic digestion technology coupled with adsorption chiller for cooling generation, in order to prevent food losses and sanitary risks in local waste management and food value chain. Project funding € 5.5 M€ - ENEA funding: 614 k€.
- **PROMETEO** (2021-2026, EU project): producing green hydrogen from renewable heat & power sources by high temperature electrolysis in areas of low electricity prices associated with photovoltaic or wind. Project Funding: 2.5 M€ - ENEA Funding: 416 k€
- **StoRIES** (2021-2025, EU Project): Storage Research Infrastructure Eco-System: the main objectives of StoRIES are linked to the energy storage development by providing access to world-class research infrastructures and services, with a focus on improving materials for devices and optimizing hybrid energy systems with a view to make energy technologies more competitive and reducing costs. Project funding: 7.0 M€, ENEA funding: 0.3 M€.
- **EuBatI – IPCEI on Batteries** (2022-2027, EU Project) The "German leaded Important project of Common European Interest" has many Member States involved and ENEA

is one of the Italian participants. ENEA role is to develop new-concept batteries suitable of being transformed into an industrial product and optimize recycling in line with circular economy approach. The aim is to fill the gap between the lab-scale and the installation and production problems at a pilot plant level to assist the industry upon the first industrial deployment stage. ENEA funding 27.0 M€.

- **CHemPGM** (2021-2025 EU Project). Reuse of platinum-group metals, recovered from spent catalysts or from e-waste as catalysts for CO_2 valorization processes (e.g., reverse water gas shift, methanation, dry reforming of methane).
  Project funding: 736 k€ ENEA funding 110 k€.
- **ALRIGH2T** (2024-2028) Airport level Demonstration of Ground Refuelling of liquid Hydrogen for Aviation. The project aims at developing innovative solutions for aircraft refueling of liquid hydrogen, delivering adequate flow rates, incorporating safety standards and demonstrating the feasibility in ana airport environment. Project Funding: 10.11 M€. ENEA Funding 400 k€.
- **SPACE-IT-UP (**2024-2026 ASI Project) Technologies for space exploration and exploitaion for Earth and humanity: Enabling Technologies for Novel Near-Earth and Exploration Mission. Project funding: 80 M€ - ENEA funding 1.158 k€.
- **FINCANTIERI** (2024-2026, industry funded, commercial project) Test of storage systems for hydrogen (compressed gaseous H2; liquid H2) and of their feeding systems to the microgasturbine of the AGATUR plant in ENEA Casaccia. ENEA Funding: 750 k€.
- **eNeuron** (2020-2025, EU Project): development of innovative tools for the optimal design and operation of Local Energy Communities integrating distributed generation and multiple energy carriers at different scales - Project Funding: 5.7 M€ - ENEA Funding: 487.0 k€.
- **PIAC(ER)2** (2023-2025 Regional Project): developing a platform for supporting Renewable Energy Communities in Emilia-Romagna region with a specific focus on rural areas and productive/industrial sectors. Project funding: 0.5 M€, ENEA funding: 0.13 M€)
- **MULTICLIMACT MULTI-faceted CLIMate adaptation ACTions to improve resilience, preparedness and responsiveness of the built environment against multiple hazards at multiple scales** (2023-2027, EU Project) is dedicated to safeguarding Europe's built environment against the increasing threats of natural and climatic hazards. Through innovative strategies tested across four pilot sites with diverse climatic conditions, MULTICLIMACT targets the urgent need for adaptive measures against floods, earthquakes, extreme weather conditions and heatwaves. Project Funding: 7.5 M€ - ENEA Funding: 495 k€.
- **CRISTAL Climate resilient and environmentally sustainable transport infrastructure, with a focus on inland waterways** (2022-2025 founded by the EU under the European Climate, Infrastructure and Environment Executive Agency CINEA). The crucial aim of the project is to create an innovative technology for monitoring and digitization of transport chains, indicating the direction of further development of business and management models that include river transport in multimodal chains. Project Funding: 6.8 M€ - ENEA Funding: 421 k€.
- **gEneSys Transforming Gendered Interrelations of Power and Inequalities in Transition Pathways to Sustainable Energy Systems"** (2023-2026, EU Project) The project conceptualizes energy transition as a dynamic, gendered, mission-oriented socio-technical innovation ecosystem with several 'subsystems': technological, policy, social, environmental, governance, and economic, each with its own sustainability

visions, values, and priorities, as well as change actors and stakeholders, who may also influence what happens in other subsystems. Project Funding: 2.6 M€ - ENEA Funding: 425 k€.

- **MOD-ENERGY** (2022-2025-National Project POC METRO 2014-2020): Application and dissemination of intervention models in the field of smart lighting, street and building for the containment of energy consumption in Metropolitan Cities. Project funding: 3,46 M€, ENEA 3,46 M€
- Three projects in the framework of Mission Innovation international initiative, funded by Italian Ministry of Economic Development (2020 – 2026, National Fund).
    1. **Hydrogen demo Valley**. The project addresses the creation of an infrastructural hub for testing and demonstration of hydrogen technologies covering production, storage, distribution and utilisation of hydrogen and blends of natural gas and hydrogen, for the energy, industrial and transport sectors. The multifunctional infrastructure would be implemented in the Casaccia Research Centre of ENEA, to act as a breeding ground for hydrogen value chain technologies and services with the aim of accelerating their deployment in view of the energy transition and overall decarbonisation. Project funding: 17.5 M€, ENEA funding: 13.8 M€.
    2. **MISSION - Multivector Integrated Smart Systems and Intelligent Microgrids for accelerating the energy transition**. The project aims to develop two smart grid demonstrators - microgrid size, full scale and multi-vector - located, respectively, at the CR ENEA in Portici (Smart Energy Microgrid ENEA) and the RSE offices in Milan and Piacenza (Extension multi-energy of the Distributed Energy Resources Test Facility RSE). The project will also study, design and implement technological solutions enabling the transition of networks towards integrated and smart multi-energy distribution systems. Project funding: 9.7 M€, ENEA funding: 3.6 M€.
    3. **IEMAP - Italian Energy Materials Acceleration Platform.** The project aims to build an innovative platform dedicated to materials for energy with application in electrochemical storage, electrolysers and photovoltaics. In particular, the project lies in the “Clean Energy Material Challenge” (Mission Innovation IC6). Project funding: 8,6 M€, ENEA funding: 4.6 M€. Research activities were concluded at the end of 2024.
- **SO-FREE** (2021-2025, Horizon 2020 Project - FCH2 - Research and Innovation Action) development of a fully future-ready solid oxide fuel cell (SOFC)-based system for combined heat and power (CHP generation). Project funding: 3,04M€.
- **DUT Driving Urban Transitions** (2022-24, 2025-2028, European Parntership) HORIZON Programme Cofund Actions – European Climate, Infrastructure and Environment Executive Agency (CINEA) - Call: HORIZON-CL5-2021-D2-01
- **SYNAPSY**: ENEA funding Programme (Proof of Concept), Thematic area: CHP production based on residual biomass and biogenic fractions valorization. SYNAPSY aims to improve the performance of a gasification plant for CHP applications, achieved by increasing the degree of syngas cleanliness obtained at a downdraft reactor integrated with an innovative gas stream cleaning system produced.
- **DD4BioPower** - (2025-2026, ENEA funding Programme - Proof of Concept) Development of an innovative Downdraft reactor for the production of biofuel from waste of plant origin
- **AMICS** (2025-2026, ENEA funding Programme - Proof of Concept)- Innovative apparatus and method for processing liquid reagents with solid catalysts aimed at optimizing the production of biodiesel from waste oils
- **eFuelSOME MultifuelSOFC system with Maritime Energy vectors** (2022-2026,

Horizon 2020 Project) The project aims to develop and validate, up to TRL 4, a novel multifuel energy generation system based on Solid Oxide Fuel Cell Technology system which will be capable of operating on various fuels and fuel mixtures. Project funding: 3M€, ENEA funding: 25k€.

- **PROTOSTACK** Tubular proton conducting ceramic stacks for pressurized hydrogen production. (2023-2025, Horizon 2020 Project). The project will develop an innovative, compact, and modular PCCEL stack design with an integrated hot-box capable of operating and delivering hydrogen at pressures up to 30 bar. Project funding: 2.5M€, ENEA funding: 25k€.
- **HASTA** (2024-2026, EU project): experimentally and computationally investigating the storage of liquid hydrogen for airborne use as fuel in civil aircraft applications. Project Funding: 3.3 M€ - ENEA Funding: 118.4 k€.
- **H2Ports** (2019-2025, Horizon 2020 project): Implementing Fuel Cells and Hydrogen Technologies in Ports - Project funding: 4M€, ENEA funding: 28,7k€.
- **BIOMETHAVERSE** (2022-2027, European Project): development of different methanation technologies for biogas plants: thermochemical, biochemical, electrochemical, and biological. Project funding € 11.5 M€ - ENEA funding: 0.6 M€.
- **AMIGDALA** (2024-2027, European Project): Developing an integrated modelling approach for the EU's Intensive Energy sector to drive informed decisions towards a sustainable and carbon-neutral future. Project funding € 6.9 M€ - ENEA funding: 266 k€.
- **NHyRA** (2024-2026, European Project): deliver reliable measurement and quantification methods, new data and rigorous calculation-based models in order to determine H2 releases from the H2 value chain and assess its potential climate impact. Project funding € 3.5 M€ - ENEA funding: 174 k€.
- **HyPEF** (2024-2026, European Project): Promoting an Environmentally – Responsible Hydrogen Economy by Enabling Product Environmental Footprint Studies. Project funding € 1.5 M€ - ENEA funding: 120 k€.
- **Project DataCLEEN (Data CLoud for Energy and Environment) in the frame of IPCEI (Important Project of Common European Interest) Cloud Infrastructure and Services** (2024-2029). The project aims to create a modern cloud infrastructure for managing large amounts of data and for developing and deploying advanced services in the energy and environment sectors. The platform will be designed to integrate artificial intelligence and high-performance computing (HPC) technologies, enabling complex problems to be addressed and supporting decision-making processes based on data, predictive models, and advanced simulations.The ENEA cloud will be federated with the national cloud and the European cloud managed by leading European companies, ensuring interoperability, security, and compliance with international standards. This approach, by hiding the complexity of computing and data infrastructures, will strengthen technological sovereignty and resource sharing, enabling the creation of a competitive and innovative digital ecosystem. ENEA funding 35 M€
- **Project EoCoE-III (Energy Oriented Center of Excellence: fostering the European energy transition with Exascale) funded within the EuroHPC JU framework of the European Commission** (2024-2026). The main objectives of the EoCoE-III project are to accelerate Europe's transition to decarbonized energy by leveraging exascale high-performance computing (HPC) for five major energy-related applications—Energy Materials, Water, Wind, and Fusion—thus demonstrating the benefits of HPC for both research and industry in the energy sector. EoCoE-III develops comprehensive, high-impact simulation codes with the aim to accelerate real-scale virtual modeling of natural

energy phenomena (such as wind farm dynamics and plasma interactions in tokamaks) to optimize performance and reduce energy losses. Funding: 6 M€ - ENEA Funding: 0,2 M€

- **Progetto "CETMA-DIHSME: CETMA-Digital Innovation Hub for SMEs"** (2023-2025). The main objectives are to disseminate advanced digital technologies (Artificial Intelligence, Supercomputing, Cybersecurity) among SMEs and public administrations in southern Italy, particularly in the regions of Puglia and Basilicata, increasing their competitiveness, sustainability, and capacity for innovation. Funding: 3 M€ - ENEA Funding: 0,2 M€
- **MSA-Trough**: (2023-2027, EU Project): development and realization of a novel parabolic trough collector that is more efficient, cost-effective, reliable, and sustainable than current commercial alternatives. The project also includes a comprehensive assessment of the social, economic, and environmental impacts of the concept. Project funding: 5.42 M€; ENEA funding: 0.468 M€.
- **SULPHURREAL (2023-2025, EU project):** demonstrating and validating a breakthrough approach for next generation, carbon-free, direct conversion of solar energy into chemicals storable for a virtually unlimited time, based on elemental sulphur produced and consumed on-demand via a solar-aided thermochemical cycle- Project Funding: M€ 3.98 - ENEA Funding: 5.28 M€
- **Joint Cooperation ENI-ENEA** (2022-2025 National Project): evaluation, on a pilot scale, of the coupling of CSP/CSH systems with thermal storage systems and their operation; analysis of possible applications in the industrial sector - ENEA funding 600 k€.
- **Joint Cooperation ENI-ENEA (**2025-2027 Commercial National Project**)**
  Design construction and testing of a new configuration of Small Parabolic Trough Collectors, with thermal oil as HTF for renewable heat production. Furthermore, field testing of an innovative concrete-based/PCM thermal storage unit using solar salt up to 450 °C as HTF - ENEA funding: 523 k€.

5. International collaboration

ENEA is present in the clean energy sector as a highly qualified player dealing with key national, EU and international initiatives. Furthermore, ENEA has concluded several comprehensive and specific cooperation agreements and MOUs with research institutes, universities and industrial stakeholders to promote research and technology transfer to industry aimed at the energy system de-carbonization.

Within the EU-funded projects, ENEA is involved in: (i) networking activities to develop the cooperation between research infrastructures, scientific community, industries and other stakeholders in the field of CSP technology; (ii) transnational access activities aiming at providing access to all European researchers from both academia and industry to singular scientific and technological solar research infrastructures; and (iii) joint research activities whose purpose is to improve the integrated services provided by the infrastructure.

The same approach is followed by the ECCSEL and StoRIES projects: ENEA is a full member of the European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL, the European Research Infrastructure on CO_2 Capture, Use and Storage). With the participation to the ECCSEL (European Carbon Dioxide Capture and Storage Laboratory) consortium, ENEA will have the opportunity to access to (i) national and regional funds for building new research facilities on advanced CCUS technologies; (ii) transnational access activities aiming at providing access to all European industry and academia to an ecosystem of CCUS technologies. Referring to the StoRIES (Storage Research Infrastructure Eco-System) project, the main

objectives are linked to the energy storage development by providing access to world-class European research infrastructures and services, with a focus on improving materials for devices and optimizing hybrid energy systems.

ENEA covers a key role within the International Initiative of Mission Innovation (MI), which is a global initiative of 24 countries and the European Union aiming at dramatically accelerate global clean energy innovation. As part of the initiative, participating countries have committed to double their governments' clean energy research and development investments over five years, while encouraging greater levels of private sector investment in clean energy technologies. The MI actions are based on eight Innovation Challenges (IC), which consist of a global network of policymakers, scientists and innovators working towards a common objective, and cover the entire spectrum of R&D, from early-stage research to technology demonstration projects. Italy has endorsed all the IC and ENEA received fund from the national government in the following sectors:

- Smart Grid Innovation Challenge (#1) aiming at enabling future grids that are powered by affordable, reliable, decentralised renewable electricity systems.
- Clean Energy Materials Innovation Challenge (#6) aiming at accelerating the advanced energy materials discovery by integrating high-throughput methods with artificial intelligence.
- Renewable and Clean Hydrogen Innovation Challenge (#8) aiming at accelerating the development of a global hydrogen market by identifying and overcoming key technology barriers to the production, distribution, storage, and use of hydrogen at gigawatt scale.

Mission Innovation 2.0, launched on 2 June 2021, is catalysing a decade of action and investment in research, development and demonstration to make clean energy affordable, attractive and accessible for all. This will accelerate progress towards the Paris Agreement goals and pathways to net zero.
The challenge of "Clean Hydrogen Mission", under the umbrella of Mission Innovation 2.0) is to demonstrate the clean hydrogen has the potential to decarbonise hard to abate sectors, such as industry and heat, which are responsible for two thirds of global emissions and help unlock the full potential of renewable energy. However, today it is up to three times more expensive than hydrogen produced directly from fossil fuels.
The Goal is to increase the cost-competitiveness of clean hydrogen by reducing end-to-end costs to USD 2 per kilogram by 2030.
The mission is focused on the goal to catalyse cost reductions by increasing research and development in hydrogen technologies and industrial processes and delivering at least 100 hydrogen valleys covering production, storage and end-use worldwide by 2030, to unleash a global clean hydrogen economy.
ENEA is also present, as Italian representative, in numerous intergovernmental bodies, regulatory bodies and international initiatives aimed at promoting the development of clean energies.

Regarding the photovoltaic topic, ENEA is involved in:

- Technology Collaboration Program (TCP) "Photovoltaic Power System" (PVPS) of IEA with activities in several tasks (task 1 "Strategic PV analysis & outreach, task 15 "Enabling framework for BIPV acceleration", task 12 "PV sustainability"; Task 14 "High penetration of PV systems in electricity grids".).
- European Energy Research Alliance Joint Programme Photovoltaic Solar Energy (EERA JP PV) that has the objective to accelerate the development of Photovoltaic Solar Energy towards an energy technology that can be implemented at a very large scale

through Joint Programming activities by key research institutes in Europe.
- All the working groups of the European Technology and Innovation Platform for Photovoltaics (ETIP PV).
- ENEA is among the founders and member of the Pemanent Consultation Board of the "Italian Network for Photovoltaic Research and Innovation - ReteIFV", which is joined by research institutions and companies
- ENEA chairs the Italian Sustainable Agrivoltaic Association (AIAS)

Regarding the Concentrated Solar Thermal topic ENEA participates in:
- IEA-SolarPACES TCP (Task 1-6).
- IEA-SHC TCP (Solar Heating and Cooling), Task 64 "Solar Process Heat".
- IEA-Industrial Energy-Related Technologies and Systems.
- EERA JP on CSP (with coordination of the SP3 - Thermal Energy Storage for CSP plants).
- ESTELA (European Solar Thermal Electricity Association)

For what concerns Wind Power technologies, ENEA is member of:
- IEA Wind TCP Task 60, CYCLEWIND (Harmonized Life Cycle Assessment for Wind Power)
- IEA Wind TCP Task 59 WREN (Working Together to Resolve Environmental Effects of Wind Energy).

In the context of hydrogen value chain ENEA:
- Is member of IEA-Hydrogen, IEA-Advanced Fuel Cells and IEA-SolarPACES Technology Collaborative Programmes.
- Coordinates Task 45 "Renewable Hydrogen Production" of the IEA-Hydrogen Technology Collaboration Program of the International Energy Agency (IEA Hydrogen TCP)
- Is member of the Clean Hydrogen Partnership).
- Is member of the EERA Joint Programme on Fuel Cells and Hydrogen.
- Is member of the Board of Directors of the Italian Association of Hydrogen and Fuel Cells.
- Contributes actively to the standardization of procedures in testing, installation, operation and life cycle assessment of fuel cell technologies within the International Electrotechnical Commission (IEC), Technical Committee 105.

Regarding the Energy Storage topic ENEA participates to:
- Joint Programme on Energy Storage (coordinating the Electrochemical Energy Storage Sub-Programme) in EERA.
- Working groups of the European Technology and Innovation Platform (ETIP) Batteries Europe, that covers holistically the entire battery value chain, with an important role as technical expert within the management board and secretariat.
- Battery 2030+ initiative, in order to pave the way for the batteries of the future.
- Recently ENEA also joined BEPA, the Batteries European Partnership Association (BEPA), confirming its commitment to improve the competitiveness of the European battery industry. Counting more than 160 members, BEPA is a leading association dedicated to creating a competitive, sustainable and circular European industrial battery value chain for stationary applications and e-mobility. The BEPA goals are to prepare Europe to manufacture and commercialize by 2030 the next-generation battery

technologies that will enable the rollout of the zero-emission mobility and renewable energy storage. BEPA represents the private side association of the BATT4EU Partnerships, the co-programmed partnership on batteries launched by the European Commission under Horizon Europe. The partnership will mobilise more 925 million euros, to boost European research and innovation in the battery sector.

- IEA-ES TCP (Energy Storage), Task 33 “Material and component development for thermal energy storage”, Task 34 “Energy storage with heat pumps - Comfort&Climate box”, Task 36 “Carnot batteries”.

In the context of final uses ENEA participates to

- Coordinator of the Joint Program Smart Cities in EERA.
- SET Plan Implementation Working Group 3.2 Europe to become a global role model in integrated, innovative solutions for the planning, deployment, and replication of Positive Energy Districts

ENEA is also Italian representative in several international networks related to bioenergy and bioresources such as:

- IEA Bioenergy Task 33 “Gasification of biomass and waste”.
- IEA Bioenergy Task 42 “Biorefining in a Circular Economy”.
- The European Alliance for excellent research in sustainable bioenergy (EERA Bioenergy).
- Bio-based Industries Joint Technology Initiative (BBI-JTI).

In the context of CCUS, ENEA acts as Italian observer in IC3 (Carbon Capture that is focused on the development of carbon capture technologies and negative CO_2 emissions technologies) and participates:

- In steering committee of the European Research Fund for Coal and Steel.
- In the Technology Collaboration Program (TCP) of IEA on Industrial and Energy related technologies and Systems (IETS) in particular in task 21 “Decarbonizing industrial systems in a circular economy framework” and subtask C: “Industrial carbon technologies and systems”.
- As a member of the Joint Programme of the European Energy Research Alliance (EERA) on CCS technologies.

In the sector of **Development Cooperation ENEA** plays a pivotal role in researching innovative solutions supporting environmental and energy transitions in developing and low-income countries through several instruments:

- agreements, networks and partnerships through a wide network of exchanges, MoUs and collaboration agreements with the main actors of development cooperation. It is member of national and international networks and collaborates with national, international and U.N. Agencies: It is member of National Council for Development Cooperation
- technical and scientific support by participating in numerous projects in several countries of Africa, Mediterranean Basin, ASEANs, Latin America, focusing on renewable energies development and implementation, energy access improvement, clean and affordable energy for productive uses.
- technology transfer: ENEA actively contributes to transferring technologies and know-how

- properly targeted at the local contexts of developing countries, also by means of demonstrative energy pilot plants, creating synergic exchange of knowledge in close connection with businesses and other local actors
- training by a wide range of attended and e-learning training and courses and capacity building

ENEA is also involved in several European and International initiatives in the field of Smart Grids:

- IEA (International Energy Agency) Task 11 "PV Hybrid systems within mini-grids"
- IEA Task 14 "High penetration of PV systems in electricity grids".
- IEA Task 18 "Off-Grid and Edge-of-Grid Photovoltaic Systems".
- IEC (International Electro-technical Commission), TC 82 "Solar photovoltaic energy systems".
- IEEE IES Industrial Energy Society TC on Smart Grids.
- Working Group (WG) EU PV Technology Platform (EUPVTP), Grid Integration (www.eupvplatform.org/about-pv-platform/ad-hoc-working-group-4.html).
- Joint Programme "Smart Grid" in EERA - European Energy Research Alliance. ENEA is the coordinator for Sub Programme 4 "Consumer and Prosumer activation and Engagement through digitalization and ICT" of Joint Programme on Smart Grids within the European Energy Research Alliance.
- Working Groups Mission Innovation 2.0 Power Mission (Pillar 1: Affordable and Reliable VRE - Pillar 2: System Flexibility and Market Design - Pillar 3: System Integration, Data and Digitalization).
- SET Plan Implementation Working Group (IWG) on HVDC

6. Future perspectives (towards carbon neutrality)

With specific reference to each technology within the range of main ENEA R&D activities, the following key innovation challenges are identified to be addressed in the near future from an R&D perspective:

- **CSP-TES** systems can play a relevant role in supporting the penetration of non-programmable renewable sources in the energy system, thanks to the possibility of efficiently and cost-effectively store thermal energy for long periods and in large scales. In this regard, the use of hybridized CSP-PV technology can be considered as a strategic solution both to i) provide low-cost electricity during the day while ensuring the electricity generation also in absence of the solar source, ii) use the excess electricity generated by photovoltaic systems to heat the storage systems of CSP plants, thus contributing to the grid stability and obtaining cost savings thanks to the reduction of ancillary services. ENEA is actively involved in this field of research, with the aim of identifying technical solutions to reduce installation and operation costs of the plants, simplify operation and increase the components' reliability and lifetime. Another relevant perspective for the consolidation of CST technology is the expected expansion of the SHIP market to address the decarbonisation of the industrial sector. In this regard, the main challenge is the development of cost-effective, modular, compact CST solutions, easy to install and integrate with the current industrial processes. In this field, ENEA is working on the on the optimization, also through the hybridization at the thermal storage level with the photovoltaic system, of CST plants integrated with endothermic processes.
- **Photovoltaic**: demonstration of very-high efficiency and large-scale manufacturing

technology for a PV system cost reduction of about 60% compared to the current cost. Pervasive presence of PV System by means of smart integration and synergies requiring innovative and collaborative efforts with building and agricultural industries. Deep digitalization of PV module and systems providing both energy and environment control facilitating the widening of PV applications. Completely and easily recyclable PV modules through the innovative eco-design developments.

- **Energy and biofuel from biomass** are expected to give an important contribution towards the achievement of the carbon neutrality by 2050. On this regard ENEA activity related to gasification will concern the topic of hydrogen production and integration with discontinuous RES. Efforts will be directed to increase the TRLs value towards the achievement of technological readiness for commercialization. Specific items will be:
    - Development of processes for green hydrogen production from biomass and biowaste at cost comparable with that from fossil fuel, i.e., steam reforming of natural gas (around 5 €/kgH_2).
    - Electricity production cost below 0.10 €/kWh by exploiting feedstocks of low-grade and using highly efficient chemical energy conversion systems, with possible integration with carbon capture and storage (BECCS).
    - Integration of gasification with intermittent RES, such as solar PV and wind, as a key technology for energy storage and grid stabilization.

  Within this subject, additional activity will concern the evaluation of integrating syngas production with green hydrogen to produce light biofuels (e.g., SNG, MeOH, DME) as a way for chemical storage of H2.

- **Hydrogen production**: green hydrogen and electrolysis technologies will be the main drivers for energy transition in Europe and most likely worldwide to decarbonize heard-to-abate industrial and mobility sectors, besides providing a more resilient energy system. This statement implies that the integration between renewable energy sources (mainly solar and wind) and hydrogen production, distribution and storage systems will have to be more and more effective and reliable. These goals will be achieved only with synergic effort of research and industrial compartments. ENEA research programs and activities aim to tackle these issues providing suitable solutions to the industrial sectors involved. The implementation of the first Italian hydrogen valley in ENEA (in the context of Mission Innovation initiative, Challenge # 8 - clean and Renewable Hydrogen) will represent the first step to a more resilient and reliable energy system.
- Hydrogen conversion to fuels: penetration of green hydrogen in the energy system will be achieved by its direct use or its direct conversion to e-fuels; the latter option will allow exploiting the actual energy infrastructure to carry and use renewable energy vectors.
- **Hydrogen final use/Fuel Cell**: the SOC is a high-temperature technology, operating at 600-800°C, and which is the reason for the high conversion efficiencies in both operating modes. It is especially promising in industrial contexts, where steam or hydrogen can be available as a process stream and can be directed towards the generation or the use of hydrogen for power production at unmatched efficiencies in an SOC.

  With their working flexibly, the SOC can give rise to innovative business propositions where price arbitrage of renewable power connected to the grid can provide adequate revenue streams, or where energy communities want to progressively emancipate themselves from grid connection.

  ENEA is active on all fuel cells technologies from low temperature PEM to high

temperature (Solid Oxide and Molten Carbonate), exploring technical feasibility, sustainability, system integration and business opportunities. ENEA has built up a comprehensive network of research and industrial partners in this process, articulated in a number of European projects.

- **Hydrogen final use/gas turbine:** the European roadmap on gas turbines, developed within the Clean Hydrogen Energy association and transferred into the "Strategic Research and Innovation Agenda" (SRIA 2020), is currently being revised in terms of Key Performance Indicators and required activities on fuel-flexible burners for gas turbines, including ammonia combustion capability. ENEA is going to develop its on-going studies on hydrogen blends combustion in fuel-flexible and low-NOX burner prototypes by performing accurate fluid-dynamic numerical simulations and experiments at both laboratory and micro-gas turbine scale, also including the EGR strategy, Ammonia/hydrogen blends have been investigated by means of numerical simulations. Special attention is given to NOx formation and how to limit it, and to real-time monitoring of combustion for instability precursor identification. The topics cover both the power generation and the aeronautic transport sectors.
- **Batteries**: ENEA has identified three main streams of key innovation challenges. 1) From one end the digitalization will be even more entangled to the batteries R&D, in many aspects all over the value chain. 2) On another end, it will be of capital importance to bridge the gap between fundamental research and first industrial deployment, in order to foster the national and European battery industry. 3) Finally, in third place, the research efforts need to be directed on systems that are intrinsically safe and sustainable, which minimize or replace Critical Raw Materials (CRMs) and contain second life (recycled) materials, which is has been mandated by Europe. These three aspects are covered by ENEA in different projects, primarily IPCEI (ongoing), Mission Innovation Challenge 6 (ended in 2024), and the RdS National Program (ended in 2024 and refinanced for 2025-2027), which will increase the long-lasting experience acquired through national and European projects conducted so far, throughout over 20 years of activities. In particular, ENEA will be actively engaged in researching next-generation batteries based on new chemistries to replace Lithium (e.g. Sodium ion systems) and reduce the use of CRMs in electrodes, such as Cobalt, Nickel, Manganese, with a special focus on intrinsically safe technology developed at ENEA by replacing organic solvents in the electrolytes. Finally, the keyword "hybridization" will be of paramount interest for the Department for Energy Technologies and Renewables in ENEA, to gather and combine synergistically diverse energy storage opportunities, as in the StoRIES network.
- **CCUS**: The perspective of ENEA is to enhance research capabilities in all fields of CCUS covering both power generation and industrial processes (i.e., cement industry, iron and steel, refining, chemicals, gas processing, biofuels, glass production) and establish a crucial link with industry, other research organizations and SME. It will be to increase the involvement in ongoing industrial CCUS projects. The future perspectives of ENEA in the field of carbon neutrality are: (i) to optimize services provided by research infrastructures to its stakeholders and industrial and scientific user groups through planned dialogues with targeted industrial sectors and the research community, fostering partnerships and collaborative projects that bridge the gap between academic research and industrial applications, ensuring that innovations in CCUS technologies are effectively translated into scalable solutions; (ii) to identify industrial research needs and select advanced solutions for CCUS to engage industry and research organizations actively; (iii) to explore and promote the integration of innovative negative emissions technologies such as Direct Air Capture (DAC) and Bioenergy with Carbon Capture and Storage (BECCS), identifying their potential

applications and benefits within various industrial contexts.

- **CCUS/Methanation**: the activities on PtG and on methanation for the conversion of captured CO_2, either from power plants or from carbon-intensive industries to a widespread marketable product, such as methane, are in line with the EU strategies addressed to create new markets for innovative industrial sectors; diversify the economic base in carbon-intensive regions; contribute to achieving a Circular Economy. Future challenges in technology are related to testing and developing of different processes of hydrogen production in P2G application (Alkaline, PEM, SOEC, etc.), to operation flexibility in terms of variable power supply and fast load variations keeping high efficiencies. Also range-ability and stand-by behavior is a point of attention. About methanation one direction of development focuses on the adaptability to various carbon sources (dac, biogas, syngas, effluents from EII, etc.) while other sectors deal with catalysts (different basis Ni, Ru…, different concepts bulk, monolith, foams, structure, etc.), new concepts for reactors (compactness, flexibility, range ability) and location: "in situ" and "ex situ" for biological reactors.
- **Smart Sector Integration**: the perspective of ENEA is to enhance research capabilities in the field of smart sector integration. More in detail, activities will focus on design, development, and testing of solutions for enabling smart sector integration in order to reach a more resilient energy system based on the diversification of primary energy sources, a prevalent presence of renewables-based energy sources and digitalization of energy networks, thus addressing both decarbonization and digitalization needs. Research activities will provide also prototypes of technologies for smart sector integration (i.e., technologies for promoting smart energy flows exchange among different sectors or networks, considering the different and mutually exchangeable forms of energy supply and their final use, also through physical and cyber-physical systems interconnected on the networks). Prototyping actions will be developed for those technologies which slow down the decarbonization of energy networks due to an energy market gap.
- **Energy Management/control systems for Smart Grid Operation** must be capable of coordinating both the energy demand and consumption, by enhancing the use of distributed and flexible resources in the energy intelligent systems at different scales and scenarios. The control strategy is a big issue to face when different prosumers are linked/connected, especially when the energy flow has to be optimized according to the end users demand. For example, in the context of local integrated energy systems as energy communities with multiple prosumers sharing energy to satisfy their needs, management and control algorithms should be based on multi-agent approaches (centralized, decentralized, cooperative, non-cooperative) that would allow to consider the perspective of prosumers in peer-to-peer energy sharing within the community. However, the greater future challenges to be considered are interoperability issues, lack of standardization (several devices coordinated by each EMS use different communication protocols) and difficulty to manage networks in charge of different providers (e.g., gas network, electrical network, etc.).
- The most important challenge to be faced in the environmental **sustainability assessment** of energy and transport systems and technologies lays in the application in full of the LCA principles of comprehensiveness (both in the life cycle stages and impact categories analyzed) to avoid trade-offs among different areas of environmental concern or life cycle stages. An additional challenge is the enlargement of the sustainability assessment to the economic and social aspects, to fully grasp the impacts on the three pillars of sustainability. Expected international collaborations are on the sustainability assessment methodological development, to the application of the methodologies to

specific case studies/technologies/ projects and the collaboration in defining standards, developing tools and provide policy recommendations.

- A common phenomenon among countries is the fact that the level of **socio-political acceptability** of RES is high, even where the government is not strongly supporting renewable energy. However, at the same time, it is also common that opposition and protest rise while these are often the only ways the public finds to give voice to its concerns and needs. This phenomenon becomes particularly frequent at the local level where place-identity implications come into play: the more space for public expression of opinions get constrained by authorization procedures that do not include public space of information and participation, the more are RES projects and carbon neutrality initiatives perceived as threats rather than opportunities. This leads to the following research questions, which represent the future challenges for social acceptability issues: to what extent are procedural justice, distributional justice and trust reflected and incorporated both in public and corporate governance, which concrete measures and tools allow to effectively engage citizens, and overall, which are the main factors that improve social acceptability, according to this framework.
- **Carbon neutrality** is one of the most relevant goals of the energy transition in Europe. This transition requires both an increase of awareness by the European citizens about their energy fingerprint and a digital transition that can foster this awareness. Renewable Energy Communities and Citizen Energy Communities are instruments to support this twofold transition: carbon neutrality will remain a dream if the citizens do not change the perspective in daily energy management, making it a common habit. ENEA is developing tools to support the energy transition in different ways: 1) tools for providing information and knowledge to the citizens using technologies for collecting data, analyze them and return to the end users and by imaging new future scenarios in which the energy management is only a leverage for creating relations and connections among the people; 2) tools and localized management policies, where REC is an innovative solution for managing the consumption and production of renewable energy; 3) tools for risk analysis and CI protection (energy, transportation, telecommunications, logistics, etc.), which - especially in urban areas - are essential for providing key services to citizens.
- **Renewable Energy Communities (REC)** are one of the new next-generation energy models that stem from technological innovation but still requires some focused refinement. Its success in terms of development, energy savings, and decarbonization depends on the cultural shift of citizens (prosumer and consumer) who agree to be active and integral participants in the energy transition. Today, the REC should not be seen as an optional choice but a necessary one, representing the new way to manage and meet one's energy needs. The future of REC is tied to a cultural transition involving the acceptance of its social and ecological purpose and recognition as a business model for the country, not just for single individuals. Where REC will become an integral part of urban management, it will have to evolve into a standard configuration for territories—a routine model for energy management by local and central government authorities. Nowadays, we are technologically mature but socially and culturally immature. The rewards for REC members, in terms of contributions, incentives, and advantages, should be more varied, for example with their participation being compensated through reduced fiscal and contributory burdens. ENEA supports the development of RECs by promoting the cultural transition among citizens and developing tools and localized management policies, where REC is an innovative solution for managing the consumption and production of renewable energy.
- Aspects related to the protection and **resilience of Critical Infrastructures (CI) and**

the Essential Services (ES) they provide have been at the forefront of the European and International Agenda for many years. Recent data shows a trend of increasing frequency and intensity of natural disasters affecting CIs, with direct consequences on citizens and rising costs due to material damage caused by such events. The use of advanced technological tools to support emergency forecasting and management actions is, therefore, a fundamental strategy to reduce global damages. ENEA has participated and continues to participate in various European and National projects, implemented in line with community guidelines. In these contexts, a series of innovative technologies and tools have been developed for risk analysis and CI protection (energy, transportation, telecommunications, logistics, etc.), which - especially in urban areas - are essential for providing key services to citizens. To achieve these objectives, it is necessary to analyze the phenomena that pose threats to infrastructures (caused by extreme natural events or human activity) in order to develop new tools and platforms for the protection and resilience enhancement of these systems. It is also important to account for the interaction between different CI systems, defining failure propagation models while considering the interdependencies. The ultimate goal is to support the definition of effective countermeasures to mitigate the impact on services and ensure efficient crisis management.

- In the context of **SMART Cities and Digital Transition**, the Public Energy Living Lab (PELL) platform and methodology aims at introducing a minimum standard of knowledge, monitoring, and evaluation - on a national scale - of urban energy-intensive and/or strategic infrastructures to meet the transition objectives, providing a static and dynamic snapshot of the Italian context. This "talking digital picture" could offer data, information, KPIs, and integrated analyses and webGIS visualizations at the municipal, provincial, regional, and national levels, so that creating a new key information asset, crucial for the development of innovation policies, definition of much more focused interventions, and addressing of investments. Moreover, ENEA carried out interoperability specifications for smart city platforms (SCPS) aimed at preventing the “vendor lock-in” situation for public administration by means of a framework which is a national standard (UNI 11973:25).

Giorgio Graditi, Ph.D. in Electrical Engineering

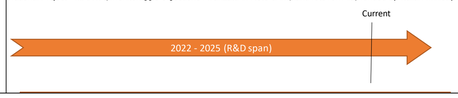
General Director of ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Rome, Italy.

He received the doctoral degree and the Laurea degree (cum laude) in Electrical Engineering from the University of Palermo (Italy). Since 2000, he is a Researcher at ENEA. Since July 2020, he is the Director of the Department of Energy Technologies and Renewable Sources of ENEA. From 2011 to 2017, he was the head of the Photovoltaic Systems and Smart Grid Unit of ENEA, whereas from 2018 to 2019 he was the head of Solar Thermal and Smart Network Division of ENEA. He is the responsible of ENEA initiatives and activities for the National recovery and Resilience Plan.
From April 2019, he is the President of MEDENER, the association recognized by the European Commission that brings together the national agencies of the Mediterranean countries engaged in the field of energy efficiency and renewable sources. He is also President of SIET S.p.A. world leader in testing for the research and development of innovative components and systems for electricity production plants, member of the Board of Directors of the University of Cassino, member of the Board of Directors of the partnership NEST - Network 4 Energy Sustainable Transition funded by the Italian Ministry of University and Research within the National Recovery and Resilience Plan, and the coordinator of the Scientific Technical Committee of the National Energy Technology Cluster funded by Italian Ministry of University and Research. He was an expert member of the MUR Working Group for the Thematic Area “Industrial Energetics”, Area “Climate, Energy and Sustainable Mobility”, National Research Plan 2021-2027. He is a member of IEA task 11 “PV Hybrid systems within mini-grids” and task 14 “High penetration of PV systems in electricity grids” and of Italian Electrotechnical Committee (CEI) CT 82 “Solar photovoltaic”, CT 316 “Connection to LV, MV and HV distribution networks” and CT 313 “Smart grids”.
In 2017, he received the Italian National Scientific Qualification as Full Professor in the sector of electrical energy engineering. He is operating as Italian member for Mission Innovation Challenge 1 “Smart Grids” and Challenge 2 “Off-grid access to electricity”, and he was a member of the H2020 National Steering Board for the “Safe, Clean and Efficient Energy” Cluster, and member of the working group of the thematic area “Industrial Energy” for the “Climate, Energy and Sustainable Mobility” area set up by the Italian Ministry of University and Research within the drafting of the national research plan 2020-2027. He is the vice-coordinator of the Joint Programme on Smart Grid (JP SG) within European Energy Research Alliance (EERA) and responsible of many National and European (FP7, H2020) projects on the topics of RES, integrated energy networks and smart grid.
His main research interests are in: design, modelling and tools development for the control and management of Smart Grids and microgrids in the presence of DER; energy conversion components and systems design and characterization; performance analysis of integrated energy networks by multi-objective techniques; design, modelling, and analysis of multi-energy hubs; management and operation optimization of local and renewable energy communities; design, characterization and testing of concentrated solar power and photovoltaic components and plants; technologies and uses of hydrogen; RES production and demand forecasting based on artificial intelligence techniques.
He has supervised several MSc and PhD theses. He is also peer review, associated editor, member of editorial and advisory board of scientific journals, and chairman in international conference. He is also responsible of

many R&D contract and agreement in the energy sector with international and national stakeholders. He is author of international scientific books and of more than 300 scientific papers (with Scopus H-index 42) published in international journals and proceedings of international conference some of them awarded as highly-cited papers.

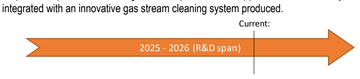
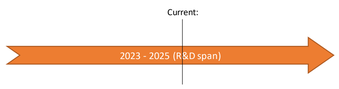
Institute/Country	Theme	Sub Theme	Related programs (with short summary)	Target / Goal Outcome	Lead person / Organization	Partnership (if any)	Related information
ENEA/Italy	Renewable Energy	PV	H2020 Project - **PHOTORAMA** (PHOTOvoltaic waste management – Advanced technologies for recovery & recycling of secondary RAw Materials End-of-Life module) - Innovation Action 	Purpose of the project is the realization and implementation of a pilot line for the recovery of precious materials from panels photovoltaic with the intention of using non-polluting materials from a chemical point of view in the future industrialization and a eco-design with low energy-intensive impact.	Claire AGRAFFEIL, CEA - France, P. Delli Veneri (Project leader for ENEA)	• ENEA - Research Institute • ENEL GP-Industry （International） • CEA: Commissariat à l'Énergie Atomique et aux Energies Alternatives - Research Institute - France • MASS - Mondragon Assembly S. COOP, Industry, Spain • PVCYC, PV Cycle France, SME - France • LUX, Luxchemtec GmbH - SME - Germany • RHP - RHP Technology GmbH, SME - Austria • MALTHA, MALTHA Glassrecyclage Belgie - Industry - Belgium; • SINTEF, Research Institute, Norway; • DFD, DENSE FLUID DEGREASING SA, Research Institute, France; • IDEN, IDENER (Optimización Orientada a la Sostenibilidad) -SME- Spain • BIFA, BIFA UMWELTINSTITUT GmbH -Research Institute- Germany • ZSI ZENTRUM FUR SOZIALE INNOVATION GmbH -Research Institute- Germany	https://www.photorama-project.eu/
ENEA/Italy	Energy storage/transport	Hydrogen Production	**European Project - PROMETEO (Hydrogen PRO duction by MEans of solar heat and power in high TE mperature solid Oxide electrolysers)**, funded by FCH JU. The Project aims at producingf green hydrogen from renewable heat & power sources by high temperature electrolysis in areas of low electricity prices associated to photovoltaic or wind 	i) Optimization of the coupling of the SOE with two intermittent sources: non-programmable renewable electricity and high-temperature solar heat from Concentrating Solar systems with Thermal Energy Storage; ii) design and realization of a fully-equipped modular prototype with at least 25 kWe SOE (about 15 kg/day hydrogen production) and TES (for 24 hours operation) connected to representative external power/heat sources and validated in real context (TRL 5).	A.Giaconia/ENEA	ENEA (Research Insitutte); FBK (Research Insitutte); Snam S.p.A. (Private Company)); NextChem (Private Company); (International) Capital Energy (Spain, Private Company); SolydEra (Switzerland, Private Company); IMDEA Energy (Spain, Research Institute); ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE (Switzerland, University); STAMICARBON B.V.(Netherland, Private Company); Green Capital Power (Spain, Private Company); Anguita Fotovoltaico (Spain, Private Company)	https://prometeo-project.eu/
ENEA/Italy	Energy storage/transport	Hydrogen Storage	**European Project - HASTA (Hydrogen Aircraft Sloshing Tank Advancement)**, funded by Horizon Europe. The Project aims at experimentally and computationally investigating the storage of liquid hydrogen for airborne use as fuel in civil aircraft applications 	Environmental concerns motivate a transition to liquid hydrogen aviation fuel in coming decades, and for this technology the size, placement and connections of the hydrogen tank on an aircraft are key decisions. The Hydrogen Aircraft Sloshing Tank Advancement project (HASTA) aims to experimentally and computationally investigate the storage of liquid hydrogen (LH2) for airborne use as fuel in civil aircraft applications. Size and position of a LH2 tank inside an aircraft are limiting factors for range, payload and aircraft size, and consequently play a crucial role in the environmental impact. The goal of facilitating tank design will be achieved through creation of design criteria for LH2 aircraft tanks; these design guidelines will be based on the different tools and models of derived during the project, in particular those aimed at complex cryogenic sloshing. The experimentally validated design tools developed during HASTA are to be used for both conceptual and detailed design in the aircraft industry, and therefore span a range of fidelities from reduced order models to full computational methods. The primary focus of this project will be the development of LH2 capabilities, and particularly the extension of mature capabilities already available for sloshing of standard civil aircraft fuel (kerosene) to the cryogenic temperatures associated with LH2. These capabilities are well reflected in the composition of the consortium, which includes partners with both experimental and modelling experience of fuel slosh, as well as cryogenics for space applications. The ultimate goal of the project is development of experimentally validated numerical and analytical simulation tools to model the complex thermo-fluid-dynamics of cryogenic LH2 coupled to the thermo–mechanical behavior of a tank and its operational environment.	Antonio Agresta (ENEA)	ENEA (Research Insitutte); CNR (Resarch Institute); University La Sapienza (University), UniCusano (University); (International) UNIVERSIDAD POLITECNICA DE MADRID (Spain, University); AIRBUS OPERATIONS SL (Spain, Private Company); AIRBUS OPERATIONS SAS (France, Private Company); AIRBUS OPERATIONS GMBH (Germany, Private Company); ARIANEGROUP GMBH (Germany, Private Company); ARIANEGROUP SAS (France, Private Company); MILITARY TECHNICAL ACADEMY FERDINAND I (Romania, Institution), SORBONNE UNIVERSITE (France, University); VON KARMAN INSTITUTE FOR FLUID DYNAMICS (Belgium, Research Institute); DEUTSCHES ZENTRUM FUR LUFT – UND RAUMFAHRT EV (Germany, Research Institute); UNIVERSITY OF CAPE TOWN (South Africa, University)	
ENEA/Italy	Hydrogen	All	**National Project - Hydrogen demo Valley** - Mission Innovation, funded by Italian Ministry of Economic Development. The project purpose is to build a complete Hydrogen demo Valley at the ENEA Casaccia Research Centre 	The project addresses the creation of an infrastructural hub for testing and demonstration of hydrogen technologies covering production, storage, distribution and utilisation of hydrogen and blends of natural gas and hydrogen, for the energy, industrial and transport sectors. The multifunctional infrastructure would be implemented in the Casaccia Research Centre of ENEA, to act as a breeding ground for hydrogen value chain technologies and services with the aim of accelerating their deployment in view of the energy transition and overall decarbonisation.	P. Deiana ENEA	– ENEA – CNR	https://mission-innovation.it/
ENEA/Italy	Energy use / application	Fuel cells	H2020 project - **SO-FREE**: development of a fully future-ready solid oxide fuel cell (SOFC)-based system for combined heat and power (CHP) generation. (FCH2 - Research and Innovation Action) 	i) In-depth understanding of the effects of variable fuel compositions – considering mixtures of natural gas, biogas and hydrogen – on the operation of SOFC stacks integrated in a combined heat and power (CHP) system ii) Optimisation of anode off-gas recirculation for the complete avoidance of fuel pre-reforming allowing to reach system CAPEX targeted by the 2024 FCH JU multi-annual work programme (MAWP) values iii) Development of a standardised stack module-system interface for full interchangeability of SOFC stack modules in any application-ready system iv) Demonstration of two 5-kWe-class systems for 9 months and >6000 operating hours each, proving efficient (>48% electrical), low-degradation (<1%/kh) and constant (>90% availability) operation in flexi-fuel conditions, each integrating both of two radically different SOFC stack technologies v) Pre-certification of the developed prototype system according to applicable EU and international directives and regulation vi) Operation in actual, residential CHP-generating environment to demonstrate decrease of CO2 emissions through flexi-fuel operation. vii) Assessment and quantification of the residential SOFC-CHP market at global level, after which a detailed country-specific review will be carried out for the Netherlands, Italy, Poland and the UK	Viviana Cigolotti (ENEA)	- ENEA - Research Institute, Università degli Studi Guglielmo Marconi - University, I.C.I CALDAIE SPA - Industry （International）: - AVL List GmbH - Industry - Austria - Elcogen OY - Industry - Finland - Fraunhofer Gesellschaft zur Foerderung der Angewandten Forschung E.V. - Research Institute - Germany - Instytut Energetyki - Research Institute - Poland - Kiwa Nederland BV - Netherlands - PGE Polska Grupa Energetyczna SA - Industry - Poland	https://www.so-free.eu/
ENEA/Italy	Energy Storage	All	H2020 project - **StoRIES (Storage Research Infrastructure Eco-System)** 	Tthe main objectives of StoRIES are linked to the energy storage development by providing access to world-class research infrastructures and services, with a focus on improving materials for devices and optimizing hybrid energy systems with a view to make energy technologies more competitive and reducing costs.	Stefano Passerini, KIT-HIU (Germany) M.Moreno (ENEA)	(Domestic): -ENEA, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, RI, Italy -CNR, Consiglio Nazionale delle Ricerche, RI, Italy -ENI, Eni SpA, industry, Italy (International): -KIT,Karlsruher Institut fuer Technologie, RI, Germany -AIT, Austrian Institute of Technology, RI, Austria -CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, RI, Spain -CLERENS, I.C. Belgium SCRL, SME, Belgium	https://www.eera-energystorage.eu/stories.html
ENEA/Italy	Energy Storage	Batteries	European project - **EuBatIn** (IPCEI on batteries - German leadership). 	The "German leaded Important project of Common European Interest" has many Member States involved and ENEA is one of the Italian participants. ENEA role is to develop new-concept batteries suitable of being transformed into an industrial product and optimize recycling in line with circular economy approach. The aim is to fill the gap between the lab-scale and the installation and production problems at a pilot plant level to assist the industry upon the first industrial deployment stage.	VDE-VDI (Germany) P. Prosini (Project leader for ENEA)		

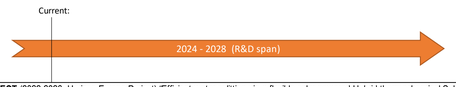
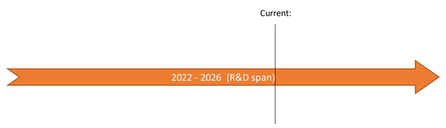
ENEA/Italy	CCUS	Carbon capture and utilization	H2020 Project - **ChemPGM: MSCA-RISE** - Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE). Reuse of platinum-group metals, recovered from spent catalysts or from e-waste as catalysts for CO2 valorisation processes (e.g. reverse water gas shift, methanation, dry reforming of methane). 	To create knowledge, provide expertise and educate the academic public and professionals regarding the chemistry of PGMs and its application in CCUS technologies	Maria Luisa Grilli/ENEA	1 Monolithos Katalites Ke Anakiklosi Etaireia Periorismenis Evthinis Greece 2 Agenzia Nazionale Per Le Nuove Tecnologie, L'energia E Lo Sviluppo Economico Sostenibile It 3 Y.S. Cypriot Catalysts Limited Cy 4 Lomartov Sl Spain 5 Universite De Liege Be 6 University Of Cape Town Za 7 Institute Of Catalysis, Bulgarian Academy Of Sciences Bg	https://chempgm.com/
ENEA/Italy	Hydrogen Use	Hydrogen use	Horizon -IA: **ALRIGH2T**: Airport Level Demonstration od Ground Refuelling of Liquid Hydrogen for Aviation 	to develop and test innovative technologies and processes for refuelling liquid hydrogen aircraft in real airport conditions, with the goal of reducing the aviation sector's environmental impact	Viviana Cigolotti (ENEA)	ENEA Coordinator Austrian Institute of Technology LKR Ranshofen Piaggio Aerospace Linde GmbH Salzburger Aluminium Group TEST-FUCHS Israel Aerospace Industries Digisky TLD EMEAI Universal Hydrogen Amelia SEA Milano Groupe ADP SINTEF French National Institute for Industrial Environment and Risks ATENA Technische Universität München Zabala Linde Kryotechnik AG	www.alrigh2t.eu
ENEA/Italy	Energy management system	Local energy communties	H2020 Project - **eNeuron (greEN Energy hUbs for local integRated energy cOmmunities optimizatioN)** 	The main goal of the eNeuron project is to develop innovative tools for the optimal design and operation of local energy communities (LECs) integrating distributed energy resources and multiple energy carriers at different scales. This goal will be achieved, by having in mind all the potential benefits achievable for the different actors involved and by promoting the Energy Hub concept, as a conceptual model for controlling and managing multi-carrier and integrated energy systems in order to optimize their architecture and operation. In order to ensure both the short-term and the long-term sustainability of this new energy paradigm and thus support an effective implementation and deployment, economic and environmental aspects will be taken into account in the optimization tools through a multi-objective approach. eNeuron's proposed tools enable tangible sustainability and energy security benefits for all the stakeholders in the LEC. Local prosumers (households, commercial and industrial actors) stand to benefit through the reduction of energy costs while leveraging local, low carbon energy. Developers and solution providers will find new opportunities for technologies as part of an integrated, replicable operational business model. Distribution system operators (DSOs) benefit from avoiding grid congestion and deferring network investments. Policy makers benefit from increasingly sustainable and secure energy supply systems. eNeuron is a high TRL project in line with the Work Programme, by developing innovative approaches and methodologies to optimally plan and operate integrated LECs through the optimal selection and use of multiple energy carriers and by considering both short- and long-run priorities. Through optimally coordinating all energy carriers and vectors, cost-effective and low-carbon solutions will be provided for fostering the deployment and implementation of this new energy paradigm at European level.	Maria Valenti/ENEA	The eNeuron consortium consists of 17 partners from 8 EU countries: Cyprus, Germany, Ireland, Italy, Norway, Poland, Portugal and Spain. In detail, the partners consist of 7 research organisations (ENEA, EPRI, IREC,IEN, DERLAB, SINTEF, TECNALIA) 3 universities (UNIVERSITY OF CYPRUS, UNIVERSIDAD POLITECNICA DE MADRID, UNIVERSITA' POLITECNICA DELLE MARCHE) , 3 industries (ENEIDA, LEDE, ICONS), 1 non-profit organisation , 1 municipality (CITY OF BYDGOSZCZ) and the Portuguese Navy (Marinha Portuguesa)	https://eneuron.eu/
ENEA/Italy	Energy management system	Energy networks	National Project - **MISSION (Multivector Integrated Smart Systems and Intelligent microgrids for accelerating the energy transitiON)**, funded by Italian Ministry of Economic Development The project aims to develop two smart grid demonstrators - microgrid size, full scale and multi-vector - located, respectively, at the CR ENEA in Portici (Smart Energy Microgrid ENEA) and the RSE offices in Milan and Piacenza (Extension multi-energy of the Distributed Energy Resources Test Facility RSE). 	The project will study, design and implement technological solutions enabling the transition of networks towards integrated and smart multi-energy distribution systems.	Maria Valenti/ENEA	The project consortium consists of following partners: ENEA Italian National Agency for New Technologies (IT) , Energy and Sustainable Economic Development, Institute of Informatics and Telematics of CNR National Research Council (IT), RSE - Ricerca sul Sistema Energetico (IT).	https://mission-innovation.it/
ENEA/Italy	Renewable Energy production	Power production	Regional Programme funding: COMPLEX RESEARCH AND DEVELOPMENT PROJECTS "CORES" - Thematic areas: Energy and Bioeconomy. **EMERA project** is related to the topic Energy; it aima at developing an efficient micro energy networks powered by only RES for the autonomy and independence of rural areas from the centralized system. In the project ENEA is involved in activity reletad to several aspect among which development of the gasification reactor, technical and economic analysis of possible biomass-energy supply chains, and establishment of guidelines for the preparation of logistics and supply plans. 	1- Identification of components and processes to be integrated into a stand-alone demonstrator. 2- Enhancement of energy valorization of residual biomass by gasification. 3- Robust integration of production and storage systems. 4- Involvement of various stakeholders to recognize needs and expectations.	D. Barisano/ENEA	CMD S.p.A (Coordinator), DIGIMAT, EES srl, ESA srl, ENEA, CNR	https://www.cmdengine.com/gruppo-cmd/progetti-innovativi/

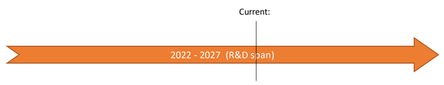
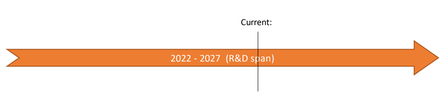
ENEA/Italy	Renewable Energy production	Power production	Call for funding of technology research projects - Three-year National Electricity System Research Plan 2019-2021 - MISE. The **RECOVERY project** aims at the energy valorization of residual materials coming from the agro-food industry (e.g., sewage sludge, digestate, and putrescible surplus materials) through syngas from gasification for self-production and self-consumption of electricity. 	1- Improvement of processes for converting residual materials into gaseous fuels usable for cogeneration purposes. 2- Energy and environmental performance optimization of internal combustion engines in cogeneration set-up running on bio-derived gaseous fuels only. 3- Analysis of techno-economic and permitting sustainability of the sludge processing chain.	E. Fanelli/ENEA	CMD S.p.A (Coordinator), Giaguaro S.p.A, ENEA	https://www.cmdengine.com/gruppo-cmd/progetti-innovativi/
ENEA/Italy	Renewable Energy production	Biofuels production	PON "Research and Innovation" 2014 - 2020 -MIUR. The **Wet Waste to Green Fuel** (WW-Green Fuel) project aims at the development of gasification process (dry and SCWG) for the exploitation of large-scale biomass and production of liquefied SNG. 	To develop and validate on a pilot scale an integrated process of valorization of organic matrices (biomass, organic waste/refluents, sludge, etc.) into liquid biomethane (CH4) as an advanced biofuel.	E. Fanelli/ENEA	Consortium DITNE (Coordinator), CNR-ITAE, UNICAL, UNIBA, POLITO, SOTACARBO, Calabra maceri, TECHFEM, SOL spa.	
ENEA/Italy	Energy use / application	Fuel cell/Ammonia	H2020 project - **FuelSOME:** MultifuelSOFC system with Maritime/Energy vectors 	"FuelSOME" is aimed to develop and validate, up to TRL 4, a novel multifuel energy generation system based on Solid Oxide Fuel Cell Technology system which will be capable of operating on various fuels and fuel mixtures. The project will go beyond the current state of the art (SOTA), by developing SOFC stacks which are for the first time able to operate successfully on ammonia and methanol in addition to hydrogen. Green hydrogen (or hydrogen in general) will also be considered as it is in the focus and general interest of the EU.	Viviana Cigolotti (ENEA)	1.AVL LIST GMBH AVL, AT 2.AEE - INSTITUT FUR NACHHALTIGE TECHNOLOGIEN, AT 3.ATENA SCARL - DISTRETTO ALTA TECNOLOGIA ENERGIA AMBIENTE, IT 4.EBOS TECHNOLOGIES LIMITED EBOS, CY 5.ELCOGEN OY, FI 6.POLITECHNIKA WARSZAWSKA, PL 7.TEKNOLOGIAN TUTKIMUSKESKUS VTT OY VTT, FI 8.ZURCHER HOCHSCHULE FUR ANGEWANDTEWISSENSCHAFTEN, CH	
ENEA/Italy	Renewable Energy	PV	National Project -**TANDEM** (Processi innovativi per una linea di produzione di celle solari TANDEM ad alta efficienza), founded by the Italian Ministry of Ecological Transition 	Creation of production systems for the fabrication of tandem solar cells that perform individual process steps and are mechanically connected to each other so that the substrates can be transferred from one system to the next remaining confined in a controlled environment in order to to avoid contaminations.	OGT - OLIVOTTO GLASS TECHNOLOGIES - Italy/ P. Delli veneri (ENEA)	- ENEA - Research Institute - OGT - OLIVOTTO GLASS TECHNOLOGIES - Industry - RISE Technology - SME - CNR - CONSIGLIO NAZIONALE DELLE RICERCHE - Research Institute	
ENEA/Italy	Renewable Energy	PV	National Project -**GoPV** (Materiali di nuova GenerazIOne Per celle fotoVoltaiche tandem) funded by Italian Ministry of Ecological Transition 	Development of: 1) Perovskite films with various chemical formulations (inorganic, without or with reduced lead content, low-dimensional perovskite) with different bandgaps to be used in PV devices; 2) Charge carriers, transparent contacts, and interfaces between the various layers of the cells; 3) New generation of perovskite/perovskite, perovskite/silicon tandem cells .	Paola Delli Veneri, ENEA (Italy)	- ENEA - Research Institute. - University of Naples "Federico II" - University of Perugia - University of Pavia - University of Tor Vergata - University of Catania - IIT - Research Institute - BeDimensional - Industry	
ENEA/Italy	Renewable Energy	PV	EU Project -**SYMBIOSYST** (From the design to the implementation, a symbiosys where PV and agriculture can have a mutually beneficial relationship) 	SYMBIOSYST will fully exploit all the degrees of freedom and potential provided by the synergy between land & crop and open or closed agri-PV systems. The ambition of the project is to create a fully integrated solution, from the design to the implementation, a symbiosis where PV and agriculture can have a mutually beneficial relationship.	EURAC (Italy)/A. Scognamiglio (ENEA)	• ENEA - Research Institute • EURAC, Research Institute, Italy （International） • TUD - Technische Univesiteit Delft - University - Netherlands • IMEC, INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM- Research Institute - Belgium • ABOVE - Industry - United Kingdom • ALEO - Industry- Germany • Katholeke Universiteit Leuven, University - Belgium • LAIMBURG, Research Institute, Italy • SBB - Association - Italy • ETA- Energia, Trasporti, Agricoltura SRL - Association - Italy • Universitat Politecnica de Catalunya -University - Spain • PHYSEE - Industryy - Netherlands • KUBO- Industry-Netherlands • CONVERT Italia S.p.a. - Industry - Italy • LUCISUN - Industry - Belgium • 3E - Industry - Belgium • ENGIE-Lab - Industry - Belgium • EF SOLARE Italia - Industry - Italy	
ENEA/Italy	Renewable Energy	PV	National Project - **MARTA**(Monitoraggio e gestione Avanzata in Rete di impianti fotovolTAici) funded by Italian Ministry of Economc Development. 	The target of the project is the monitoring and advanced management of photovoltaic systems.	T.E.A. TEK, SpA (Italy)/G. Di Francia (ENEA)	T.E.A. TEK, SpA - PMI (Italy) ENEA - - Research Institute	

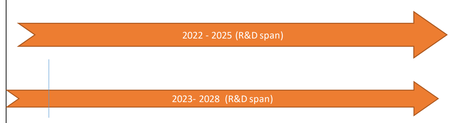
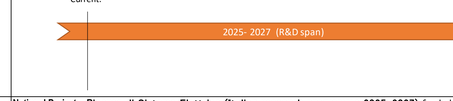
ENEA/Italy	ALL	ALL	National Project - **Ricerca di Sistema Elettrico** (Italian research programme 2025-2027) funded by the Italian Ministry of Environment and Energy Security. 	The programme includes several projects focusing on two macro-areas: (i) decarbonization and (ii) , digitalization	ENEA	ENEA, CNR, RSE S.p.A., numerous Italian universities and research institutes	
ENEA/Italy	Renewable energies	Concentrated Solar Energy	Horizon Europe Project - **SALTOpower** (Horizon CSA) Ther projects aims aims at enhancing the scientific excellence and innovation capacity of the Consortium in the foregoing exploitation of their unique reserche infrastructures on Molten Salt-Linear concentrated Solar Thermal systems, enabling the study and experimental test of e.g. materials, components and O&M procedures. 	i) Creating the reference European facility for the development and testing of Molten Salt based technologies for energy storage and dispatchable power production solutions, for the integration of different renewable energy sources, power and gas grids; ii) strengthening the research management and administration skills of the Widening Research Infrastructures	Pedro Horta/ UNIVERSIDADE DE EVORA / M. D'auria (ENEA)	- ENEA (Research Institute); (International) - DLR (Germany, Research Institute) - UEVORA (Portugal, University).	web-site under realization
ENEA/Italy	Renewable energies	Concentrated Solar Energy	National Commercial Project - **Joint Cooperation Eni-ENEA**. The project aims at developing, implementing and testing advanced technologies and solutions for concentrating solar systems coupled to thermal storage for the generation of electricity and / or heat, 	i) development and validation of innovative solutions for linear collectors and thermocline thermal storage units based on concrete; ii) identification of application scenarios for the CSP / CST technologies coupled to thermal storage iii) definition of business plans for the enhancement of these technologies; iii) identification of partnerships with national and international organizations for the design of industrial solutions in the contexts of interest identified	Raffaele Liberatore / ENEA	- ENEA (Research Institute); Eni (Private company)	not available
ENEA/Italy	Renewable energies	Concentrated Solar Energy	Horizon Europe Project - **CST4all** (Horizon CSA) The CST4ALL project defines an array of hybridisation and cooperation initiatives at the interface between CST and other technologies for applications relevant to the sectors of electricity, heat and fuels 	i) bringing together and incentivising the interaction of main stakeholders at key technology interfaces with the CSP sector building on combined technological and nontechnological improvements; ii) organizing an intertwined set of workshops with respective industry and R&I focus	Marcel Bial / ESTELA/L. Turchetti (ENEA)	- ENEA (Research Institute); (International) - EUROPEAN SOLAR THERMAL ELECTRICITY ASSOCIATION (Belgium, organzation) - DLR (Germany, Research Institute); Odtu Gunes Enerjisi Uygulama Ve Arastirma Merkezi (University, Turkey)	web-site under realization
ENEA/Italy	H2	R&D all technologies	**National Recovery and Resilience Plan: Hydrogen R&D** - Ministry of Environment and Energy Security - research activities on hydrogen to promote interdisciplinary and multidisciplinary interactions through the sharing of knowledge, skills, experiences, infrastructures and networks of laboratories in order to contribute to the increase of qualified critical mass and to the pursuit of objectives challenges 	Production of green and clean hydrogen Innovative technologies for the hydrogen storage and distribution and its transformation into derivatives and e-fuels Fuel Cells Digitalization of Hydrogen-based infrastructures	Giulia Monteleone - ENEA	ENEA - numerous national Universities	
ENEA/Italy	H2	R&D H2 technologies	**IPCEI (Important Project of Common European Interest) Hy2Tech**. Development of innovative hydrogen technologies up to te first Industrial Deplyment phase 	Development of pilot lines and innovative laboratories and experimental facilities to support research and innovation and first industrial deployment in the hydrogen technology value chain.	Giorgio Graditi - ENEA	ENEA - European Member States	
ENEA/Italy	Smart Gtid and Diigitalization	R&D all technologies	**EU-DREAM** – Effective Uptake of Digital Services to Repower European Consumers and Communities as Active Participants in Energy Transition and Markets (2024-2027, EU Project). The project aims at accelerating innovation in digital tools for the energy sector. 	1) introduction of an AI-based assistant and a Natural Language Processing (NLP) intermediary to translate complex energy market details into everyday language, making it easier for users to manage their energy consumption. 2) Experimental validation: the project will validate its solutions in six Living Labs.	Joao Catalao (Uviversidade Do Porto - Project Coordinator); M. Valenti (Project leader for ENEA)	UNIVERSIDADE DO PORTO (Coordinator), ENEA, CLEANWATTS DIGITAL SA, EPRI EUROPE DAC, SSE AIRTRICITY LTD, DCSIX TECHNOLOGIES LIMITED, AALBORG UNIVERSITET AAU Energy, TEKNOLOGIAN TUTKIMUSKESKUS VTT OY, AKKA HIGH TECH, UNIVERSIDAD DE CASTILLA, CONSORZIO INTERUNIVERSITARIO NAZIONALE PER ENERGIA E SISTEMI ELETTRICI, FONDAZIONE LINKS - LEADING INNOVATION & KNOWLEDGE FOR SOCIETY, IREN SPA, ARISTOTELIO PANEPISTIMIO THESSALONIKIS, DOMX IDIOTIKI KEFALAIOUCHIKI ETAIREIA, VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK N.V.	web-site under realization

ENEA/Italy	Energy use / application	H2 storage and Combustion	Commercial Project, Industry funded - **FINCANTIERI** funded by FINCANTIERI 	Test of storage systems for hydrogen (compressed gaseous H2; liquid H2) and of their feeding systems to the microgasturbine of the AGATUR plant in ENEA Casaccia.	ENEA	ENEA / FINCANTIERI	
ENEA/Italy	Space / application	Technologies for space exploration	PNRR Project, funded - **SPACE-IT-UP** funded by 	Technologies for space exploration and exploitaion for Earth and humanity: Enabling Technologies for Novel Near-Earth and Exploration Missions; • Advanced Design and Analysis of Space Missions and Systems and Innovative Digitalization e System Engineering and Digital Twin; • Future imaging systems for microwave and optical remote sensing; • Remote non-imaging/high energy particles; • Planetary protection and geohazards mitigation; • Protection of critical infrastructures and Space Weather; • Space for the sustainable development of the planet; • Robotic and Human Exploration of Extraterrestrial Habitats, Architectures and Infrastructures; Habitat space and science	Politecnico di Torino	Aerospace Logistics Technology Engineering Company S.p.A.; Argotec S.R.L.; Alma Mater Studiorum - Università Di Bologna; Centro Italiano Ricerche Aerospaziali S.C.P.A. - C.I.R.A.; Fondazione Centro Euro - Mediterraneo Sui Cambiamenti Climatici - CMCC; Consiglio Nazionale Delle Ricerche - CNR; E-geos S.P.A.; Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile - ENEA; Fondazione Bruno Kessler - FBK; Gran Sasso Science Institute - GSSI; Istituto Italiano di Tecnologia - IIT; Istituto Nazionale di Astrofisica - INAF; Istituto Nazionale di Fisica Nucleare - I.N.F.N.; Istituto Nazionale di Geofisica E Vulcanologia - INGV; Istituto Nazionale di Ricerca Metrologica - INRiM Leonardo S.p.A.; Fondazione Leading Innovation & Knowledge For Society - Links; Mapsat - Telerilevamento Euromediterraneo S.R.L.; Politecnico di Bari; Politecnico di Milano; Politecnico Di Torino; Università degli Studi di Firenze Università degli Studi di Napoli Federico II; Università degli Studi di Padova; Università di Pisa; Università degli Studi di Roma "La Sapienza"; Università degli Studi di Roma "Tor Vergata"; Università degli Studi di Trento; Università della Calabria; Sitael S.p.A; Thales Alenia Space Italia S.p.A.; Telespazio S.p.A.; Tyvak International S.R.L.	
ENEA/Italy	Energy use / application	R&D all technologies	**MOD-ENERGY** (2022-2025 - National Project POC METRO 2014-2020): Application and dissemination of intervention models in the field of smart lighting, street and building for the containment of energy consumption in Metropolitan Cities. 	Realization in the Municipality of Palermo of a metropolitan scale demonstration of technical and technological solutions for energy monitoring (public buildings and lighting systems) and seismic monitoring. Dissemination of the models developed for their replicability	Sabrina Romano-ENEA	ENEA, Municipality of Palermo, Cursa	https://modenergy.enea.it/
ENEA/Italy	Critical Infrastructures	R&D all technologies	**MULTICLIMACT** EU HORIZON-CL5-2022-D4-02 Project (2023-2027) - MULTI-faceted CLIMate adaptation ACTions to improve resilience, preparedness and responsiveness of the built environment against multiple hazards at multiple scales 	Safeguarding Europe's built environment against the increasing threats of natural and climatic hazards. Through innovative strategies tested across four pilot sites with diverse climatic conditions, MULTICLIMACT targets the urgent need for adaptive measures against floods, earthquakes, extreme weather conditions and heatwaves	C. Fuggini (RINA Consulting SpA - Project Coordinator); A. Di Pietro (Project leader for ENEA)	RINA CONSULTING SPA, ENEA, UNIVERSITA POLITECNICA DELLE MARCHE, UNIVERSITA DEGLI STUDI DI CAMERINO, FONDAZIONE CENTRO EURO-MEDITERRANEOSUI CAMBIAMENTI CLIMATICI, COMUNE DI CAMERINO, LIVE INFORMATION SYSTEM SRL, ICLEI EUROPEAN SECRETARIAT GMBH, UNIVERSITAETSKLINIKUM AACHEN, STEINBEIS INNOVATION GGMBH, FIBRISTERRE SYSTEMS GMBH, TECHNISCHE UNIVERSITEIT DELFT, FUNDACION TECNALIA RESEARCH & INNOVATION, COMSA SAU, CYPE SOFT SL, BRIGAID CONNECT, NATURALEA CONSERVACIO, SL, AJUNTAMENT DE BARCELONA, KUNGLIGA TEKNISKA HOEGSKOLAN, UPONOR OYJ, RIGA MUNICIPAL AGENCY "RIGA ENERGY AGENCY", NATIONAL CENTER FOR SCIENTIFIC RESEARCH "DEMOKRITOS", UNIVERSIDADE DO MINHO	https://multiclimact.eu/
ENEA/Italy	Critical Infrastructures	R&D all technologies	**CRISTAL** EU HORIZON-CL5-2021-D6-01 Project (2022-2025) - CLIMATE RESILIENT AND ENVIRONMENTALLY SUSTAINABLE TRANSPORT INFRASTRUCTURE, WITH A FOCUS ON INLAND WATERWAYS 	The crucial aim of the project is to create an innovative technology for monitoring and digitization of transport chains, indicating the direction of further development of business and management models that include river transport in multimodal chains	M. Cudzilo (Centrum Nowoczesnej Mobilności - Project Coordinator); S. Giovinazzi (Project leader for ENEA)	ALICE, ALLIANCE FOR LOGISTICS INNOVATION THROUGH COLLABORATION IN EUROPE, Alleanza, Belgio ENEA, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE, Ente Pubblico, Italia AIPo, AGENZIA INTERREGIONALE PER IL FIUME PO, Agenzia Interregionale istituita con Accordo Costitutivo, Italia Fraunhofer, FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV, Istituto di Ricerca, Germania IV, INFRASTRUTTURE VENETE SRL, Società a responsabilità limitata s.r.l, Italia SOGESCA, SOGESCA s.r.l, Società a responsabilità limitata s.r.l, Italia UAntwerpen, UNIVERSITEIT ANTWERPEN, Università, Belgio UnGda, UNIWERSYTET GDANSKI, Università, Polonia VNF, VOIES NAVIGABLES DE FRANCE, Ente Pubblico, Francia KTI, KTI KOZLEKEDESTUDOMANYI INTEZET NONPROFIT KFT, Organizzazione no-profit, Ungheria CERTH, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, Centro tecnologico, Grecia UniCa UNIONE ITALIANA DELLE CAMERE DI COMMERCIO INDUSTRIA ARTIGIANATO E AGRICOLTURA UNIONCAMERE, Ente Pubblico, Italia UniTra, UNIONTRANSPORTI SCARL, Società consortile a responsabilità limitata S.c.a.r.l., Italia. EUMO, EUROMOBILITA SRO, Società a responsabilità limitata, Repubblica Ceca	https://www.cristal-project.eu/
ENEA/Italy	Critical Infrastructures / Energy	R&D all technologies	**gEneSys** EU Project (2022-2026) - Transforming Gendered Interrelations of Power and Inequalities for Just Energy Systems 	The project conceptualises energy transition as a dynamic, gendered, mission-oriented socio-technical innovation ecosystem with several 'subsystems': technological, policy, social, environmental, governance, and economic, each with its own sustainability visions, values, and priorities, as well as change actors and stakeholders, who may also influence what happens in other subsystems.	L. Pisacane (CNR-IRPPS- Project Coordinator); A. De Nicola (Project leader for ENEA)	· CNR, CONSIGLIO NAZIONALE DELLE RICERCHE · ENEA, AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE · UNIWERSYTET JAGIELLONSKI, POLAND · FRAUNHOFER, GERMANY · THE AFRICAN INSTITUTE FOR MATHEMATICAL SCIENCES, RWANDA · PORTIA GGMBH, GERMANY · VIU, VENICE INTERNATIONAL UNIVERSITY, ITALY · IMPERIAL COLLEGE OF SCIENCE TECHNOLOGY AND MEDICINE, UNITED KINGDOM (associated partner)	https://genesys-project.eu/

ENEA/Italy	Energy use / application	R&D all technologies	**DUT** (2022-24, 2025-2028)- European Parntership Driving Urban Transitions" HORIZON Programme Cofund Actions – European Climate, Infrastructure and Environment Executive Agency (CINEA) - Call: HORIZON-CL5-2021-D2-01 	The DUT Partnership steps up the game to tackle urban challenges. Through research and innovation and capacity building, we enable local authorities and municipalities, service and infrastructure providers, and citizens to translate global strategies into local action. It develop the skills and tools to make urban change happen and boost the urgently needed urban transformations towards a sustainable future with enhanced quality of life in cities.	Margit Noll (Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie – BMK- Project Coordinator); P. Clerici Maestosi (Project leader for ENEA)	OSTERREICHISCHE FORSCHUNGSFORDERUNGSGESELLSCHAFT MBH (FFG); AUSTRIATECH – GESELLSCHAFT DES BUNDES FUR TECHNOLOGIEPOLITISCHE: MASSNAHMEN GMBH (A-Tech); FONDS VOOR WETENSCHAPPELIJK ONDERZOEK-VLAANDEREN (FWO); VLAAMSE GEWEST (VLO). PIC 999575107 INNOVIRIS (Innoviris);FONDS DE LA RECHERCHE SCIENTIFIQUE- FNRS (F.R.S.-FNRS) 8. BULGARIAN; NATIONAL SCIENCE FUND ; COMISSAO DE COORDENACAO E DESENVOLVIMENTO REGIONAL DO NORTE; TECHNOLOGICKA AGENTURA CESKE REPUBLIKY (TACR;. MINISTRY OF INDUSTRY AND TRADE (MPO) INNOVATIONSFONDEN (IFD); MAJANDUS JA KOMMUNIKATSIOONIMINISTEERIUM (MKM); SIHTASUTUS EESTI TEADUSAGENTUUR (ETAg); TYÖ- JA ELINKEINOMINISTERIÖ (MEE); AGENCE NATIONALE DE LA RECHERCHE (ANR); FORSCHUNGSZENTRUM JULICH GMBH (FZJ-PtJ); DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV (DLR); MINISTERO DELLO SVILUPPO ECONOMICO (MiSE); GENIKI GRAMMATIA EREVNAS KAI KAINOTOMIAS (GSRI); ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS (CERTH); NEMZETI KUTATASI FEJLESZTESI ES INNOVACIOS HIVATAL (NKFIH); RANNSOKNAMIDSTOD ISLANDS (Rannis); Ministero dell'università e della ricerca (MUR) 2AGENZIA LATVIJAS ZINATNES PADOME (LCS); Lietuvos mokslo taryba (LMT); MINISTERIE VAN BINNENLANDSE ZAKEN EN KONINKRIJKSRELATIES (MINBZK);; NEDERLANDSE ORGANISATIE VOOR WETENSCHAPPELIJK ONDERZOEK (NWO); NORGES FORSKNINGSRAD (RCN); NARODOWE CENTRUM BADAN I ROZWOJU (NCBR); DIRECAO-GERAL DE ENERGIA E GEOLOGIA (DGEG); FUNDACAO PARA A CIENCIA E A TECNOLOGIA (FCT); DIRECAO GERAL DO TERRITORIO (DGT); UNITATEA EXECUTIVA PENTRU FINANTAREA INVATAMANTULUI SUPERIOR, CERCETARII DEZVOLTARII SI INOVARII (UEFISCDI); MINISTERSTVO SKOLSTVA VEDY VYSKUMU A SPORTU SR (MINEDU); JAVNA AGENCIJA ZA RAZISKOVALNO DEJAVNOST REPUBLIKE SLOVENIJE (ARRS); AGENCIA ESTATAL DE INVESTIGACION; CENTRO PARA EL DESARROLLO TECNOLOGICO INDUSTRIAL. (CDTI); VERKET FOR INNOVATIONSSYSTEM (VINNOVA) FORSKNINGSRÅDET FÖR MILJÖ, AREELLA NÄRINGAR OCH SAMHÄLLSBYGGANDE (FORMAS) STATENS ENERGIMYNDIGHET (SWEA); TURKIYE BILIMSEL VE TEKNOLOJIK ARASTIRMA KURUMU (TUBITAK); AGENCE DE L'ENVIRONNEMENT ET DE LAMAITRISE DE L'ENERGIE (ADEME); COMISSAO DE COORDENACAO E DESENVOLVIMENTO REGIONAL DO CENTRO (CCDR-C); FONDS INNOVEREN EN ONDERNEMEN (FIO)	https://dutpartnership.eu/
ENEA/Italy	Energy use / application	R&D all technologies	**PIAC(ER)2** (2023-2025)- Platform for enabling Renewable Energy Communities in Emilia-Romagna Region (Piattaforma per l' Abilitazione delle Comunità Energetiche Rinnovabili in Emilia-Romagna) 	Develping tools for planning and managing Renewable Energy Communities (REC) in Emilia-Romagna Region in Italy. The platform will support the REC from the early stage of planning to the long term management and forecasting.	M. Zatti(LEAP - Project Coordinator); A. Brutti (Project leader for ENEA)	LEAP (Laboratorio Energia Ambiente Piacenza), ENEA, CIDEA, Università di Bologna, Università degli Studi di Ferrara	
ENEA/Italy	Renewable Energy production	biomass/Power production	**SYNAPSY**: ENEA funding Programme (Proof of Concept), Thematic area: CHP production based on residual biomass and biogenic fractions valorization. SYNAPSY aims to improve the performance of a gasification plant for CHP applications, achieved by increasing the degree of syngas cleanliness obtained at a downdraft reactor integrated with an innovative gas stream cleaning system produced. 	Enhancement of energy valorization of residual biomass by gasification; Raising the commercialization potential of the gasification reactor; Valorization of biochar from gasification in agricultural sector as soil ammendant.	D. Barisano/ENEA	ENEA(Coordinator) & CMD S.p.A	
ENEA/Italy	Renewable Energy production	biomass/Power production	**DD4BioPower** - ENEA funding Programme (Proof of Concept) Development of an innovative Downdraft reactor for the production of biofuel from waste of plant origin (2025-206) 	Enhancement of energy valorization of residual biomass by gasification;	E. Fanelli/ENEA	ENEA(Coordinator) & Licar International	
ENEA/Italy	Renewable Energy production	biomass/biofuels	**AMICS** :ENEA funding Programme (Proof of Concept)- Innovative apparatus and method for processing liquid reagents with solid catalysts aimed at optimizing the production of biodiesel from waste oils (2025-2026) 	production of biofuesl from waste oils	A. Blasi/ENEA	ENEA(Coordinator) & MISO SRL	
ENEA/Italy	Renewable Energy production	bioamss/biobased products/biofuels	**PERCIVAL** – Extraction processes of bioproducts from agro-industrial waste and cascade valorisation. (PON Ricerca e Innovazione MUR 2014-2020) (2023-2025) 	development of innovative processes for pre-treatment, extraction/separation and subsequent valorisation of agro-industrial waste, using a 'cascade' biorefinery approach to obtain bioactive compounds , chemicals/building blocks and materials.). Biofuels (biomethane) and agricultural products (soil improvers, biochar, biostimulants) will be obtained from the transformation residues/by-products.	F. Liuzzi ENEA	ENEA(Coordinator))/DITNE	
ENEA/Italy	Renewable Energy production	biomass/biochar	**REVINE** : Progetto Revine "Regenerative agricultural approches to improve ecosystems" (European PRIMA Project) (2022-2025) 	Convert biomass of pruning waste in biochar in order to improve carbon storage, vineyard performance and sustainability in a circular economy perspective. Studying the effect of biochar treatments on vine-associated microbial communities.	Fiammetta Alagna	CREA-Italy, ENEA-Italy, Cyprus University of Technology, Associação para a Investigação e Desenvolvimento de Ciências-Portugal, Instituto Nacional de Investigação Agrária e Veterinária-Portugal, Agricultural Research Center-Egypt, Regional Centre of Agriculture Research of Sidi Bouzid-Tunisia, Burgundy School of Business-France, Società agricola D'Alessandro and Azienda Agricola San Marco in Italy, Vasiliko Oinopoieio Kyperoundas and Vlassides Winery in Cyprus	

ENEA/Italy	Renewable Energy	bioenergy	**KijaniBox**. EU HORIZON-IA / HORIZON-CL5-2023-D3-02-16 / 101147463 / Transforming African Organic Waste into Green Energy for Cooling. It is a highly innovative project that will accelerate the African green transition and provide energy access for small businesses along the food supply chain. The target is to leverage the organic waste and transform them into green energy for cooling and refrigeration applications in order to prevent food losses and sanitary risks (2024-2028) 	The project aims to demonstrate the concept in 3 pilot sites in partnership with local waste management companies, food value chain actors and cold supply chain industries. In order to implement the concept, the project proposes highly innovative approaches called "Green Transition Enablers". These are i) KijaniBox System itself, a small-scale, off-grid, industrial-grade waste to cooling system ii) Application Solution Boxes (ASB), application specific KijaniBox solution for three use cases iii) Co-creation Factory, enabling the local manufacturing capabilities for cost-effective solution, and finally iv) Businessin- a-Box, a comprehensive toolkit for entrepreneurs and stakeholders business support in order to ensure successful takeup and commercialization of the solution. The ultimate target of KijaniBox is to pave the way for long-term sustainable economic growth and job creation opportunities in Africa and Europe.	Beate Brenner (TUD - Germany)/ G. Stoppiello (ENEA)	1. TECHNISCHE UNIVERSITAET DRESDEN (TUD), Germany, Coordinator 2. POLITECNICO DI MILANO (POLIMI), Italy, 3. AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE (ENEA), Italy, 4. WAZIUP EV (WAZIUP), Germany, 5. INNEUROPE INITIATIVE S.L. (INN), Spain, 6. ESCOLA SUPERIOR DE COMERC INTERNACIONAL (ESCI-UPF), Spain, 7. INNOTEC21 GMBH (IT21), Germany, 8. AFRICA BIOENERGY PROGRAMS LIMITED (ABPL), Kenya, 9. DEDAN KIMATHI UNIVERSITY OF TECHNOLOGY (DeKUT), Kenya, 10. SOLAR FREEZE LIMITED (SF), Kenya, 11. ECOH HOLDINGS LIMITED (EHL), Kenya, 12. BIOGAS SOLUTIONS UGANDA LIMITED BY GUARANTEE (BSUL), Uganda, 13. NATIONAL AGRICULTURAL RESEARCH ORGANISATION (NARO), Uganda, 14. UNIVERSITE GASTON BERGER DE SAINT LOUIS (UGB), Senegal, 1. TECHNISCHE UNIVERSITAET DRESDEN (TUD), Germany, Coordinator	
ENEA/Italy	Renewable Energy	Hydrogen Production	**HYSELECT** (2022-2026, Horizon Europe Project) "Efficient water splitting via a flexible solar-powered Hybrid thermochemical-Sulphur dioxide depolarized Electrolysis Cycle". 	The project will demonstrate the production of hydrogen (H2) by splitting water via concentrated solar technologies (CST) with an attractive efficiency and cost, through the hybrid sulphur cycle (HyS).	Dimitrios Dimitrakist (DLR), Michela Lanchi (ENEA)	DLR (Germany), ENEA (Italy), University of AALTO (Finaland), GRILLO (Germany), CEERTH (Greece), SEN Research (Austria)	www.hyselect.eu
ENEA/Italy	Renewable Energy	Hydrogen Production	**MECCA Green H2 from bioMEthane cracking,** (PNRR national project 2022-2025) 	The project aims to produce green hydrogen using an innovative biogas cracking technology, making it competitive in both cost and carbon footprint (i.e., the measure of environmental impact human activities have on climate change) compared to hydrogen produced through electrolysis.	Donatella Barisano (ENEA)	University of Messina, Fondazione Bruno Kessler,NEXTCHEM S.p.A, ENEA, University of Calabria	
ENEA/Italy	Renewable Energy	Fuel Cell	**CALIPSO - Celle A combustibiLe innovative ad alta Potenza in Sistemi stazionari e di mObilità** (PNRR national project 2022-2025) 	The project aims at developing innovation in the field of high-power PEM and MC fuel cell technologies for both stationary and mobility applications. i) Development of novel components and production processes; ii) performance characterization and sustainability assessment of such components; iii) design of stacks and modules compatible with the developed components; iv) evaluation of technology transfer opportunities.	Elio Jannelli (Università degli Studi di Napoli Parthenope), Massimiliano Della Pietra (project leader for ENEA)	Università degli Studi di Napoli Parthenope, Università degli Studi di Genova, ENEA, ARCO FC S.r.l., ECOSPRAY TECHNOLOGIES S.r.l.	
ENEA/Italy	Renewable energies	Biomass	National Commercial Project - **Joint Cooperation Eni-ENEA Biomass project nr. 2,** 	The project aims at developing, implementing and testing advanced technologies and solutions for biomethane, microbial oils, and biochar production	Raffaele Liberatore / ENEA	- ENEA (Research Institute); Eni (Private company)	
ENEA/Italy	Hydrogen	Hydrogen Production	**European Project - PROTOSTACK (Tubular proton conducting ceramic stacks for pressurized hydrogen production)**, funded by Horizon Europe. The Project aims at developping an innovative, compact, and modular PCCEL stack design with an integrated hot-box capable of operating and delivering hydrogen at pressures up to 30 bar. 	PROTOSTACK will develop an innovative, compact, and modular PCCEL stack design with an integrated hot-box capable of operating and delivering hydrogen at pressures up to 30 bar. The stack will be demonstrated at 5 kW, providing a pathway for future scale-up to systems of hundreds of kW. These milestones will serve as a significant proof of technological feasibility, advancing PCCEL technology from TRL 2 to TRL 4. To achieve these ambitious objectives, the project brings together leading research and industry partners specializing in proton ceramic technologies, with expertise in electrolysers, membrane reactors, materials science, electrochemistry, and process engineering. The consortium is committed to extensive communication and dissemination activities to maximize the project's impact, and the industry partners are highly focused on business exploitation and commercialization of PROTOSTACK technology.	Viviana Cigolotti (ENEA)	ENEA (Italy, Research Insitutte); SINTEF (Norway, Resarch Institute); ATENA (Italy, Resarch Institute), Agencia Estatal Consejo Superior De Investigaciones Cientificas (Spain, Research Institute); Shell (Netherlands, Company); Coorsteck (Norway, Private Company); Demcon Energy (Netherlands, Company)	
ENEA/Italy	Energy use / application	Fuel cells	H2020 project - **REACTT**: the projects aims at realizing a Monitoring, Diagnostic, Prognostic and Control Tool (MDPC) for SOE and rSOC stacks and systems. (FCH2 - Research and Innovation Action) 	i) Improved durability, reliability and maintainability of SOE and rSOC stacks by developing innovative algorithms for diagnostics and prognostics of their remaining useful life. Ii) Advanced control strategy with self-optimizing and fault-tolerant features iii) Hardware module for implementation of the monitoring, diagnostics, prognostics and control iv) Characterization of stacks and systems in SOE and rSOC nominal and faulty conditions and validation of the product prototype	Đani Juričić, IJS (Slovenia). Davide Pumiglia (Project leader for ENEA)	- ENEA - Research Institute, Università degli Studi di Salerno - University, Bitron S.p.A. - Industry （International）: - Institut Jožef Stefan - Research Institute - Slovenia - Commissariat à l'Énergie Atomique et aux Énergies Alternatives - Research Institute - France - École Polytechnique Fédérale de Lausanne - University - Switzerland - SOLIDpower S.A. - Industry - Switzerland - VTT: Teknologian tutkimuskeskus - Research Institute - Finland - AVL List GmbH - Industry - Austria	
ENEA/Italy	Energy use / application	Fuel Cells/heavy duty	H2020 project - **H2Ports**: Implementing Fuel Cells and Hydrogen Technologies in Ports 	H2Ports aims to boost the transition of the European port industry towards an effective lowcarbon/zero-emission and safe operative model, piloting, evaluating and demonstrating new FC technologies oriented to increase energy efficiency, decarbonisation and safety of port terminals. The main objective is to deploy port equipment equipped with FC technologies and the use of hydrogen as zero-emission fuel through innovative market sided solutions to be ready for market adoption by the end of the project.	Viviana Cigolotti (ENEA)	1.Fundación de la Comunidad Valenciana para la Investigación, Promoción y Estudios Comerciales de Valenciaport, Spain 2.Ballard Power Systems Europe, Denmark 3.Autoridad Portuaria de Valencia, Spain 4.Centro Nacional de Experimentación de Tecnologías de Hidrógeno y Pilas de Combustible Consorcio CNH2, Spain 5.Mediterranean Shipping Company Terminal Valencia, Spain 6.Hyster – Yale Nederland B.V., Netherlands 7.Grimaldi Euromed S.P.A, Italy 8.ATENA SCARL – Distretto Alta Tecnologia Energia Ambiente, Italy 9.ENAGÁS, Spain	

ENEA/Italy	renewable energy	e-fuels; methanation	**BIOMETHAVERSE** - Demonstrating and Connecting Production Innovations in the Biomethane Universe (2022-2027, EU project). BIOMETHAVERSE aims to diversify the technology basis for biomethane production in Europe, to increase its cost-effectiveness, and to contribute to the uptake of biomethane technologies.To this aim five innovative methanation pathways will be demonstrated in five European countries: France, Greece, Italy, Sweden and Ukraine. 	BIOMETHAVERSE's research and pilot technologies set out to boost the production of biomethane in Europe, thus contributing to energy independence and competitive sustainable growth, whilst creating green jobs. The project production routes cover one or a combination of the following production pathways: thermochemical, biochemical, electrochemical, and biological. As a starting point, four demonstration plants use conventional anaerobic digestion (AD), and one uses conventional gasification.	Stefano Proietti (ISINNOVA); Alessandro Agostini (ENEA)	Istituto di Studi per l'Integrazione dei Sistemi (ISINNOVA) IT; European Biogas Association (EBA) BE; Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA) IT; Bioenergy Association of Ukraine (UABIO) UA; Bioaerio Lagada (BLAG) EL; Ethniko Kentro Erevnas Kai Technologikis Anaptyxis (CERTH) EL; RISE Research Institutes of Sweden (RISE) SE; Cortus Energy (CORTUS) SE ; Wartsila Sweden (WARTSILA) SE; ENGIE (ENGIE) FR ; AERIS Tecnologias Ambientales (AERIS) ES ; Acondicionamento Tarrasense Associacion (LEITAT) ES ; Danmarks Tekniske Universitet (DTU) DK ; Friedrich-Alexander-Universitaet (FAU) DE ; CAP Holding (CAP) IT; Energigas Sverige Service (SGA) SE; PrJSC "MHP Eko Energy" (MHP) UA; Politecnico di Milano (POLIMI) IT; Consorzio Italiano Compostatori (CIC) IT; Società Italiana Acetilene e Derivati (SIAD) IT; Deutsches Biomasseforschungszentrum gemeinnützige (DBFZ) DE; Ellman Engineering (EE) DE;	https://www.biomethaverse.eu/
ENEA/Italy	Integrated modelling	J ndstries pathways to decarbonisati	**AMIGDALA**: Alliance for modelling industries towards the Green Deal's objectives and circularity (2024-2027, EU project). AMIGDALA is a Horizon Europe project which seeks to facilitate decision-makers in governments and industry to define and evaluate pathways and market uptakes of transformative solutions for circular, climate neutral and competitive industries. 	The overall objective of AMIGDALA is to assist government and industry decision-makers in defining and evaluating pathways toward circular, climate-neutral, and competitive industries, using common databases and integrated models aligned with the Green Deal's sustainability objectives by: - Developing an integrated modelling approach for the EU's Intensive Energy sector. - Addressing the lack of standardisation in model integration. - Providing consistent and validated data to support climate objectives. - Enhancing transparency and understanding between model results and decision-makers' needs. - Driving informed decisions towards a sustainable and carbon-neutral future.	Judith Kessens (TNO); Alessandro Agostini (ENEA)	Nederlandse organisatie voor Toegepast-Natuurwetenschappelijk Onderzoek (TNO) - Coordinator, The Netherlands; European Research Services (ERS), Germany; Vlaamse Instelling voor Technologisch Onderzoek (VITO), Belgium ; DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V. (DEC) , Germany; International Institute for Applied Systems Analysis (IIASA), Austria; Italian National Agency for New Technologies, Energy and Sustainable Economic Development – ENEA (ENEA), Italy; Deloitte (DEL), France; GreenDecision (GD), Italy; Katholieke Universiteit Leuven – KU Leuven (KUL), Belgium; VDEh-Betriebsforschungsinstitut GmbH (BFI), Germany; Sustainable Innovations Europe S.L. (SIE), Spain;	https://amigdalaproject.eu/
ENEA/Italy	H2	climate impacts of H2	**NHyRA**: pre-Normative Research on Hydrogen Releases Assessment. (2024-2026, EU project). NHyRA aims to deliver reliable measurement and quantification methods, new data and rigorous calculation-based models in order to determine H2 releases from the H2 value chain and assess its potential climate impact 	The project will deliver a "H2 releases" inventory to serve as a reference for the scientific and industrial community. New or adequately adapted experimental, theoretical, and simulation methodologies will be validated to perform laboratory or in-field measurements to achieve the ambitious goal. Experimental tests will also be performed on the most critical elements of the H2 value chains by the partners of the Consortium. A complete picture of the H2 releases' scenarios in the middle (2030) and long (2050) term will be developed to enable decision-makers to identify and prioritize effective mitigation actions. And finally, the project will formulate recommendations for Standards and Technical Specifications.	Matteo Robino (SNAM); Alessandro Agostini (ENEA)	SNAM S.p.a. - Coordinatore, Italia; ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA, Italia; Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italia; Nuovo Pignone Tecnologie S.r.l., Italia; ENGIE, FR; ENAGAS TRANSPORTE SA E, ES; INSTYTUT NAFTY I GAZU - PANSTWOWY INSTYTUT BADAW, PL; DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV, DE; GERG LE GROUPE EUROPEEN DE RECHERCHES GAZIERES, BE; Fondazione Bruno Kessler, IT; NPL Management Limited , UK; University of Surrey, UK; Linde Gmbh, DE; The Regent of the University of California, USA; Equinor Energy, AS;	https://nhyra.eu/
ENEA/Italy	H2	Product Environmental footprint	**HyPEF**: Promoting an Environmentally - Responsible Hydrogen Economy by Enabling Product Environmental Footprint Studies(2024-2026, EU project). HyPEF complements methodological guidelines available for Product Environmental Footprint (PEF) and the latest recommendations on LCA (Life Cycle Assessment) of FCH systems by developing category rules specific to FCH products (FCH-PEFCRs). HyPEF-produced FCH – PEFCRs will pave the way for subsequent PEF initiatives in the FCH sector. 	The overall objective of AMIGDALA is to assist government and industry decision-makers in defining and evaluating pathways toward circular, climate-neutral, and competitive industries, using common databases and integrated models aligned with the Green Deal's sustainability objectives by: - Developing an integrated modelling approach for the EU's Intensive Energy sector. - Addressing the lack of standardisation in model integration. - Providing consistent and validated data to support climate objectives. - Enhancing transparency and understanding between model results and decision-makers' needs. - Driving informed decisions towards a sustainable and carbon-neutral future.	Javier Dofour (IMDEA); Claudio Carbone (ENEA)	Fundación IMDEA Energía (IME)- Coordinatore, Spain; Istituto di Studi per l'Integrazione dei Sistemi (ISINNOVA), Italia; Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italia; EIFER Europäisches Institut für Energieforschung EDF-KIT EWIV (EIFER), Germania; Ecoinnovazione srl (ECOI), Italia; ENGIE (ENGIE), Francia; Advanced Energy Technologies Ae Ereunas & Anaptyxis Ylkon & Proiontononaneosimon Pigon Energeias & Synafon Symvouleftikon y Piresion (ADVENT), Grecia; Hexagon Purus GmbH (HexPur), Germania;	https://www.hypef.eu/
ENEA/Italy	ICT	Cloud technologies	Project DataCLEEN (Data CLoud for Energy and Environment) in the frame of IPCEI (Important Project of Common European Interest) Cloud Infrastructure and Services 	The project aims to create a modern cloud infrastructure for managing large amounts of data and for developing and deploying advanced services in the energy and environment sectors. The platform will be designed to integrate artificial intelligence and high-performance computing (HPC) technologies, enabling complex problems to be addressed and supporting decision-making processes based on data, predictive models, and advanced simulations. The ENEA cloud will be federated with the national cloud and the European cloud managed by leading European companies, ensuring interoperability, security, and compliance with international standards. This approach, by hiding the complexity of computing and data infrastructures, will strengthen technological sovereignty and resource sharing, enabling the creation of a competitive and innovative digital ecosystem.	Massimo Celino /ENEA	ENEA - European Member States	web-site under realization
ENEA/Italy	ICT	High Performance Computing	Project EoCoE-III (Energy Oriented Center of Excellence: fostering the European energy transition with Exascale) funded within the EuroHPC JU framework of the European Commission 	The main objectives of the EoCoE-III project are to accelerate Europe's transition to decarbonized energy by leveraging exascale high-performance computing (HPC) for five major energy-related applications—Energy Materials, Water, Wind, and Fusion—thus demonstrating the benefits of HPC for both research and industry in the energy sector. EoCoE-III develops comprehensive, high-impact simulation codes with the aim to accelerate real-scale virtual modeling of natural energy phenomena (such as wind farm dynamics and plasma interactions in tokamaks) to optimize performance and reduce energy losses.	Massimo Celino /ENEA	ENEA - European Member States	web-site under realization
ENEA/Italy	ICT	High Performance Computing	National Recovery and Resilience Plan: ICSC - Italian Research Center on High Performance Computing, Big Data and Quantum Computing 	The main objective of the ICSC national center is to create a powerful national infrastructure for HPC and data at the national level, with cloud services, data lakes, and supercomputers available for research, industry, and public administration. The national center will be a center of excellence where technology transfer and the creation of synergies between public bodies, universities, and industry will be encouraged, and the development of new hardware/software technologies in the fields of HPC, Big Data, and quantum computing will be promoted. In parallel with infrastructure activities, vertical communities and expertise have been created to address major challenges in scientific and industrial domains (climate, environment, space, medicine, materials, etc.) through complex simulations, data analysis, and advanced applications.	Massimo Celino /ENEA	Coordinator INFN. Italian Partners	https://www.supercomputing-icsc.it
ENEA/Italy	ICT	Technologies for Innovation	National Recovery and Resilience Plan: Rome Technopole 	The main objective is to create a regional innovation ecosystem, transform the Lazio Region into a European technology hub, foster the competitive growth of local industry, and promote sustainable development in key sectors such as energy transition, digitalization, and health.	Marta Chinnici (ENEA)	Coordinator Sapienza. Italian Partners	https://www.rometechnopole.it/

ENEA/Italy	ICT	Technologies for Innovation	Progetto "CETMA-DIHSME: CETMA-Digital Innovation Hub for SMEs" 	The main objectives are to disseminate advanced digital technologies (Artificial Intelligence, Supercomputing, Cybersecurity) among SMEs and public administrations in southern Italy, particularly in the regions of Puglia and Basilicata, increasing their competitiveness, sustainability, and capacity for innovation.	Angelo Mariano (ENEA)	Coordinator CETMA. Italian Partners	https://www.cetma-dihsme.eu/
ENEA/Italy	H2	R&D H2 technologies	IPCEI (Important Project of Common European Interest) Hy2Tech. Development of innovative hydrogen technologies up to te first Industrial Deplyment phase 	Development of pilot lines and innovative laboratories and experimental facilities to support research and innovation and first industrial deployment in the hydrogen technology value chain.	Giorgio Graditi - ENEA	ENEA - European Member States	
ENEA/Italy	Renewable energies	Concentrated Solar energy/Energy Storage	**SULPHURREAL** (An innovative thermochemical cycle based on solid sulphur for integrated long-term storage of solar thermal energy) funded by HORIZON-EIC. The project aims at developing a novel technology for direct conversion of solar energy into chemicals, storable for a virtually unlimited time. 	i) demonstrating and validating a breakthrough approach for next generation, carbon-free, direct conversion of solar energy into chemicals storable for a virtually unlimited time, based on elemental sulphur produced and consumed on-demand via a solar-aided thermochemical cycle ii) implementing new technical solutions to optimize the three major process steps, namely the H2SO4 decomposition, SO2 disproportionation and elemental sulphur combustion	Christos Agrafiotis (DLR)/ Salvatore Sau (ENEA)	- ENEA, (Research Institutes); (International) - DLR (Germany, Research Institute); CERTH(Greecey, Research Intitute); KARLSRUHER INSTITUT FUER TECHNOLOGIE (Germany, Research Institute);UNIVERSITY OF PATRAS (Greece, University); Trinity College Dublin (Ireland, University); Research Insituttes of Sweden (Sweden, Research Institute); ExoMatter GmbH (Germany, Private Company); SAINT-GOBAIN CREE (France, Private Company);	https://sulphurreal.eu/
ENEA/Italy	Renewable energies	Concentrated Solar Energy	**MSA Trough:** The project focuses on developing a novel parabolic trough collector system for molten salt applications, funded under the Horizon Europe Programme (Cluster 5: Climate, Energy and Mobility) and implemented by the European Climate, Infrastructure and Environment Executive Agency (CINEA). 	The objective of the project is to develop a new parabolic trough collector designed to achieve higher efficiency, lower costs, greater reliability, and improved sustainability compared to current commercial solutions. Efficiency gains result from advances in optical design, structural improvements, tracking precision, secondary concentration, and mirror cleaning, together with strategies to reduce thermal and hydraulic losses, eliminate leakage-prone joints, and improve drainage. Overall, the concept enhances CSP plant competitiveness, supports the SET Plan objectives for global leadership in CSP, and facilitates the integration of higher shares of variable renewable energy.	Diogo Canavarro (UEVORA), Francesco Rovense (ENEA)	UNIVERSIDADE DE ÉVORA (University, Portugal), FERRUM TECNOINDUSTRIAL SL (Private for-profit entity, Spain), DEUTSCHES ZENTRUM FÜR LUFT- UND RAUMFAHRT EV (Research Organisation, Germany), ENEA (Research Organisation, Italy), OBSERVATOIRE MÉDITERRANÉEN DE L'ÉNERGIE (Research Organisation, France), RODAMA MAQUINARIA SL (Private for-profit entity, Spain)	https://www.msa-trough.eu/
ENEA/Italy	Renewable energy	Concentrated Solar Energy, Thermal Storage	**National Commercial Project - Joint Cooperation Eni-ENEA THERMAL STORAGE & CSP** nr. 2, 	This project is a follow-up to JCA Project 3, which was devoted to thermal storage and CSP. The main objectives are: 1-Design, construction and experimentation of a row of oil-based Small Parabolic Trough Collectors (SPTC): 25 meters in length composed of 4 modules. The expected temperature range is approximately 200-390°C. 2-Field testing and data processing for an innovative TES (Thermal Energy Storage) system experimentation. The experimental plant consists of a sensible heat concrete module of approximately 150 kWh and two latent heat modules having different kind of phase change materials with a storage capacity of about 40 kWh each. The plant, currently under construction, uses solar salts as heat transfer fluid, with temperatures reaching up to 450°C.	Raffaele Liberatore (ENEA); Michele Pellegrino (Eni)	ENEA (Research institute); Eni (Private Company)	not available
ENEA/Italy	Renewable energy	ALL	**National Project - Ricerca di Sistema Elettrico (Italian research programme 2025–2027)** funded by the Italian Ministry of Ecological Transition. The programme includes several projects focusing on: (i) renewable technologies to increase the flexibility of the grid (Concentrated Solar Thermal, ...); (ii) Energy storage, (iii) Hydrogen production and use 	The main objectives of the project are: - development of innovative technical solution to reduce costs of the production of dispatchable heat/electricity by CST tecnology; -development of compact and efficient thermal and thermochemical energy storage solutions capable of being charged by renewable heat and electricity; - research on Innovative materials for hydrogen production through thermochemical processes	Paola Polito (ENEA)	ENEA and several italian universities	not available
ENEA/Italy	Renewable energy	PV/Concentrated Solar thermal	**NEST -** NETWORK 4 ENERGY SUSTAINABLE TRANSITION" funded by MUR SPOKE 1- Solar: PV, CSP, CST (Workpackage 1.4 New concept for CSP/CST systems & Workpackage 1.5 Structural components and subsystems for high-efficiency solar systems). 	The main objective is the development of innovative components and algorithms to beapplied in PV and CSP/CST plants to enhance the energy production, energy forecasting and to reduce the impact of O&M)	Maurizio Cellura (University of Palermo), Walter Gaggioli (ENEA)	ENEA and several italian universities	

The 7th RD20, September 22nd 2025

Summary of activities on on Renewable Energies

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

1. Introduction

Mexico's energy sector has historically relied heavily on fossil fuels, leading to significant environmental problems such as ecological disasters, industrial pollution, and urban degradation. While there have been attempts to shift towards cleaner energy, progress has been hindered by various challenges and policy changes. Nevertheless, new initiatives indicate a renewed dedication to decarbonization. Mexican institutions, including Cinvestav, are contributing their expertise to future developments. The country's expanding network of universities and research centers focused on clean energy technologies is fostering a dynamic research environment.

2. R&D 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 urban location fosters collaborations with other research centers and industrial partners, facilitating the translation of laboratory discoveries into practical applications.

In Merida, the campus leverages the region's abundant solar resources to specialize in various aspects of solar energy. This includes the development of more efficient photovoltaic cells, the optimization of solar thermal systems for both electricity generation and industrial processes, and research into concentrated solar power technologies. Their work also often involves addressing the unique challenges and opportunities presented by tropical climates.

The Queretaro campus is a hub for research in hydrogen technologies and biofuels. Its scientists are actively involved in developing sustainable methods for hydrogen production, exploring fuel cell technologies for transportation and stationary power, and investigating advanced biorefining processes to convert biomass into valuable fuels and chemicals. This campus is also known for its work on catalytic processes essential for these applications.

Finally, the Saltillo campus concentrates on areas such as energy efficiency, and the development of sustainable materials for energy applications. Researchers here explore innovative approaches to reducing energy consumption in industrial and residential settings, and the creation of new materials that enhance the performance and durability of clean energy systems.

Collectively, these four Cinvestav campuses are at the forefront of developing sustainable and efficient energy solutions, addressing critical challenges related to energy security, environmental protection, and economic growth in Mexico and beyond. Their interdisciplinary approach and commitment to cutting-edge research underscore Cinvestav's leadership in the global clean energy landscape.

Specific research activities at Cinvestav include:

- **Solar Energy:** Research in solar energy is making significant progress, particularly in enhancing solar cell efficiency. Key areas of focus include advancements in Cu-Zn compounds for more cost-effective and environmentally friendly thin-film solar cells, and the development of dye-based technologies. These efforts aim to overcome limitations of current silicon-based solar cells, paving the way for more efficient, economical, versatile, and environmentally friendly solar energy solutions.
- **Hydrogen:** Cinvestav is conducting research into advanced methods for producing green hydrogen, an initiative crucial for the global transition to sustainable energy. Their work focuses on using renewable energy for electrolysis to separate water into hydrogen and oxygen without emissions. Green hydrogen is a clean and versatile energy carrier with diverse applications in transportation, electricity generation, and industrial processes, offering a zero-emission alternative and helping to decarbonize emission-intensive activities. Cinvestav's efforts are key to developing the technologies needed to realize green hydrogen's full potential for a sustainable future.

- **Biofuels:** Researchers are actively exploring sustainable methods for biofuel production to mitigate climate change and reduce reliance on fossil fuels. Two promising avenues include utilizing agricultural waste, such as crop residues and manure, through biochemical and thermochemical conversion processes, and cultivating algae (especially microalgae) which

can rapidly grow and be converted into various biofuels. These efforts aim to develop cost-effective and sustainable biofuel production methods to contribute to a cleaner energy future and reduce carbon footprints.

3. Specific Research Projects

In addition to the general research areas mentioned above, Cinvestav has undertaken several specific projects:

- **Electrolysis of water using solar energy (2018-2026):** This project aims to produce hydrogen from water using solar energy, providing a clean and renewable source of hydrogen.
- **Development of efficient green Solar Cells (2018-2026):** Researchers are focusing on creating solar cells based on Cu-Zn compounds, which have the potential to be more efficient and cost-effective than traditional silicon-based cells.
- **Green Hydrogen development (2020-2028):** Cinvestav is working on methods to produce green hydrogen at a larger scale, making it more accessible and affordable for various applications.
- **Development of Dye-based Solar Cells (2016-2026):** This project explores the use of dyes in solar cells to improve their efficiency and reduce costs.
- **Development of fuel-cell propelled prototype vehicles (2016-2026):** Cinvestav is developing vehicles powered by fuel cells, which use hydrogen to generate electricity. These vehicles have the potential to reduce greenhouse gas emissions and improve air quality.

Progress on those projects is variable.

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

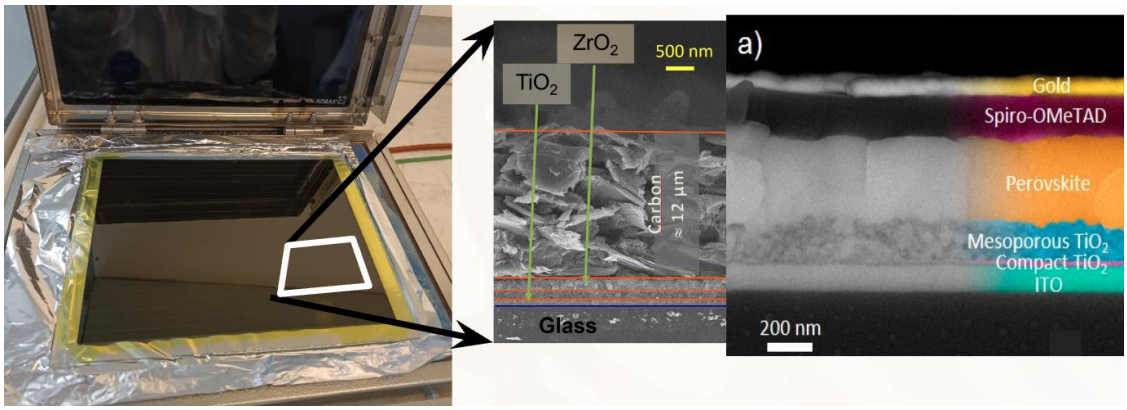
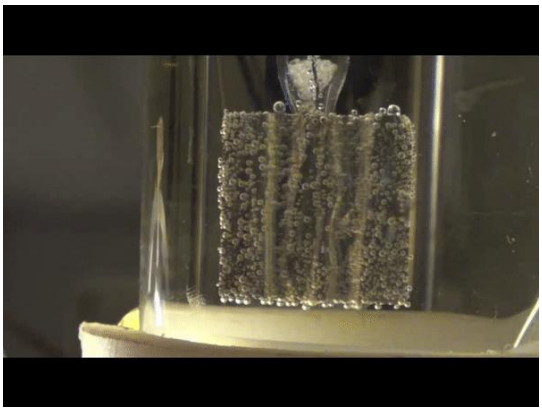


Fig. 2: Prototype of green hydrogen production using photoelectrolysis of water.



4. International Collaboration

Cinvestav has established strong international collaborations with French universities, including the University of Le Mans, the Polytechnic University of Hauts-de-France, and the University of Limoges. These partnerships facilitate knowledge exchange, enhance research capabilities, and provide access to global resources. Additionally, Cinvestav participates in joint research initiatives with other G20 research organizations, submitting proposals to international funding agencies. These collaborations are crucial for fostering innovation, particularly in clean energy technologies, and for addressing global challenges, promoting sustainable development, and advancing shared scientific progress.

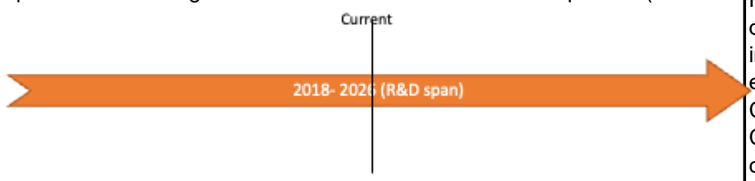
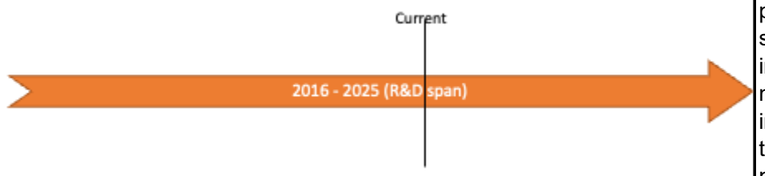
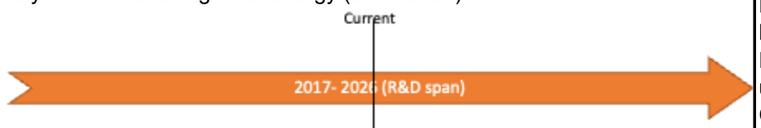
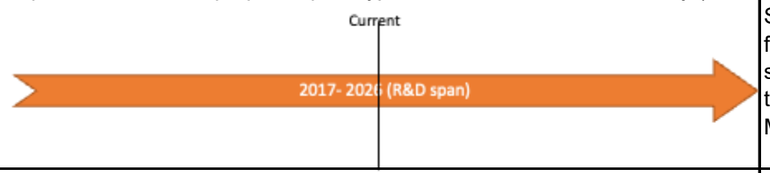
5. Future Perspectives

Cinvestav is a leading institution in clean energy research and development, crucial to Mexico's sustainable energy future. Its strength lies in its expert researchers, robust infrastructure, and extensive international collaborations that foster interdisciplinary research and accelerate solutions. Cinvestav is developing innovative technologies in solar, biofuels, and green hydrogen production, alongside research in energy efficiency, carbon capture, and socio-economic aspects. By addressing challenges like cost, Cinvestav aims to drive economic growth, enhance energy security, reduce pollution, and improve public health, positioning itself as a vital force in shaping a cleaner energy landscape for Mexico and globally.

Dr. Alberto Sanchez Hernandez

Director General of the Center for Research at Advance Studies (Cinvestav), Mexico

1994-2015 Dzero experiment at Fermilab, USA
1997 PhD in Physics, Cinvestav
1997-1999 Associate Researcher at CBPF, Brazil
1999- Research at Physics Department, Cinvestav
2001-2011 Leader of the Mexican group in the Focus-Fermilab experiment, USA
2003-2004 Visiting researcher, Fermilab, USA
2005- CMS experiment at LHC, Switzerland
2017-2019 Management Board of CMS experiment al LHC
2019-2022 Head of the Physics Department

nstitute/Countr	Theme	Sub Theme	Related programs (with short summary)	arget / Goal Outcon	Lead person / Organization	Partnership (if any)	Related information
Cinvestav/Mexi	Solar Cells		Development of efficient green Solar Cells based on Cu-Zn compounds (2018-202 	Role of structural defects in increasing efficiencies in Cu2ZnSnS4 and CdS/CdSe based cells	Dr. Jose Mustre / Cinvestav-Merida, Dr. Velumani Subramanian / Cinvestav-Mexico-City	(Domestic) Universidad Marista Merida, (International) Stanford Synchroton Radiation Lab, (International) University of	
			Development of Dye-based Solar Cells (2016-2025) 	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 (2017-2026) 	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- 	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 (2021-2027) 	Use of Bi-Pb-oxides in water electrolysis to obtain hydrogen using clean energies	Dra. Lilana Lemus / Cinvestav-Saltillo, Dr. Javier Rodriguez / Cinvestav-Saltillo, Dr. Jose Mustre / Cinvestav-Merida, Dr. Geonel Rodriguez / Cinvestav-Merida	(Domestic) University of Yucatan, (Domestic) Instituo Politecnico Nacional, Mexico	

The 7th RD20, Oct. 3 2025

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

Chang-Keun Yi
Korea Institute of Energy Research (KIER), Republic of Korea

1. Introduction

The Korean government's 2025 energy transition strategy places renewable energy at the center of its roadmap toward carbon neutrality by 2050. The plan targets the expansion of renewable capacity to 78 GW by 2030, supported by accelerated permitting, streamlined regulatory processes, and large-scale offshore wind projects in regions such as Jeju and the West Coast. Solar PV deployment will be diversified across industrial complexes, parking lots, and public facilities, while the government has committed to a complete phase-out of coal-fired power generation by 2040.

Policy reforms are underway to simplify contracting procedures, reduce local permitting burdens, and relax land-use restrictions for renewable installations. In parallel, the government is strengthening industrial competitiveness through next-generation solar and offshore wind technologies, including advanced turbines, components, and installation systems. Community-based solar cooperatives and integrated renewable service companies are being fostered to ensure citizen participation and regional economic benefits.

Furthermore, Korea aims to establish RE100 industrial clusters in renewable-rich areas, supported by incentive-based legislation and distributed energy transaction models. These initiatives will enhance Korea's role as a global leader in renewable deployment, renewable technology exports, and balanced regional growth.

The Korea Institute of Energy Research (KIER) serves as the nation's premier institute for clean energy innovation. As a strategic hub driving the transition to carbon neutrality, KIER integrates hydrogen, renewables, energy storage, CCUS, and AI-enabled solutions across the full energy value chain. Its mission is to deliver scalable technologies that combine scientific excellence with industrial applicability, while strengthening Korea's international collaboration in clean energy.

- **Advancing Frontier Technologies**: Development of high-efficiency hydrogen production and storage, tandem and flexible photovoltaics, offshore wind design and O&M, and breakthrough CCUS processes such as low-duty sorbents and electrochemical CO_2 conversion.
- **Global Collaborative Leadership**: Strong partnerships with leading institutes worldwide (e.g., NREL, Fraunhofer, NRC, CSIRO), joint laboratories, inter-laboratory benchmarking, and multilateral frameworks such as RD20.
- **Digital & AI Integration**: Application of big data, digital twins, and intelligent control systems to optimize distributed energy resources, strengthen grid flexibility, and accelerate low-carbon innovation.

Through these initiatives, KIER not only supports Korea's national carbon neutrality strategy but also strengthens its role as a trusted international partner in delivering sustainable and scalable 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 R&D for low iridium loading and durability improvement; 2022-, AEMWE R&D for highly active and durable materials and stack)
- Development of Planar Type of SOC stack module for green hydrogen production and distributed power generation (2019-, 10kW SOFC module, degradation rate <0.5%/kh)
- 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℃) 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 'operation and maintenance technology for offshore wind farm' 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 2027) Perovskite/Si tandem solar cell; Flexible perovskite/CIGS tandem solar cell (> 30% by 2025); Light-weight (>100 W/kg) flexible CIGS compound thin-film solar cell by 2025)
- 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)
- Offshore-wind farm optimal design for high efficiency (2020-, LCOE reduction >10% by low-cost O&M technology and high efficiency blade technology)
- 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 the Fundamental Technology for CCU Project (2020-, Development of innovative CO_2 capture material and process (regeneration heat ≤1.5 GJ/ton-CO_2 for coal-fired power generation, regeneration heat ≤3.5 GJ/ton-CO_2 for LNG power generation), Development of CO_2 capture material and process for coal-fired power generation from 2020 to 2022, and targeted development for LNG power generation from 2023 to 2025.
- Development of Technologies for Co-electrolysis of CO_2 and Low-grade By-products for the Production of Valuable Chemicals Project (2021-, Development of large-area membrane-electrode assembly technology and bench-scale (5kg/day) co-electrolysis technology for the co-production of CO and organic acids)
- 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 cooperation at the core of its mission to accelerate clean energy innovation and achieve global carbon neutrality. By strengthening multilateral networks, adopting AI-driven collaboration tools, and nurturing global talent exchange, KIER is expanding its leadership role in addressing worldwide energy challenges.

[Global Research Network Expansion]

- Forge stronger partnerships with leading international research institutes to advance joint R&D in hydrogen, renewables, CCUS, and energy storage.
- Actively participate in multilateral platforms such as RD20, focusing standardization, performance benchmarking, and inter-laboratory testing.
- Promote flagship international demonstration projects and joint pilot plants to tackle urgent energy and climate issues.

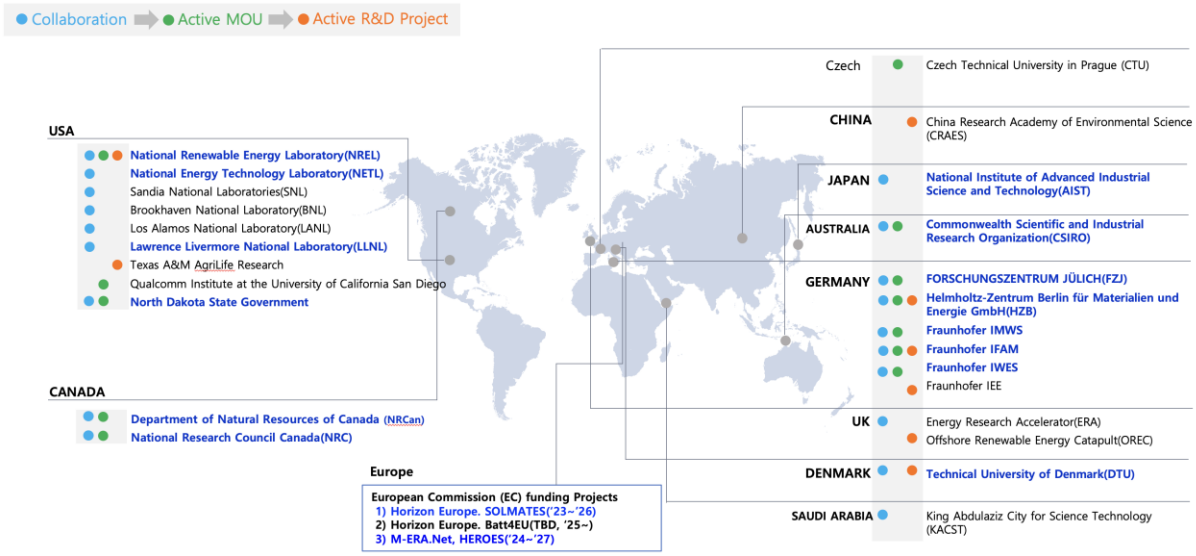
[AI and Data-Driven Collaboration]

- Apply AI-driven landscape analysis and bibliometric mapping to identify top research institutions and strategic partners worldwide.
- Deploy digital platforms and data-sharing infrastructures that enhance efficiency, transparency, and impact of joint research programs.
- Share KIER's AI-based trend analysis tools with partners to co-design collaborative roadmaps and accelerate innovation cycles.

[Strengthening Strategic Cooperation]

- Build global expert pools in hydrogen economy, renewable integration, and next-generation CCUS technologies.
- Develop "K-Energy Mega Impact Projects" in partnership with global institutions to deliver transformative clean energy solutions with measurable global impact.
- Align KIER's initiatives with global frameworks (e.g., IEA Technology Roadmaps, Mission Innovation, and UN SDGs) to ensure international relevance and policy synergy.

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



<Fig. International Collaboration Activities of KIER at 2025>

4. Future perspectives (Towards carbon neutrality)

Aligned with Korea's 2050 Carbon Neutrality Roadmap and the 2025 Energy Transition Policy, KIER has identified five strategic directions so-called "mega transitions" that will shape the pathway toward a decarbonized future. These areas also represent priority domains for international collaboration under RD20.

Area 1. Production of carbon-free electricity

· Rapid expansion of renewables (solar, wind, hydro) supported by grid flexibility, smart O&M, and storage integration.

Area 2. Utilization of carbon neutral fuels and product (H_2 and NH_3, Biofuel)

· Development and deployment of hydrogen, ammonia, and advanced biofuels for heavy industry, shipping, and aviation

Area 3. Electrification of energy system

· Accelerated electrification of transport, heating, and industry with high-efficiency power electronics and digitalized grid solutions.

Area 4. Development of high-efficient low-carbon society combining existing energy efficiency technology with Energy AI.

· Energy AI enables optimization of industrial energy use, demand-side management, and predictive maintenance.

Area 5. CCUS of Industrial GHG Emissions, especially for steel and cement industry.

· Development of electrochemical CO_2 conversion and low-energy capture processes as scalable industrial pathways.

Profile of the President of KIER

Dr. Chang-Keun Yi,
Korea Institute of Energy Research (KIER)

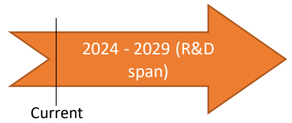
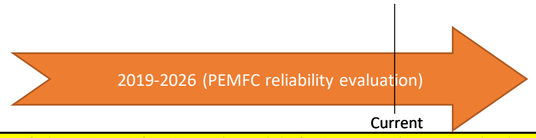
Dr. Chang-Keun Yi is President of the Korea Institute of Energy Research (KIER), the nation's leading government-funded energy research institute, and recently served as President of the Korean Society for New and Renewable Energy from 2023 to 2024.

With over three decades of experience in energy and climate R&D, Dr. Yi has played a central role in advancing Korea's clean energy innovation ecosystem. He joined KIER as a researcher in 1985 and has since led national R&D programs on carbon capture and storage (CCS), high-efficiency clean energy technologies, and climate change mitigation.

Dr. Yi held several key leadership positions at KIER, including Director of the Fossil Energy and Environmental Research Division, the High-Efficiency Clean Energy Research Division, and the Climate Change Research Division, before serving as Vice President from 2020 to 2022. He was appointed as President of KIER in June 2023.

Internationally, Dr. Yi represented Korea in the Carbon Sequestration Leadership Forum (CSLF) Technical Group—an initiative hosted by the U.S. Department of Energy—from 2005 to 2017. He also served on the editorial board of *Korean Journal of Chemical Engineering* (SCIE) and contributed to various international collaborative research efforts on decarbonization and energy transition.

Dr. Yi received his Ph.D. in Chemical Engineering from Lehigh University in the United States in 1994.

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		1) AEMWE: high efficiency 43 kWh/Kg-H2 @ 1.0 A/cm2 2) PEMWE: high durability with low iridium loading <0.1 mg-Ir/cm2 3) Development of 100 kW-class stacks and materials for AEM and PEM water electrolyzer	Sang-Kyung Kim, Ph.D. / KIER		
KIER/Korea			Development of Planar Type of SOC Stack Module for Green Hydrogen Production and Distributed Power Generation 	10kW SOFC module Durable SOEC module (degradation rate < 0.5%/kh)	Ji Haeng Yu, Ph.D. / KIER	(Domestic) Bumhan Fuel Cell, SAMSUNG ELECTRO-MECHANICS, Dentium (Foreign) DTU, DLR, Fraunhofer-IKTS	
KIER/Korea			Development of clean hydrogen manufacuring by high-temperature electrolysis 	Development of Materials, Cells, Stacks, and 6Nm3/h_H2 Class Systems for Enhanced Durability and Efficiency of Intermediate-Temperature (700℃) 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 	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 	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	
KIER/Korea		Utilization	Development of Planar Type of SOC Stack Module for Green Hydrogen Production and Distributed Power Generation 	10kW SOFC module 10kW SOEC module (H2 production rate > 4 Nm3/h, degradation rate < 1%/kh)	Ji-haeng Yu, Ph.D. / KIER	(Domestic) Bumhan Fuel Cell, Korea Institute of Ceramic Eng. & Tech. (KICET), SAMSUNG ELECTRO-MECHANICS	

The 7th RD20 conference, Oct. 3, 2025
(Activity Summary Template)

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

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

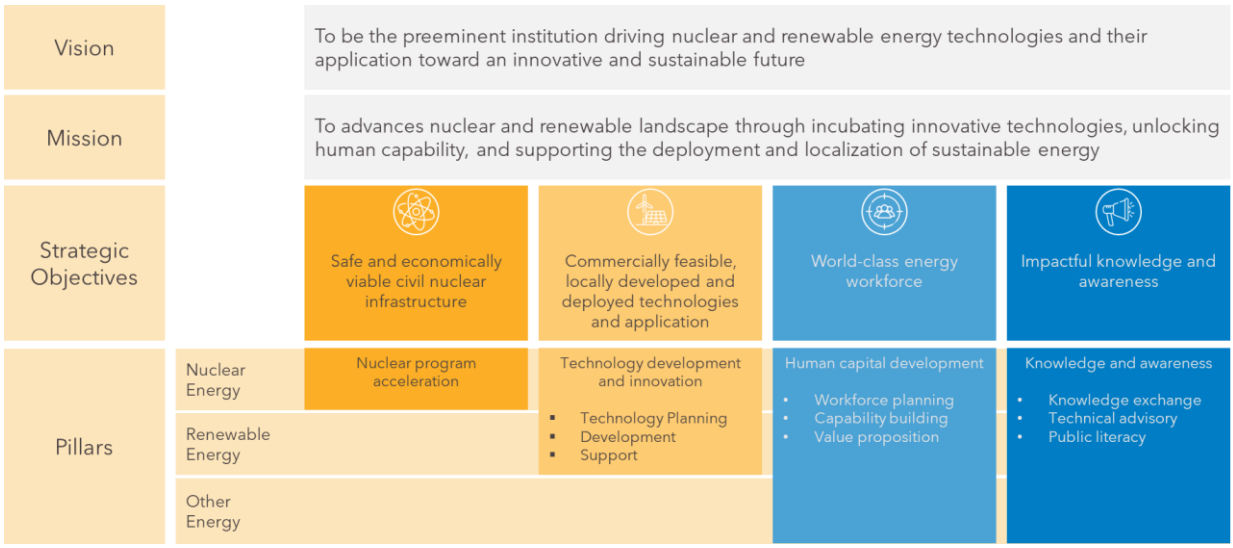
1. Introduction

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)

Sustainability has been at the core of Saudi Arabia's Vision 2030 since its inception, and the Kingdom has set an ambitious target of reaching Net Zero by 2060. This vision reflects the national commitment to accelerate the energy transition, achieve sustainability goals, and attract new waves of investment. Within this framework, Saudi Arabia introduced the Circular Carbon Economy (CCE) during its G20 Presidency, which was endorsed by G20 leaders. The CCE provides a holistic approach to addressing climate change through reducing, reusing, recycling, and removing carbon, while promoting economic diversification and sustainable growth.

The Kingdom's energy policy emphasizes diversifying energy resources and optimizing the national energy mix. By 2030, renewable energy is expected to contribute up to 50% of the total energy mix, displacing high-value fossil fuels and avoiding significant emissions. With abundant solar and wind resources, Saudi Arabia has launched large-scale renewable projects and is strategically investing in sustainable technologies.

King Abdullah City for Atomic and Renewable Energy (K.A.CARE) plays a central role in advancing these goals by leading research, development, and deployment in clean energy. K.A.CARE's mission is aligned with Vision 2030 and the Kingdom's net-zero ambitions, focusing on renewable and atomic energy while fostering technology localization and capacity building.



K.A.CARE strives to achieve its strategic objective of developing commercially feasible, locally developed and deployed technologies by working closely with leading local and international research institutions. Through collaborative R&D programs, prototype development, and technology demonstration projects, K.A.CARE fosters innovation and accelerates the transition of clean energy solutions from research to market.

K.A.CARE is also responsible for providing the most up-to-date and comprehensive information through the **Renewable Resource Atlas**. KACARE ensures the availability of reliable and validated datasets for solar irradiation and wind resources, enabling beneficiaries to conduct accurate studies across Saudi Arabia with low uncertainty.

In addition, K.A.CARE supports renewable energy development through activities such as resource data analytics, calibration standards, and maintaining the renewable energy data repository. These efforts provide stakeholders with trusted information that underpins project design, feasibility studies, and policy development.

Through its **Technology Localization and Commercialization (TLC) initiative**, K.A.CARE further promotes the indigenization and commercialization of renewable energy technologies. This includes cost-sharing models with the private sector, financial support for innovative projects, and programs designed to strengthen local content and enhance the Kingdom's competitiveness in clean energy.

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 deploying advanced renewable technologies with a strong focus on:
    - 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.

- Technology Localization & Commercialization: Promoting local content development by supporting R&D, prototype and product development, commercial demonstration, and private sector partnerships to accelerate technology indigenization.

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:

1. 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)
2. Prototype development for renewable energy technologies – Imam Abdulrahman bin Faisal University. Design and test an enhanced concentrated photovoltaic module. (2022-2024)
3. Prototype development for renewable energy technologies– King Abdullah University of Science and Technology. Scale-up perovskite silicon tandem solar cell. (2024-2025)
4. 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).

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.

International cooperation is at the heart of K.A.CARE strategy, recognizing that joint R&D challenges require global partnerships and knowledge exchange. K.A.CARE actively collaborates and exchanges experiences with regional and international universities, research institutions, organizations, and specialized houses of expertise worldwide in the fields and applications relevant to clean energy.

Key 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

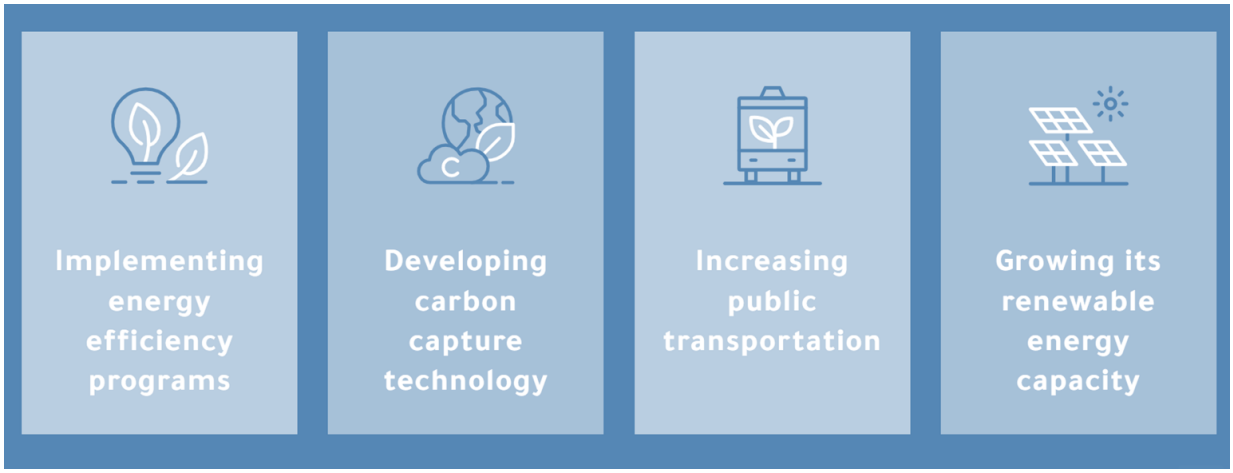
programs, in collaboration with leading international partners and prestigious universities (e.g. IAEA, IRENA, MIT, Texas A&M …etc.).

- 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.

The future of energy is green. At the inaugural Saudi Green Initiative Forum 2021, HRH Crown Prince Mohammed bin Salman revealed the roadmap for the Kingdom's energy transition. Ambitions announced include an upgraded Nationally Determined Contribution (278 mtpa), an aim to reach net zero by 2060, and joining the Global Methane Pledge to cut global methane emissions by 30%, placing Saudi Arabia at the forefront of the fight against climate change. A set of ambitious initiatives focus on reducing emissions and increasing Saudi Arabia's renewable energy capacity. Saudi is reducing its carbon emissions through a multidimensional approach, which includes



K.A.CARE seeks to play a central role in advancing the Kingdom's renewable and atomic energy capacity by focusing on technology development as a core mandate. To achieve its objectives, KACARE addresses challenges, and its efforts include:

1. Developing and localizing technologies in renewable and atomic energy through dedicated research, applied studies, and innovation programs, with the aim of strengthening local content and supporting commercialization.
2. Providing technical and advisory services to support the peaceful uses of atomic energy and renewable energy applications and raising its contribution to the energy mix.
3. Cooperation and exchange of experiences with universities, research centers, institutions, councils, regional and international organizations, and specialized expertise

houses inside and outside the Kingdom, in the fields and applications related to their competence.

4. Participate in the preparation of national plans related to the fields of peaceful uses of atomic energy and its technologies and applications of renewable energy and its techniques, develop the necessary strategic plans for their implementation, and propose laws and regulations related to its competence.

Eng. Hamad Mudij

Eng. Hamad Mudij is Sector Head 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.

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

Current Status and Future Perspectives on Energy Technologies at the National Renewable Energy Laboratory (NREL)

Dr. Martin Keller, Director
National Renewable Energy Laboratory, USA

1. Introduction

The National Renewable Energy Laboratory (NREL) strives to achieve our vision of an affordable and secure energy future through our mission: leading research, innovation, and strategic partnerships to deliver integrated solutions for an affordable and secure energy future (https://www.nrel.gov/about/vision). NREL is a national laboratory of the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy. The lab's unique strength lies in developing and integrating a broad array of energy technologies into robust, resilient systems—addressing the entire energy spectrum, from generation to distribution to end use. As a leading energy systems laboratory, we bridge foundational research with practical applications to ensure various energy sources, industry, storage, buildings, transportation, and emerging technologies work together to lower energy costs, drive economic growth, bolster national security, and deliver abundant energy. Our researchers are focused on solving high-priority problems that result in market-ready solutions. Engaging in partnerships with industry, start-ups, and government enables us to drive innovation.

2. Energy Technology R&D

NREL is currently focused on R&D to advance low cost, secure, and resilient energy systems. NREL's unique strength lies in developing and integrating a broad array of energy technologies into robust, resilient systems—bridging foundational research with practical applications to lower energy costs, drive economic growth, bolster national security, and deliver abundant and reliable energy. NREL has developed three critical objectives to guide our research and development (R&D): integrated energy pathways, electrons to molecules, and integrated value chains for energy materials.

Integrated Energy Pathways

NREL's ***integrated energy pathways*** research aims to modernize our grid to support a high level of energy systems integration; incorporate storage and advanced controls; and expand energy choices while maintaining grid reliability and security.

Research, development, analysis, and deployment enable and accelerate progress toward an affordable and secure power sector. NREL's R&D focuses on developing foundational knowledge and technologies to integrate a wide range of energy technologies into robust, resilient systems, thereby ensuring a secure and resilient electric grid. R&D is focused in three areas:

- Generation, storage, and integration
- System security and resilience
- Advanced energy system analysis.

These advancements will involve millions of interconnected devices, multiple types of generation sources, and increased operational autonomy across all devices.

Electrons To Molecules

The lab's ***electrons to molecules*** research explores how to use affordable electricity to convert low-

energy molecules—such as water and carbon dioxide—to generate higher-value, and higher-energy chemicals, fuels, and materials. Key research areas include:

- Hydrogen and fuel cells
- Cost-competitive biofuels and bio-based routes to chemicals and materials
- Reactive capture and conversion of biomass and waste resources
- Enhanced growth and innovation for industry
- Increased energy reliability and availability.

NREL's research advances are lowering the cost and increasing the scale of technologies to make, store, move, and use hydrogen across multiple energy sectors. The emphasis is on the use of hydrogen to stabilize the grid and interconnect the grid with heavy industry to provide high reliability and availability of energy solutions.

Integrated Value Chains for Energy Materials

NREL's ***integrated value chains for energy materials*** research aims to secure the nation's energy supply chains. The lab is exploring innovative ways to reduce waste, preserve resources, and recycle, reduce, and replace critical minerals and to support industry partners to manufacture key energy materials, components, and systems. Specifically, our supply chain studies seek to understand:

- Cost competitiveness of raw material, component supply, and manufacturing
- Resilience of supply chains to global policies and market impacts
- Cybersecurity risks and other supply chain vulnerabilities that could affect critical infrastructure and prevent the country from meeting energy, market, and economic demands
- Prioritization of areas for investing in supply chain analysis to meet future challenges.
- Product reliability and durability, including degradation science and lifetime prediction
- Next-generation materials, microelectronics, and manufacturing processes.

The lab's ***critical materials*** researchers are also exploring opportunities to recover low-abundance materials, including rare earth and other critical minerals, from land, water, and waste. Areas of focus include:

- Pathways for concentration and separation of critical minerals from low-grade feedstocks
- Nutrient recovery from wastewater treatment
- Chemical and biochemical catalytic systems to recover useful molecules from plastics and textiles
- Design of polymeric materials for enhanced functionalities, performance, and recyclability.

NREL explores pathways to reduce waste and increase product innovation while supporting human health, livelihood, and job creation.

3. Specific Research Activities

NREL's research spans a wide range of technologies and energy systems—and the science behind them—for a future powered by affordable and secure energy (https://www.nrel.gov/research/areas.html).

Energy Abundance

Advanced scientific research in a wide range of energy technologies and systems remains central to NREL's mission, with foundational work taking place in geothermal, bioenergy, hydrogen and fuel cells, solar (photovoltaics [PV] and concentrating solar power [CSP]), and wind and water power. Our research couples innovation and discovery with analysis, reliability, and systems integration to accelerate both the deployment of current technologies and the development of new technologies.

Geothermal

NREL develops and advances the commercial-scale deployment of geothermal technologies, analyzes supply chains, and partners with government and industry to integrate geothermal into the grid. For example, NREL provides third-party evaluation of geothermal technologies for military bases that require reliable and dispatchable electricity and heating. NREL has partnered with CPS Energy in San Antonio, Texas, to assess various technologies for electricity generation, local geological conditions, and geothermal potential. And NREL is working with Con Edison, which runs the world's largest steam-based district heating system, to study the feasibility of using geothermal energy.

Bioenergy

NREL's fundamental science program for ***biological energy conversion*** creates mechanistic understandings that enable control over biochemical and biophysical pathways and processes in living organisms, cell-free, biohybrid, and catalytic systems. A cornerstone of NREL's ***fundamental bioenergy research*** is our partnership in the Center for Bioenergy Innovation, led by Oak Ridge National Laboratory, which aims to provide breakthroughs for a new generation of industrially relevant, cost-competitive, and performance-advantaged materials, chemicals, and biofuels, including synthetic aviation fuels from waste carbon sources, diesel for heavy-duty fleets, and marine fuels. Feedstocks range from woody biomass to corn stover, corn starch, municipal solid waste, wet waste (including sludge), algae, and syngas.

Our scientists pioneer biotechnologies designed to deliver high-performance and affordable polymers, chemicals, and fuels. Using world-class facilities, NREL collaborates with industry, government agencies, academia, national laboratories, and other organizations to integrate and scale-up bioenergy technologies and processes for commercial adoption. For example, NREL has:

- Developed an aromatic-rich synthetic aviation fuel by deconstructing lignin in plants and hydrodeoxygenating the resulting molecules to jet-range blendstocks (an MIT-NREL technology, which is licensed by Comstock Fuels in 2024).
- Signed a 10-year, $100M agreement with ExxonMobil to identify long-term options for fuels that are scalable, minimize the drain on natural resources, and are more efficient both in final use and in the production process.
- Partnered with Amazon to develop innovative packaging solutions that reduce supply chain risks and strengthen its domestic manufacturing capabilities.

NREL bioenergy and bioeconomy research accelerates innovation through patents and intellectual property for biotechnology companies to license and grow on the open market.

Hydrogen and Fuel Cells

NREL's research advances are lowering the cost and increasing the scale of technologies to make, store, move, and use hydrogen across multiple energy sectors. Our emphasis is on using hydrogen to stabilize the grid and interconnect our energy systems with heavy industry to provide high reliability and availability energy solutions.

NREL has unique capabilities to conduct megawatt-scale research on hydrogen generation, energy storage, power production, and distribution—demonstrating how integrated hydrogen systems can increase grid resilience and connect the grid with industry to provide secure, reliable energy solutions.

Our work supports DOE's H2@Scale (https://www.energy.gov/eere/fuelcells/h2scale) vision, in which hydrogen can be a central component for an affordable, reliable, and flexible energy system. NREL leads or plays a leading role in several R&D consortia in hydrogen production, storage, delivery, and utilization, including:

- H2NEW: Hydrogen from Next-Generation Electrolyzers of Water (https://h2new.energy.gov/)
- HydroGEN: Advanced Water Splitting Materials Consortium (https://h2awsm.org/)

- HyMARC: Hydrogen Materials Advanced Research Consortium (https://www.hymarc.org/)
- HyBlend: Opportunities for Hydrogen Blending in Natural Gas Pipelines (https://www.energy.gov/eere/fuelcells/hyblend-opportunities-hydrogen-blending-natural-gas-pipelines)
- M2FCT: Million Mile Fuel Cell Truck (https://millionmilefuelcelltruck.org/).

NREL's research improves the efficiency, scalability, and manufacturability of hydrogen and fuel cell technologies and systems. The lab has decades of experience in polymer electrolyte membrane electrolysis and fuel cell science and technology, including electrocatalysis, membranes, durability, and stack testing. Researchers at NREL are now applying these capabilities to the electrolytic production of hydrogen from water splitting. Our researchers bring capabilities in integration science; multiscale computational modeling; thermo-, electro-, and bio-catalysis; and comprehensive decision support analyses to valorize abundant domestic waste streams and drive cost reductions to support industry.

Photovoltaics

NREL's photovoltaics research is multifaceted, incorporating basic energy science, applied R&D, engineering, and analysis. Our researchers actively work with industry to address fundamental challenges from new materials to modules, systems, and reliability. Key initiatives include:

- A decadal partnership with First Solar to increase cadmium telluride efficiency
- Next-generation perovskites and tandems for domestic applications and power generation
- High-efficiency multi-junctions as well as high-throughput manufacturing methods and lower cost designs for space and power beaming.

NREL also plays a critical role in the advancement of CSP technologies. Our research goes beyond electricity generation, moving into emerging markets for long-duration thermal energy storage, process heat, solar fuels, and desalination. Other key areas include improved affordability, reliability, and manufacturing; next-generation PV technologies to secure abundant, reliable energy; solar market research and analysis to inform the efficient and affordable adoption for industry and households; workforce development.

Advanced, Transformative, Integrated Energy Systems

NREL's research enables an energy system that is secure, affordable, and reliable. Our advanced energy research and analysis leverage computational science, applied mathematics, AI-driven solutions, high-performance computing and analytics, advanced visualization and data, and large-scale numerical simulation to drive strategic energy planning, data-driven decision-making, and reduced-risk project development.

Advanced Research on Integrated Energy Systems

NREL's ***Advanced Research on Integrated Energy Systems (ARIES)*** is the nation's most advanced research platform for energy system integration R&D. The platform offers unmatched scale and complexity to accelerate the validation of secure, affordable, and integrated technologies across all energy sectors. ARIES:

- Validates next-generation hybrid systems and regional energy solutions by combining real-world infrastructure with high-fidelity modeling—helping partners integrate a wide variety of energy technologies to meet growing demand.
- Offers configurable architecture and world-class capabilities, enabling technology developers, utilities, and regulators to reduce costs and de-risk investments through realistic testing, system optimization, and cross-sector integration.
- Uniquely combines cyber, physical, and virtual systems to assess full-spectrum threats and ensure energy resilience, underpinning national efforts like the U.S. Department of Energy's Energy

Threat Analysis Center to evaluate infrastructure vulnerabilities and guide defense strategies.
- Supports accelerated energy innovation by uniting national labs, industry, and communities in one collaborative platform—enabling partners to test, validate, and scale integrated energy systems under real-world conditions.

ARIES comprises three pillars networked together to provide an interconnected and scalable research platform: the Energy Systems Integration Facility at NREL's South Table Mountain Campus; the Flatirons Campus, which allows us to work at higher voltages and scales; and the Virtual Emulation Environment, which further amplifies the platform. The Virtual Emulation Environment is powered by Kestrel, NREL's 44-petaflop supercomputer, which allows us to study system sizes and configurations that go beyond hardware capabilities. ARIES provides the ability to create, prove, and validate complex energy systems by interconnecting hardware and software that imitate energy configurations and solutions along with interconnected grid-scale devices and distributed energy resources for the highest-fidelity experimentation.

Artificial Intelligence

NREL is advancing real-time grid operations by integrating artificial intelligence and developing new grid technologies, advanced control strategies, and power electronics like grid-forming inverters. NREL provides advanced computing systems and services—and enables their highly productive use—for applied energy research while advancing the forefront of mathematics and scientific computing for energy applications.

NREL has formed a strategic collaboration with the three applied energy labs (INL, NETL, NREL) to bring AI solutions and technologies to applied energy systems for DOE's AI strategy in synergy with Science and NNSA labs. Through the ACTUATES (Applied Collaboration To Unlock Advanced Transformative Energy Systems) project, our researchers aim to:

- Develop, adapt and use AI models for applied energy
- Design new AI technology based on real data, real systems, and real testbeds
- Define energy problems with stakeholder engagement
- Integrate AI across energy applications with a systems approach
- Integrate science lab and industry technologies for applied energy applications

NREL's Chips-to-Grid concept addresses the urgent challenge of powering AI data centers, which require vast and rapidly fluctuating energy loads but face multi-year delays in securing grid connections. NREL's solution blends liquid cooling, demand flexibility, and an "all-of-the-above" energy strategy—including fossil, nuclear, storage, and more—to accelerate deployment timelines and reduce strain on utilities. The initiative explores the integration of geothermal cooling and thermal energy storage to reduce cooling-related power needs, manage peak loads, and improve off-grid viability.

Energy Storage

Our researchers are developing transformative energy storage solutions that can flexibly respond to changing conditions, emergencies, and growing energy demands—ensuring energy is available when and where it is needed. NREL's systems-level approach to energy storage guides basic science and research to develop and characterize high-performing materials and components with a focus on reliability, longevity, durability, and enhanced energy affordability.

NREL's work in this space includes electrochemical storage (for both stationary and transportation applications), chemical storage, and thermal storage. NREL also aims to develop and improve power electronics-based technologies, which will be increasingly deployed in the future for the management of energy grids. NREL's work includes detailed modeling and analysis of energy storage deployment and development needs.

Energy Security and Resilience

NREL's energy security and resilience research protects our evolving energy systems from manmade and natural hazards, through energy threat analysis, resilient system design, consequence modeling, and novel security solutions. NREL's capabilities include:

- The ***Advanced Research on Integrated Energy Systems (ARIES) Cyber Range***: A one of its kind capability that enables researchers to examine and understand the interdependencies between electric and communication networks, safely explore system vulnerabilities and mitigation strategies, and de-risk novel technologies.
- The ***Energy Threat Analysis Center (ETAC)***: Brings together utilities, government, and other national lab experts to provide timely, intelligence-informed, and actionable products.
- ***Energy Resilience Building & Units***: Flexible, multi-purpose office and laboratory space to support research to better understand the nexus of energy infrastructure resilience, energy security, and national security.

Supply Chains for Energy Materials

NREL researchers are investigating supply chain impacts on critical minerals, manufacturing, and cybersecurity. Energy technologies require a range of critical, supply-constrained minerals to produce, and significant opportunities exist to add value along the supply chain, with implications for the development of new related industries in countries around the world. And some supply chain stages are heavily concentrated in certain countries, creating a resilience liability. NREL's goals are to:

- Improve circular economy technologies for these materials to minimize waste, reduce cost, and drive new capabilities
- Explore alternative technologies that reduce dependence on critical minerals
- Create opportunities for near-shoring stages of energy supply chains to bolster supply chain resilience, create economic growth, and develop international partnerships.

NREL is a partner in the Argonne National Laboratory-led ReCell Center, a collaboration of researchers from industry, academia, and national laboratories who are working to develop direct recycling processes and increase the value of recycling (https://recellcenter.org/).

NREL leads the Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment (BOTTLE™, https://www.nrel.gov/manufacturing/bottle.html) consortium, which is developing new chemical upcycling strategies for today's plastics and redesigning tomorrow's plastics to be recyclable-by-design. BOTTLE conducts high-impact R&D to deliver scalable technologies that enable cost-effective recycling, upcycling, and increased energy efficiency for plastics. Under the BOTTLE research framework, the consortium is working to deconstruct waste plastics with catalysis and use chemical and biological transformations to upcycle the resulting intermediates to produce recyclable-by-design polymers.

Fundamental Science

NREL's ***basic energy sciences program*** aims to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels. We aim to provide the foundations of new technologies for energy generation, conversion, transmission, storage, and use. NREL researchers develop foundations for affordable, secure, and reliable energy solutions through core capabilities in semiconductors and materials science, nanomaterials synthesis and modification, synthesis and fabrication, photochemistry, electrochemistry, bioscience, theory, computation, and advanced spectroscopy. These capabilities allow us to develop a better scientific understanding of photonic, electronic, atomic, molecular, nanoscale, semiconductor, and biological materials, systems, and processes.

NREL's fundamental materials science research spans materials discovery, state-of-the art first-

principles theory, and materials growth and characterization to understand and control fundamental electronic and optical processes in semiconductors and related systems.

NREL is also a partner in the Liquid Sunlight Alliance (LiSA, https://www.liquidsunlightalliance.org), one of two projects in the Fuels from Sunlight Energy Innovation Hub funded by DOE's Office of Science, Basic Energy Sciences that focuses on research for the generation of liquid fuels from sunlight, water, CO_2, and nitrogen. NREL leads two Energy Frontier Research Centers—The Center for Hybrid Organic-Inorganic Semiconductors for Energy (CHOISE) and A Center for Power Electronics Materials and Manufacturing Explorations (APEX)—and is a partner in six other Energy Frontier Research Centers.

Analysis and Assessment

NREL conducts credible, objective analysis, develops tools, and builds data resources that inform our affordable and secure energy future. NREL ***energy analysis*** and decision support span grid planning and analysis, decision science, complex systems analysis, future systems scenarios, market and policy impact analysis, techno-economic analysis, and geospatial data science.

Of particular note, NREL partners with the U.S. Department of Agriculture on the Rural Energy for America Program (REAP), which brings advanced energy systems and energy efficiency improvement grants to agricultural producers and rural small business owners. NREL also transformed Cordova, Alaska's electrical system into a resilient and smart microgrid, with real-time sensing through project RADIANCE (Resilient Alaskan Distribution system Improvements using Automation, Network analysis, Control, and Energy storage).

NREL has developed a wide range of modeling and simulation tools—such as reV, ReEDS™, Sienna, PRECISE™, and dGen™— that are widely used by energy stakeholders. NREL develops datasets, maps, models, tools, and software for the analysis and development of energy technologies and systems. Many of these resources are publicly available to support industry. Data and tools can be found at https://www.nrel.gov/research/data-tools.html. Through integrated energy solutions, NREL accelerates energy solutions through a system-of-systems approach that considers technology, policy, and market systems. We assist partners at home and around the world to meet ambitious energy goals.

4. International Collaboration

NREL engages global partners to advance energy security and resilience, strengthen critical supply chains, and promote shared prosperity through the application of energy systems research and technical expertise (https://www.nrel.gov/international/). NREL leads global initiatives and partnerships that advance affordable, reliable, and secure energy systems—contributing to international energy security, reliability, and affordability goals. The lab conducts its international programs in support of many U.S. agencies, companies, and international sponsors and includes analyses and assessments as well as research on grid integration, energy modeling, energy system resilience, and tools and trainings.

NREL partners with U.S. government agencies and national laboratories to support countries to accelerate progress toward their energy objectives while ensuring energy security and resilience or to scale up energy analysis and deployment to support economic and energy security goals with countries in all regions. The lab also collaborates with private sector firms, multilateral development banks, international agencies, and philanthropies in implementing advancing energy cooperation programs.

NREL teams with countries in all regions of the world through bilateral research, analysis, and deployment activities that advance shared priorities for accelerating progress toward low cost, reliable, and secure energy systems. This includes cooperation with over countries in Africa, Asia and the

Pacific, Europe, Latin America and the Caribbean, and North America.

NREL supports the Clean Energy Ministerial, a high-level global forum focused on advancing technologies and programs that drive economic growth through the development and deployment of advanced energy technologies, including nuclear energy. This includes NREL technical support for the Nuclear Innovation for Clean Energy, Energy Solutions, and Supercharging Battery Storage CEM initiatives.

The RD20 Leaders Statement codifies the need for international collaboration to accelerate energy innovation. Workshops, summer schools, and clear standards for analysis/assessment are all good starting points for enhancing interactions. NREL is keen to help launch these concepts as well as other areas identified, such as increased communication, task forces, and researcher exchange.

5. Innovation for Applied Energy

NREL is currently focused on R&D to advance low cost, secure, and resilient energy systems. *Integrated* solutions are critical to achieve a secure, robust, and resilient energy future that depends on a broad array of energy technologies. Spurring an innovation ecosystem—from new materials discovery to integrated energy systems development and deployment—requires a systems-based approach guided by advanced analysis and assessment, AI solutions, novel technology designs and concepts, enhanced supply chains and use of critical materials, and strategic partnerships. Solutions are needed for:

- Improved efficiency, scalability, and manufacturability of energy technologies and systems to drive cost reductions that yield more affordable and accessible energy for U.S. consumers and industries.
- Enhanced affordability, performance, and reliability for energy technologies, including geothermal, bioenergy, and hydrogen.
- Reliable supply chains for advanced energy materials, components, and systems to lower production costs, creating jobs, and sustaining economic growth.
- Transformative and reliable energy storage to enhance system resilience and energy affordability

Industrial sectors have made major progress and can continue to benefit from additional advances in technologies and processes. Strategic partnerships and collaborations can accelerate the needed innovation and integration. NREL is poised to support these critical partnerships and help advance energy technologies and systems worldwide.

Martin Keller, Ph.D.

Director, National Renewable Energy Laboratory

Martin Keller has served as director of the National Renewable Energy Laboratory (NREL) and president of the Alliance for Sustainable Energy (the company that operates NREL for the U.S. Department of Energy) since 2015. On October 30, 2024, the Helmholtz Association, one of the world's leading research institutions, elected him to be their next president. He will assume his role on November 1, 2025.

Dr. Keller is a visionary leader who is committed to people, teams, and partnerships. He innovatively and pragmatically applies private-sector best practices at NREL to achieve game-changing scientific outcomes. Working collaboratively with his leadership team, Martin developed a strategy for NREL focused on three key initiatives: integrated energy pathways, electrons to molecules, and integrated value chains for energy materials. This strategy drives advanced scientific research, programs, projects, and partnerships at NREL. Under his leadership, the laboratory's active partnerships with industry, universities, foundations, and governments now number more than 1,100—generating more than $1 billion in research and development. The number of full-time employees at NREL has increased by more than 82%, with more than 3,700 staff.

From 2006 to 2015, Dr. Keller led energy, biological, and environmental research programs at Oak Ridge National Laboratory (ORNL). His efforts culminated in being promoted to serve as the associate laboratory director for the Energy and Environmental Sciences Directorate during his last six years at ORNL.

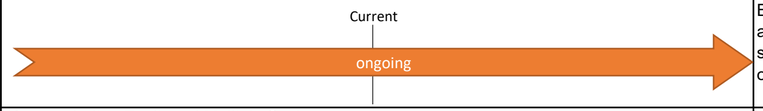
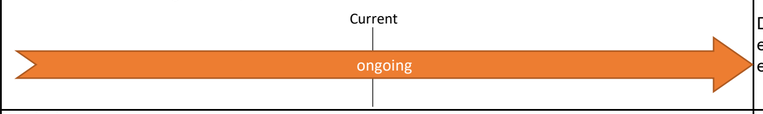
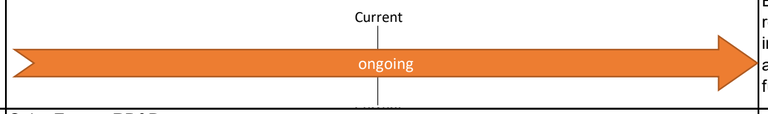
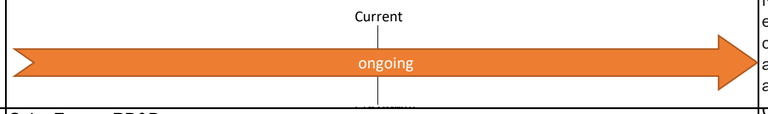
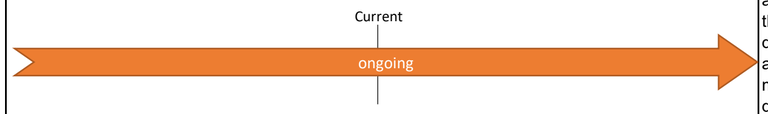
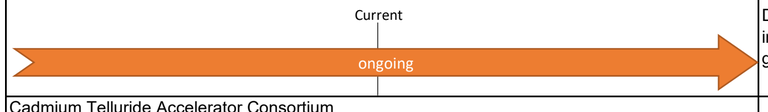
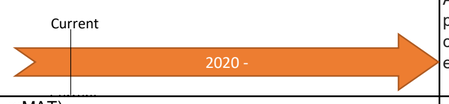
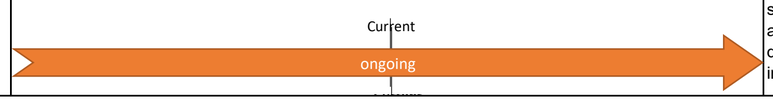
Earlier in his career, Dr. Keller's dedicated work in a variety of research management positions at Diversa Corporation enhanced and developed the microbiology expertise of this biotech company.

Currently, Dr. Keller is a Fellow of the American Association for the Advancement Science (AAAS), and he recently retired as chair of the AAAS Industrial Science and Technology Section. In addition, he is a member of the Scientific Advisory Council for Forschungszentrum Jülich and serves on numerous other scientific advisory boards. In 2022, he was named a Most Admired CEO by the *Denver Business Journal*, and in 2024, he was named Laboratory Director of the Year by the Federal Laboratory Consortium for Technology Transfer.

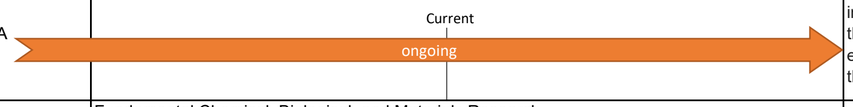
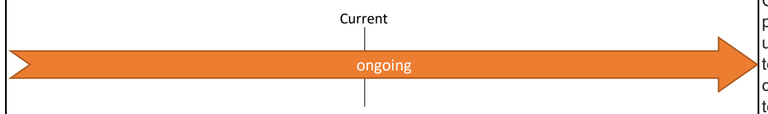
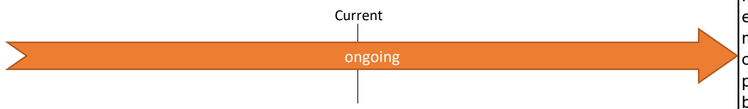
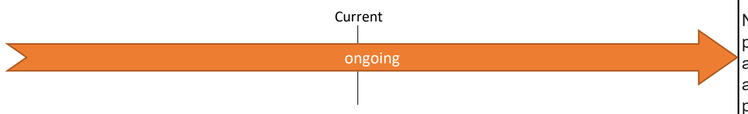
Dr. Keller received his Ph.D. in microbiology from the University of Regensburg in Germany.

Institute/Country	Theme	Subtheme	Related Programs (with short summary)	Target/Goal Outcome	Lead Person/Organization	Partnership (if any)	Related Information
NREL/United States	Energy Analysis	Energy Anaysis	Energy Analysis Current ongoing	NREL's energy systems analysis provides actionable insights to inform an affordable, secure, and reliable energy future by integrating data, modeling, and expertise across sectors and systems.	Jaqueline Cochran/NREL	NGOs, U.S. DOE, industry, academia, national labs, international, …	https://www.nrel.gov/analysis/index.html
		Advanced Research on Integrated Enregy Systems (ARIES)	ARIES ongoing	Advanced Research on Integrated Energy Systems (ARIES) is the U.S. Department of Energy's most advanced energy systems research platform—offering unmatched scale and complexity to accelerate the validation of secure, affordable, and integrated technologies across all of the country's energy sectors.	Jennifer Kurtz/NREL Jerry Davis/NREL John Farrell/NREL		www.nrel.gov/aries/
		Energy Systems Integration Facility	NREL Energy Systems Integration Facility Current 2011 -	NREL's Energy Systems Integration Facility (ESIF) is a collaborative research hub for future-ready, secure, reliable, and affordable energy technologies.	Juan Torres/NREL	NGOs, U.S. DOE, industry, academia, national labs, international, …	https://www.nrel.gov/esif/index.html
		Grid Modernization	Grid Modernization Current 2011 -	NREL drives affordable, reliable, and secure power grids at all scales by developing and applying innovative technologies, tools, and technical expertise.	Juan Torres/NREL	NGOs, U.S. DOE, industry, academia, national labs, international, …	https://www.nrel.gov/grid/index.html
		Integrated Energy	NREL Energy Systems Integration Facility Current ongoing	NREL addresses unique energy system challenges and identifies solutions that will shape the future by providing tools and approaches to enable better integration with the electric grid and other energy infrastructure, diversification of integrated energy streams for resilience, cybersecurity risk management, and customer participation in smart load management and energy generation	Juan Torres/NREL John Farrell/NREL	NGOs, U.S. DOE, industry, academia, national labs, international, …	https://www.nrel.gov/esif/integrated-energy
Energy Storage		Battery Materials and Durability	Silicon Consortium Project, funded by the U.S. DOE Office of Energy Efficiency and Renewable Energy (EERE) Vehicle Technologies Office (VTO) Current 2019 - 2025	Tackle the barriers associated with the development of advanced lithium-ion negative electrodes based on silicon as the active material, with a specific focus on understanding the formation and evolution of the solid-electrolyte interphase to solve the calendar life challenge currently limiting the development of silicon anodes.	Anthony Burrell/NREL	NREL and other U.S. national labs (Argonne, Sandia, Oak Ridge, Pacific Northwest, and Lawrence Berkeley)	https://www.nrel.gov/transportation/silicon-anode-consortium.html
		Battery Recycling	ReCell, VTO's advanced battery recycling R&D center to advance recycling technologies along the entire battery life cycle for current and future battery chemistries Current 2020 - 2025	Make battery recycling profitable by recovering high-value materials; design processes to optimize yield, productivity, and cost; ensure future supplies of energy storage critical materials for increased national security.	Jeffrey Spangenberger/Argonne National Laboratory	Argonne, NREL, and other national laboratories, universities, and companies	https://recellcenter.org
		Grid Storage and Integration	Energy Systems Integration Current 2011 -	The ESIF provides an unmatched research space to explore energy storage pathways at the intersection of technologies and domains. Research focuses on designing solutions that maximize efficiency and value for a variety of energy storage technologies	Juan Torres/NREL	Industry, academia, national laboratories, consortia https://www.nrel.gov/esif/work-with-us.html	https://www.nrel.gov/esif/energy-storage
		Large-Scale Testing	Advanced Research on Integrated Energy Systems (ARIES), a research platform that can match the complexity of the modern energy system and conduct integrated research to support the development of groundbreaking new energy technologies Current 2020 -	ARIES unites research capabilities at multiple scales and across sectors to create a platform for understanding the full impact of energy systems integration.	John Farrell/NREL Jennifer Kurtz/NREL. Jerry Davis/NREL	Industry, industrial consortia, academia, NGOs, other national labs	https://www.nrel.gov/aries/

	Energy Storage for Transportation and Mobility	Energy Storage R&D, Analysis, and Modeling Current ongoing	NREL innovations accelerate the development of high-performance, cost-effective, and safe energy storage systems to power the next generation of electric-drive vehicles (EDVs).	Matt Keyser/NREL John Farrell/NREL	Wide range of partners	https://www.nrel.gov/transportation/energy-storage.html
	Behind-the-Meter Storage	Behind-the-Meter Storage Current 2019-	Develop energy storage technologies for stationary applications below 10 megawatt-hours. Target the development of innovative critical-material-free energy storage technologies to minimize the need for significant upgrades to the electric grid. Such technologies could also eliminate excess demand charges that electric vehicle fast charging would incur using current technologies. This work leverages battery storage solutions that can discharge at high power but recharge at standard lower-power rates—essentially acting as power reservoirs bridging the gap between the grid and on-site energy generation technologies such as photovoltaics.	Anthony Burrell/NREL	U.S. DOE national lab consortium	https://www.nrel.gov/transportation/behind-the-meter-storage-consortium.html
	Thermal Energy Storage	Energy Storage R&D, Analysis, and Modeling Current ongoing	Through industry partnerships, NREL researchers address technical barriers to deployment and widespread adoption of thermal energy storage in buildings.	Roderick Jackson/NREL Judith Vidal/NREL	Wide range of partners	https://www.nrel.gov/buildings/storage.html
Hydrogen	Hydrogen and Fuel Cells	Hydrogen and Fuel Cell Technology Development ongoing	NREL's hydrogen and fuel cell research advances are lowering the cost and increasing the scale of technologies to make, store, move, and use hydrogen. Our research focuses on technologies and integrated systems that provide flexibility to meet rising energy demands across the country and in multiple sectors of the economy.	Keith Wipke/NREL	Industry, academia, national laboratories, consortia, international	https://www.nrel.gov/hydrogen/index.html
	Production	Hydrogen From Next-Generation Electrolyzers of Water (H2NEW), a consortium of nine DOE national laboratories focused on making large-scale electrolyzers—which produce hydrogen from electricity and water—more durable, efficient, and affordable Current 2021- 2026	Address components, materials integration, and manufacturing R&D to overcome technical barriers and enable manufacturable electrolyzers that meet required cost, durability, and performance targets, simultaneously, to enable $2/kg hydrogen by 2026.	Bryan Pivovar/NREL	DOE national lab consortium led by NREL, Idaho National Laboratory, and Lawrence Berkeley National Laboratory with six other national labs	https://h2new.energy.gov/
		HydroGEN Consortium for Advanced Water Splitting Materials, a consortium that facilitates collaborations between federal laboratories, academia, and industry for photoelectrochemical, high- and low-temperature electrolysis, and solar thermochemical processes Current 2016 - 2026	Address advanced water splitting materials challenges by making unique, world-class national lab capabilities in photoelectrochemical, solar thermochemical, and low- and high-temperature electrolytic water splitting more accessible to academia, industry, and other national labs.	Huyen Dinh/NREL	Led by the NREL and includes Lawrence Berkeley National Laboratory, Sandia National Laboratories, Idaho National Laboratory, and Lawrence Livermore National Laboratory. HydroGEN is funded by DOE's Hydrogen and Fuel Cell Technologies Office in the Office of Energy Efficiency and Renewable Energy.	https://h2awsm.org
	Storage	Hydrogen Materials Advanced Research Consortium (HyMARC), a consortium that addresses gaps in foundational knowledge needed to accelerate materials discovery and performs synthesis and characterization of advanced storage material concepts Current 2021- 2026	Provide foundational understanding, synthetic protocols, new characterization tools, and validated computational models to accelerate discovery of solid-phase and liquid materials that meet industry requirements.	Mark Allendorf/Sandia National Laboratories (Co-Director) Tom Gennett/NREL (Co-Director and Task Lead)	Sandia National Laboratories, NREL, Pacific Northwest National Laboratory, Lawrence Livermore National Laboratory, and Lawrence Berkeley National Laboratory	https://www.hymarc.org
	Utilization	Million Mile Fuel Cell Truck (M2FCT), a DOE-funded consortium formed by five primary national labs Current 2020- 2026	To advance efficiency and durability of proton exchange membrane fuel cells at a pre-competitive level to enable their commercialization for heavy-duty vehicle applications with an initial focus on long-haul trucks.	Rod Borup/Los Alamos National Laboratory Adam Weber/Lawrence Berkeley National Laboratory	Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, Argonne National Laboratory, NREL, Oak Ridge National Laboratory	https://millionmilefuelcelltruck.org/

	Hydrogen	DOE H2@Scale Initiative 	Bring together stakeholders to advance affordable hydrogen production, transport, storage, and utilization to enable revenue opportunities across multiple sectors.	Sunita Satyapal/DOE EERE Hydrogen and Fuel Cell Technologies Office Keith Wipke/NREL	National labs, universities, and industry	https://www.energy.gov/eere/fuelcells/h2scale
	Demonstrations	Demonstration Testing at Multiple Scales 	Design, develop, and test advanced experimental and analytical methods to improve electrolyzer stack and system efficiency.	Kevin Harrison/NREL Jennifer Kurtz/NREL	Industry	https://www.nrel.gov/hydrogen/renewable-electrolysis.html
	Analysis	Analysis 	Energy analysis tools, models, and other resources for researchers, developers, investors, and others interested in the viability, analysis, and development of hydrogen and fuel cell technologies and systems.	Keith Wipke/NREL	NGOs, U.S. DOE, industry, academia, national labs, international, …	https://www.nrel.gov/hydrogen/data-tools.html
Solar Energy	Solar	Solar Energy RD&D 	NREL's solar energy research leverages our expertise—from materials to systems to commercialization—to continually improve the affordability, performance, and reliability of this abundant, domestic energy resource.	Mary Werner/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/solar/
	Photovoltaics (PV)/ Devices	Solar Energy RD&D 	Conduct RD&D spanning fundamental and applied research and development, including theory and modeling, materials deposition, device design, engineering, and measurements and characterization on concepts, devices, modules, and relability to accelerate the development of PV technologies to meet DOE goals. This area includes thin films, tandems, advanced processing, and reliability. Develop high-efficiency solar cells with a conversion efficiency of over 35%.	Nancy Haegel/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/solar/index.html
	Thin-Film PV	Solar Energy RD&D 	Develop polycrystalline thin-film photovoltaics, including cadmium telluride and copper indium gallium diselenide solar cells.	Nancy Haegel/NREL Lorelle Mansfield/NREL Matt Reese/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/pv/polycrystalline-thin-film-photovoltaics.html
		Cadmium Telluride Accelerator Consortium 	Accelerate the development of cheaper, more efficient cadmium telluride (CdTe) solar cells.	Lorelle Mansfield/NREL Mike Heben/University of Toledo	University of Toledo (lead), First Solar, Colorado State University, Toledo Solar Inc., Sivananthan Laboratories	https://www.nrel.gov/pv/cadmium-telluride-photovoltaics-accelerator-consortium-solicitation.html
	Perovskite PV	Perovskite Photovoltaics - U.S. Manufacturing of Advanced Perovskites (US-MAP) Consortium 	Accelerate domestic commercialization of perovskite technologies by providing access to comprehensive research capabilities that establish a solid technical foundation.	Joe Berry/NREL Laura Schelhas/NREL	NREL, University of Toledo, University of Washington Clean Energy Testbed, University of Toledo Energy Testbeds, University of North Carolina at Chapel Hill, and leading U.S. companies pursuing perovskite technologies	https://www.nrel.gov/pv/perovskite-organic-photovoltaics.html https://www.usa-perovskites.org/
	PV Modules	Durable Module Materials Consortium (DuraMAT) 	Discover, develop, de-risk, and enable the commercialization of new materials and designs for PV modules—with the potential for a levelized cost of electricity of less than 3 cents per kilowatt-hour.	Teresa Barnes/NREL	NREL, Sandia National Laboratories, Lawrence Berkeley National Laboratory, SLAC. Brings together the national lab and university research infrastructure with the photovoltaic and supply-chain industries.	https://www.duramat.org/
	PV Reliability	International Photovoltaic Quality Assurance Task Force (PVQAT) 	Lead global efforts to craft quality and reliability standards for solar energy technologies to assess causes of PV failures in the field and determine how best to conduct quick, inexpensive, and accurate screenings.	Ingrid Repins/NREL	Global collaboration	https://www.pvqat.org/

	Concentrating Solar Power (CSP)	Concentrating Solar Power Current ongoing	Provide scientific, engineering, and analytical expertise to advance innovation in concentrating solar power (CSP) technologies for electricity and fuels.	Craig Turchi/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/csp/
		Heliostat Consortium Current 2022 - 2024 ongoing	Support research, development, validation, commercialization, and deployment of low-cost and high-performance heliostats with optimized operations and maintenance for CSP and concentrating solar-thermal applications.	Guangdong Zhu/NREL	NREL, Sandia National Laboratories, and the Australian Solar Thermal Research Institute work closely with the U.S. Department of Energy (DOE) and CSP developers, component suppliers, utilities, and international experts.	https://www.nrel.gov/csp/heliocon.html
Wind	N/A	Wind Current ongoing	NREL continues to pioneer many of the components and systems that have taken wind energy technologies to new heights, providing global leadership in fundamental wind energy science research, development, and validation activities.	Nick Johnson/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/wind/
Geothermal	N/A	Geothermal Current ongoing	Advance cutting-edge geothermal technologies, conducting world-class analysis, and improving access to data critical to unleashing tens of gigawatts of domestic resources for always-on power, heating, cooling, and storage.	Amanda Kolker/NREL	Universities, U.S. DOE national labs, companies	https://www.nrel.gov/geothermal/
Carbon Capture, Utilization, and Storage (CCUS)	Solar Fuels	The Liquid Sunlight Alliance (LiSA), a DOE Basic Energy Sciences (BES) Energy Innovation Hub devoted to advancing the science of liquid solar fuels Current 2020 - 2025	Create solar fuels systems of the future with unprecedented catalytic selectivity, energy efficiency, and durability using co-design principles to realize assemblies of coupled chemical microenvironments, with inspiration from nature, to form complex chemical products.	Harry Atwater/Caltech	Caltech, Lawrence Berkeley National Laboratory, NREL, SLAC, University of California (Irvine and San Diego), University of Oregon	https://www.liquidsunlightalliance.org/
	Solar Fuels	NREL Core DOE BES Program in Solar Photochemistry Current ongoing	Conduct fundamental R&D on solar photoconversion in molecular, nanoscale, and semiconductor systems to capture, control, and convert high-efficiency solar radiation into electrochemical potential for electricity, chemicals, or fuels.	Garry Rumbles/NREL	NREL and university professors	https://www.nrel.gov/chemistry-nanoscience/solar-photochemistry.html
	CCUS	CCUS RD&D Current 2017-	Electrons to molecules and carbon capture, utilization, and storage spanning TRLs for industry and fuels/chemicals/materials.	Randy Cortright/NREL Josh Schaidle/NREL Mike Resch/NREL	Universities, U.S. DOE national labs, companies, international, research consortia	https://www.energy.gov/eere/bioenergy/co2-reduction-and-upgrading-e-fuels-consortium
	Renewable Methane	Renewable Hydrogen Electrolysis Coupled With CO2 Conversion Current ongoing	Electrolyzer/bioreactor integration using novel organisms to reduce CO2 to methane using hydrogen.	Kevin Harrison/NREL Nancy Dowe/NREL	NREL, Southern California Gas Company, Electrochaea GmbH, University of Chicago	
Bioenergy and Biofuels	Biofuels	Bioenergy and Biofuels Current	Develop innovative, cost-effective, and performance-advantaged biotechnologies that tap into America's abundant biomass and waste resources.	Maureen McCann/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/bioenergy/
	Sustainable Aviation Fuels	Current 2021 -	Combines extensive experience in combustion mechanisms and alternative fuels with high-performance computing to provide detailed insights for manufacturers.	Zia Abdullah/NREL	Research consortia, universities, national labs, industry partners	https://www.nrel.gov/bioenergy/ https://www.nrel.gov/transportation/sustainable-aviation-fuels.html

Buildings	N/A	Buildings RD&D 	Transform energy through building science and integration. Our research significantly enhances the resiliency, efficiency, and affordability of energy systems across the United States and the world.	Roderick Jackson/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/buildings/
Basic Energy Sciences	N/A	Fundamental Chemical, Biological, and Materials Research 	Conduct use-inspired and discovery R&D to provide underpinning knowledge and understanding for energy conversion and technologies. Develop solutions for energy conversion and storage and related technologies. We utilize NREL's strong capabilities in semiconductors and materials science, nanomaterials synthesis and modification, synthesis and fabrication, photochemistry and advanced spectroscopy, and bioscience.	Bill Tumas/NREL	Academia and national labs; international: solar fuels, degradation science	https://www.nrel.gov/research/basic-energy-science.html
	N/A	Center for Hybrid Organic-Inorganic Semiconductors for Energy 	A cohesive centerwide effort to accelerate discovery and elucidate design principles for unprecedented control over emergent properties involving spin, charge, and light-matter interactions, leading to new energy-efficient advanced technologies.	Matthew Beard/NREL	DOE-funded Energy Frontier Research Center, NREL-led; University of Colorado, Boulder; Duke University; the University of North Carolina, Chapel Hill; San Diego State University; the University of Toledo; the University of Utah; the University of California, Santa	https://www.choise-efrc.org/index.html
Fundamental Biological Science	N/A	Biological and Environmental Research 	NREL's fundamental science of biological energy conversion research capabilities creates mechanistic understanding that enables control over biochemical and biophysical pathways and processes in living organisms, cell-free, biohybrid, and catalytic systems.	Maureen McCann/NREL	Industry, government agencies, academia, national laboratories, and other organizations	https://www.nrel.gov/bioenergy/science-of-biological-energy-conversion-research
Computational Science	N/A	Computational Science 	NREL's computational science, high-performance computing, applied mathematics, and advanced computer science, visualization, and data drive economic growth, accelerate process innovations, enhance reliability, and enable reduced risk across the energy ecosystem.	Ray Grout/NREL	Universities, U.S. DOE national labs, companies, international	https://www.nrel.gov/computational-science/

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Progress of research and development related to clean energy at RIKEN

Kazuki Saito
Executive Director of Science

1. Introduction

RIKEN is Japan's largest comprehensive research institution renowned for high-quality research in a wide array of scientific areas spanning physics, engineering, chemistry, computational science, biology, and medicine. Founded in 1917 as a private research foundation, RIKEN has grown rapidly in size and scope, today encompassing a network of world-class research centers and institutes across Japan.

Now, as a national research and development institute, RIKEN's mission is to maximize research and development outcomes effectively and efficiently. We must at all times remain keenly aware of our responsibility to society, while at the same time ensuring the autonomy and creativity of our scientists. We will link our discoveries in science and technology to the creation of new value, integrate the synergies that distinguish RIKEN, and strengthen our collaborations with partners inside and outside Japan. We will do this by continuing with basic research, which is the source of knowledge, and by developing outstanding technologies. As a world leader in science, RIKEN will strive to create a better life for the Japanese people and contribute to the global community.

In 2015, two historic proposals - the Paris Agreement on global warming (COP21) and the United Nations 2030 Agenda for Sustainable Development - were supported by more than 190 countries. Japan promised to work on realizing the Agenda's 17 sustainable development goals (SDGs) and to move toward a 26 per cent reduction of greenhouse gases from 2013 levels by 2030. This reduction target was raised to 46% and declared at the Leaders' Climate Summit hosted by the U.S in April 2021. To fulfill Goal 7 (affordable and clean energy) of the SDGs and to achieve the greenhouse gas emissions reduction target, Japan has undertaken and expanded scientific initiatives in clean energy technology research and development as a part of its national science policy. As one of RIKEN's missions is to advance R&D based on national strategies, we have also strategically engaged in R&D in this field.

2. R&D activities related to carbon neutrality

The basic research promoted by RIKEN is not only scientifically valuable, but also has the potential to break through the limitations of existing technology and create major innovations. In the face of climate change and other environmental crises, we emphasize that science is an enterprise that truly connects the world and has universality (from "The Usefulness of Useless Knowledge"). RIKEN Center for Sustainable Resource Science (CSRS) has been a leader in creating a sustainable society through transdisciplinary integration of plant science, chemical biology, and catalytic chemistry since its establishment in 2013. Using as guides the Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 and the agreement of the COP21 on achieving zero greenhouse gas emissions, we have been promoting five flagship projects, which later expanded to six. Each of these projects aims to further advance basic research in the efficient creation, exploration, and use of beneficial substances from natural resources, sustainable food production, and bioproduction that CSRS has been undertaking in the past. In addition, the projects will move beyond the boundaries of research fields and develop manufacturing methods with less impact on the environment. In particular, advances made in recent years in AI and data science can bring about a significant step forward. While

actively nurturing the next generation of scientists with a strong background in information science, CSRS will lead in creating a future world where people can live healthy and prosperous lives. As the former Center Director Saito, who was appointed to the position in April 2020, advocated for a new research field called “sustainable resource science” in the academic community, CSRS will take the initiative in disseminating this new field while promoting international cooperation. In April 2025, Sodeoka has been appointed as the Center Director. Under the new leadership, we continue to advance the same policy direction through four restructured strategic programs.

Specific efforts of CSRS are as follows.

- RIKEN CSRS is aiming to establish a new field for the future called "Sustainable Resource Science".
- To contribute to CO_2 reduction, RIKEN CSRS collaborates with industry to develop production technologies using *E. coli* for valuable compounds, promoting translational research aimed at the social implementation of bioproduction.
- In 2022, CSRS had launched Accelerated Priority Program “Carbon Neutrality and Beyond” consisting of next-generation PIs, to promote research that contributes to carbon neutrality. This program ended in 2025 with transferring to the new strategic research programs of CSRS.

In addition to CSRS, other research centers are also involved in research and development for element technologies that can help advance clean energy technologies. Research and development is conducted through the integration of research fields, the promotion of joint research inside and outside of RIKEN, and the effective use of large-scale facilities such as supercomputers and synchrotron radiation facilities. In 2025, RIKEN has introduced a system of five “research domains” including “Sustainable Science Domain” with the aim to create new academic knowledge across fields, including while maintaining the research centers and other facilities as the basic units of research management. This system encourages cross-disciplinary collaboration based on advanced expertise, and will accelerate the creation of new knowledge.

3. Specific research activities

Carbon dioxide capture and utilization (CCU) is a technological solution that aims to use CO_2 as a source to produce useful substances, such as chemicals and fuels, by capturing and reducing CO_2 via chemical reactions (by using catalysts), biological reactions (by using plants and algae), or a hybrid of the two.

To reduce greenhouse gas emissions and develop alternative means to create energy, RIKEN is currently advancing R&D projects related to hydrogen, CCU, and other relevant technologies. Research topics include artificial photosynthesis, converting CO_2 and H_2O into chemical fuels, and biological approaches that help plants and algae absorb CO_2 and/or produce useful substances. Supported by the Japan Science and Technology Agency (JST), CSRS collaborates with the RIKEN Center for Advanced Photonics (RAP) and they jointly focus on hydrogen production by water electrolysis, a candidate technology to master the use of natural energy sources that, while carbon-free, experience substantial fluctuations. Specifically, this technology R&D project is working to design and control a hydrogen production system that uses a non-noble or less-noble metal catalyst with an incorporated electrochemical water oxidation mechanism so that H_2 can be produced efficiently from H_2O at a low cost.

RIKEN is also involved in a development project for a system that uses electricity obtained from renewable energy and a non-noble metal catalyst to directly and efficiently produce basic chemical compounds such as ethylene from CO_2 and H_2O under ordinary temperatures and normal pressures. In the project, RIKEN also contributes to the system development for

electrochemical CO_2 enrichment from relatively low-concentration CO_2 gas. RIKEN has been promoting research and development for comprehensive systems related to CCU, which is a research project adopted by NEDO under the Moonshot Research and Development Program launched by the Cabinet Office, by using cutting edge underlying technology developed by RIKEN and collaborating with universities and research institutes in Japan and overseas.

Furthermore, RIKEN is conducting research on alternatives for fossil fuels. For example, we are focusing on microalgae that can produce an abundant amount of oil. Through our research on cellular metabolism and gene expressions of micro-algal species, we are working on gene discovery to improve productivity of microalgal species beneficial to industry. Based on our research facilities for life science and biotechnologies, we have continued matching fund-based cooperative research with micro-algal industries through a joint research team established inside RIKEN and a research consortium aiming to develop technologies for microalgae biorefinery. In 2021, the partner company of our joint research team demonstrated the use of bio-based jet fuel for commercial flights, and in 2024 the company also started constructing a commercial plant in Malaysia to produce bio-jet fuel and renewable diesel. In parallel, since 2022 we have advanced international research projects, including a JICA/JST SATREPS project in Indonesia on CO_2 fixation and utilization with microalgal biomass. Moreover, since 2023 RIKEN has been leading a JST/GteX project to establish CO_2-based biomanufacturing, leveraging its bioresources and research infrastructure.

- Degradation analysis and stabilization improvement of polymer membrane water electrolyzer with non-precious metal catalyst under fluctuating power source (NEDO, 109 million JPY for FY 2018-FY 2022）
- Operation, manufacturing, and large-scale development of manganese oxide oxygen evolution reaction (OER) catalysts for water electrolysis (NEDO, 39 million JPY for FY2023-FY 2024)
- Development of Innovative Water Electrolysis System for Green Hydrogen Production (JST, GteX WInG, the project budget for FY2023-FY2026 is undisclosed)
- Hybrid Electrocatalysts for C2 Production from CO_2 and the Appropriate System (NEDO, 181 million JPY (including the budget for the other collaborative organizations) for FY 2018-FY 2019)
- Develop an innovative system to turn CO_2 into a valuable resource using electrochemical reactions (NEDO, Moonshot Research and Development Program; the budget for the confirmed part is 340 million JPY for FY 2020-2027.)
- Development of innovative technology to increase biofuel of microalgae (the budget for the project for FY 2018-FY 2024 is undisclosed)
- Establishment of cutting-edge plant platforms for biomanufacturing (GST, GteX Biomanufacturing, the project budget for FY2023-FY2027 is undisclosed)
- Integrated Sustainable Energy and Food Production from Microalgae-based Carbon Capture and Utilization (JST/JICA SATREPS, the project budget for FY2022-FY2027 is undisclosed)

4. International collaboration

Concerning the research activities on hydrogen and CCU by RAP and CSRS, RIKEN has collaboration with Lawrence Berkeley National Laboratory (US), National University of Singapore, Nanyang Technological University (Singapore), Agency for Science, Technology and Research (A*STAR) (Singapore), The University of Melbourne (Australia), The University of New South Weles (UNSW) (Australia), Korea Institute for Advancement of Technology, Chonnam National University (Korea), Strasbourg University (France) and Dalian National Laboratory for Clean Energy (China).

(1) Most prioritized issues / Key issues raised
  (a) In order to launch a new sustainable resource science, we are strategizing that basic science is also important in addition to applied science.
  (b) Technologies for hydrogen production, energy management systems, and carbon dioxide reduction using renewable energy.
    - Are the devices and systems safe for the global environment and resource consumption? (For example, the polymer electrolyte water electrolysis cell, which is strong in variable power sources, uses IrOx as a catalyst for oxygen generation, but when this polymer electrolyte water electrolysis cell is used worldwide, Ir will be in short supply.)
    - Globally, what are the targets and timeframes for achieving the required fossil fuel-free systems and their installation and use?
    - What is the sentiment regarding the economic comparison with using fossil fuels and how to promote their use?
    - Can we achieve carbon-negative systems?
  (c) Production of biofuel from microalgae
    - Human resource development with incentives to promote social acceptability of Biomass Carbon Removal and Storage (BiCRS), and development of economically rational roadmap.
    - Are cultivation, harvesting, and conversion processes, including energy, nutrient, and water use, sustainable at large scale?
    - How can residual biomass after materials extraction be effectively managed or utilized to avoid waste and improve overall carbon balance?

(2) Best practices
  (a) In 2022, CSRS had launched Accelerated Priority Program “Carbon Neutrality and Beyond” consisting of next-generation PIs, to promote research that contributes to carbon neutrality, and it ended in 2025 with reformulation to the new strategic research programs of CSRS.
  (b) Technologies for hydrogen production, energy management systems, and carbon dioxide reduction using renewable energy:
    - A proposal for a feedback control method on green energy system based on biomimetics.
    - With regard to hydrogen technology, through RIKEN Innovation Co., Ltd. (an affiliated company in which RIKEN has a stake) a technology study group has been established with the participation of companies and local governments, with a view to practical application and social implementation.
  (c) Research and development that utilizes a matching fund with companies that develop clean energy technologies and promote their social implementation through a system that promotes industrial collaboration.

(3) Effective measure for facilitating international cooperation
  (a) Facilitate networking and matching using remote/online tools.
  (b) Create a mechanism to attract investment and human resources in international cooperation.

5. Future perspectives (towards carbon neutrality)

To address global issues, including SDGs, not only advancement of science and technology but also collaboration among all governments, private sectors, and societies is critical. Especially when implementing large-scale clean energy projects, we must unify element technologies, including conversion, transportation, and storage, into one system, and collaboration with a variety of sectors is essential for this unification. We will endeavor to engage in collaborative research with other sectors to create problem-solving models as we continue to drive innovation in the development of technology that can produce game-changing outcomes.

Kazuki Saito, Ph.D.

Executive Director of Science, RIKEN
Professor Emeritus, Chiba University

Professor Kazuki Saito obtained his Ph.D. from the University of Tokyo in 1982. After staying at Keio University in Japan and Ghent University in Belgium, he was appointed a full professor in 1995 at the Graduate School of Pharmaceutical Sciences, Chiba University, until his retirement in 2020. He is currently Professor Emeritus of Chiba University. Since 2005, he has been additionally appointed as a group director at the RIKEN Center for Sustainable Resource Science (CSRS) (formerly, RIKEN Plant Science Center) to direct metabolomics research, and from 2020 to 2025, he served as the Center Director. After retiring from both roles in 2025, he served as Executive Director of Science at RIKEN. He is engaged to lead the sustainability domain in RIKEN.

He has received numerous prestigious honors, including the Medal with Purple Ribbon by the Japanese Government, the Shimadzu Prize, and the title of Knight in the Order of Léopold from the Kingdom of Belgium. He has been recognized as one of the “Highly Cited Researchers” in the field of Plant & Animal Science for eleven consecutive years (2014–2024).