Progress of research and development related to clean energy at RIKEN

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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. 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 clean energy technology

The RIKEN Center for Sustainable Resource Science (CSRS) plays a major role in research and development for clean energy technologies within RIKEN. Since its establishment in 2013, CSRS has been a leader in creating a sustainable society through transdisciplinary integration of plant science, chemical biology, and catalytic chemistry. 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 are promoting five flagship projects. 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 Center Director Saito, who was appointed to the position in April 2020, advocates for a new research field called "sustainable resource science" in the academic community, CSRS will take the initiative in disseminating the new field while promoting international cooperation.

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.

3. Specific research activities in renewable energies, next generation energy management system with batteries; hydrogen; carbon dioxide capture, utilization and utilization (CCUS); and related technologies

Carbon dioxide capture and utilization (CCU) is a technological solution that aims to use CO2 as a source to produce useful substances, such as chemicals and fuels, by capturing and compressing CO2 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 CO2 and H2O into chemical fuels, and biological approaches that help plants and algae absorb CO2 and/or produce useful substances. Supported by the New Energy and Industrial Technology Development Organization (NEDO), the RIKEN Center for Advanced Photonics (RAP) collaborate with CSRS 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 metal catalyst with an incorporated photosynthesis mechanism so that H2 can be produced efficiently from H2O 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 CO2 and H2O under ordinary temperatures and normal pressures. In 2020, RIKEN will promote 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, we are conducting research on alternatives for fossil fuels, focusing on algae that can produce an abundant amount of oil. Using microalgae analysis and metabolic analysis techniques, CSRS is working on research to discover a metabolic pathway related to the amount of fat and oil production through the analysis of metabolic products and gene expressions of microalgae beneficial to industry. Using matching funds from a corporation that aims to develop microalgae biofuels for practical application, RIKEN has also established a joint research team engaged in developing techniques to mass-produce these biofuels through gene search and gene modification techniques. To disseminate such advances in research to society, RIKEN and Universiti Teknologi Malaysia (UTM) jointly hosted a workshop for middle and high school students (grades 7-12) on the UTM campus in December 2019. RIKEN also participated in the FY 2020 Co-creation Consortium for Functional Bio-Research, which was established by the Japan Science and Technology Agency (JST) under its “Open Innovation Platform with Enterprises, Research Institute and Academia (OPERA)” program with the aim of developing microalgae biorefinery to reduce CO2 emissions and environmental impact. (14 research institutes/universities and 18 enterprises participated in the event.)

- Degradation analysis and stabilization improvement of polymer membrane water electrolyzer with non-precious metal catalyst under fluctuating power source (NEDO, 109 million yens for FY 2018-FY 2020）
- Hybrid Electrocatalysts for C2 Production from CO2 and the Appropriate System (NEDO, 181 million yens (including the budget for the other collaborative

organizations) for FY 2018-FY 2019)

- Develop an innovative system to turn CO2 into a valuable resource using electrochemical reactions (NEDO, Moonshot Research and Development Program; the budget for this project for FY 2020 and onwards is being adjusted.)
- Development of innovative technology to increase biofuel of microalgae (the budget for the project for FY 2018-FY 2023 is undisclosed)

4. International collaboration

4-1 International alliance/networking development

RIKEN is not yet involved in such activities.

4-2 International joint R&D activities

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), Korea Institute for Advancement of Technology, Chonnam National University (Korea), Strasbourg University (France) and Dalian National Laboratory for Clean Energy (China).

5. Future perspectives (beyond 2030)

To address global issues, including SDGs, not only science and technology but also collaboration among all governments, private sectors, and societies is important. 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.

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Yuko Harayama is an Executive Director at RIKEN charged of international affairs, promotion of young researchers and diversity. Prior to joining RIKEN, she spent five years at the Cabinet Office of Japan, as an Executive Member of the Council for Science, Technology and Innovation (CSTI), two years at the OECD as the Deputy Director of the Directorate for Science, Technology and Industry (STI), and ten years at the Graduate School of Engineering of Tohoku University as a professor of Science and Technology Policy. Her experience prior to Tohoku University includes being a Fellow at the Research Institute of Economy, Trade and Industry (RIETI) in Japan and an Assistant Professor in the Department of Political Economy at the University of Geneva. Ms. Harayama holds a Ph.D. in Education Sciences and a Ph.D. in Economics both from the University of Geneva. She has received Chevalier de la Légion d'honneur in 2011 and was awarded honorary doctorate from the University of Neuchâtel in 2014.
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