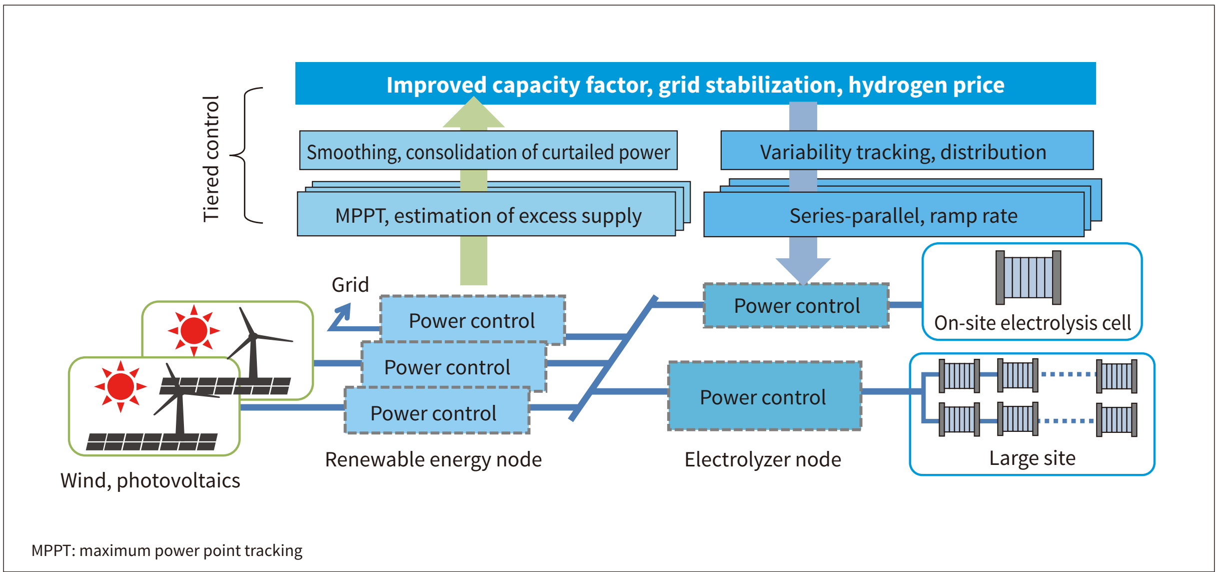
Exploratory Research



1 Tiered control and scalable design of grid-linked electrolyzers

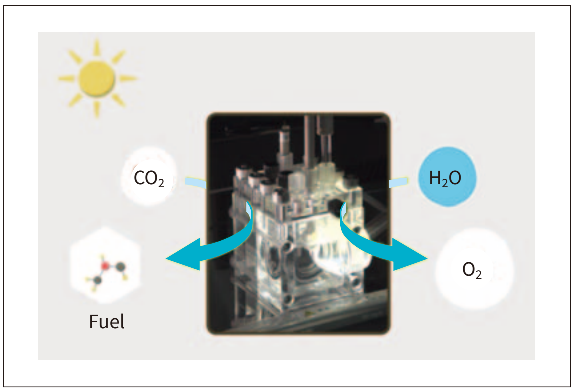
1 Low-cost Supply of Green Hydrogen Using Renewable Energy

To promote the wider use of green hydrogen produced using renewable energy such as wind and photovoltaics, Hitachi is developing a technique for hydrogen production that connects to the grid. This involves optimizing the configuration of the power control equipment and how the electrolysis systems are connected as well as the development of operational control techniques based on tiered control in order to achieve highly efficient production of hydrogen using curtailed power and variable grid-connected renewable energy. Hitachi has also been conducting tests on a virtual plant that models the behavior of wind and other generation plant and incorporates a physical model of the electrolysis process to devise a scalable green hydrogen production system suitable for use across distributed sites as well as at large electricity sites.

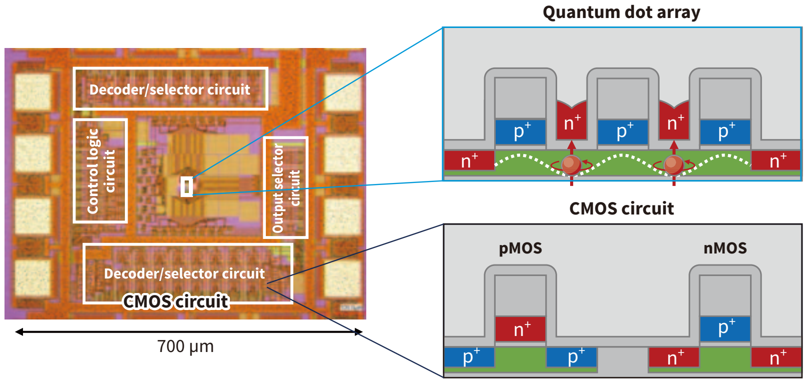
Through initiatives that include collaboration between industry, academia, and government on demonstration projects for hydrogen-using green energy systems like this, Hitachi is working toward the production of green hydrogen at the low cost of 30 yen/m^3 or less and the wider adoption of hydrogen in Japan and elsewhere.

2 Development of Artificial Photosynthesis for Achieving Circular Economy

With goals of restoring the global environment and moving to a circular economy, Hitachi is developing artificial photosynthesis capable of manufacturing clean fuels directly from water, air, and sunlight. The artificial photosynthesis reaction involves producing “solar hydrogen” by electrolysis using a photocatalyst and photoelectrode, with solar fuels being a promising technology because of their ability to be produced using simple apparatus. The problem with past photocatalysts, however, was that they worked by ultraviolet light and were only able to use a small fraction of the energy in sunlight.



2 Overview of artificial photosynthesis



3 Integration of CMOS circuit with quantum dot array

In response, Hitachi has been working to improve solar energy conversion efficiency by developing materials that respond to visible light, using simulation and materials informatics to devise optimal materials and structures, which include oxysulphides and oxynitrides.

In the future, Hitachi aims to use technology to overcome societal challenges by combining biotech with inorganic device technologies to apply artificial photosynthesis techniques that enable resource recovery with zero environmental impact on the use of atmospheric carbon dioxide (CO_2) for pharmaceuticals, fibers, and other materials with high added-value that are difficult to manufacture using conventional chemical synthesis.

3 Large-scale Integrated Silicon Quantum Computer

Quantum computers represent a new concept in computing technology that can solve problems that are intractable using conventional computers. The fundamental building block of a quantum computer is the qubit, but existing devices do not yet have enough qubits for their application to real-world problems. The challenge for the future is to build devices that contain qubits numbered in the millions.

Hitachi is seeking to achieve the early realization of quantum computers by taking advantage of the outstanding integrability possible with silicon integrated circuits. Control of qubits is the bottleneck to using them in large numbers. To overcome this challenge, Hitachi has developed a process for fabricating a two-dimensional array of quantum dots (a way of confining individual electrons that, with precise control, can act as qubits) together with the complementary metal-oxide semiconductor (CMOS) circuit used for control.

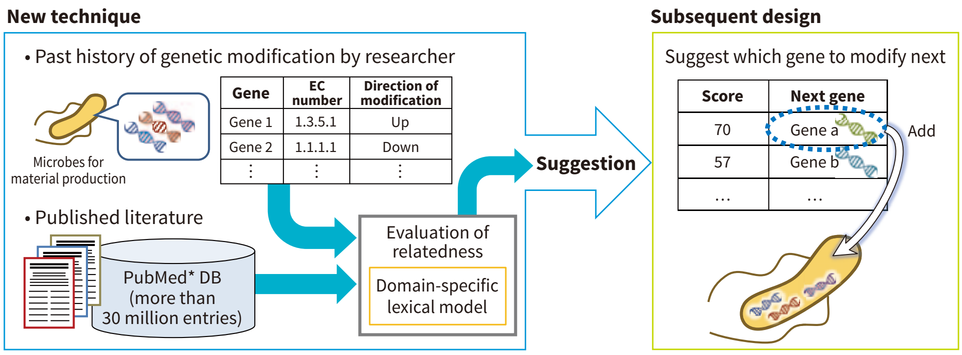
Through the use of open innovation, including the Moonshot Research and Development Program of the Japan Science and Technology Agency (JST), and by working with Hitachi Cambridge Laboratory on the development of quantum algorithms, Hitachi is seeking to achieve the early realization of quantum computing as a practical technology.

This research was supported by grant number JPMJMS2065 of the JST Moonshot Research and Development Program.

4 Gene Suggestion AI for Creating Microbes for Material Synthesis

The transition to a sustainable society will likely be accompanied by a shift away from methods of producing materials by chemical synthesis that rely on fossil fuels, instead using bio-synthesis for production from biomass with a low impact on the environment. Biosynthesis is a way of producing pharmaceutical precursors or other chemicals using specialist microbes that have been genetically modified for material synthesis. It can also be used to produce complex substances that are difficult to achieve by chemical synthesis. Unfortunately, the creation of these specialist microbes is very time consuming as it involves a repeated process of trial and error that draws on the expertise of the researcher as they modify different genes and test the results.

In response, Hitachi has developed an artificial intelligence (AI) that supports the creation of specialist microbes by suggesting which gene modification to try next. It works by conducting a comprehensive search of the publicly available literature that is relevant to the researcher's past history of genetic modification and uses a domain-specific lexical model to weight the results based on their relatedness to material synthesis. Using these results, it then suggests which genes to modify based on how related they are to the researcher's past history. Genetic modifications suggested by the AI



EC: enzyme commission DB: database
* See "Trademarks" on page 150.

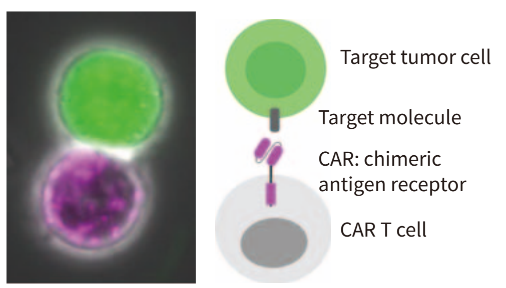
4 Overview of gene suggestion for creating microbes for material synthesis

succeeded in making a 19.5% improvement in the ability of the state-of-the-art strain of specialist microbes to produce shikimic acid, a pharmaceutical precursor.

Note that some of the technology described here was the result of work on the "Development of Production Techniques for Highly Functional Biomaterials Using Plant and Other Organism Smart Cells" project commissioned by the New Energy and Industrial Technology Development Organization (NEDO), details of which were published in the August 2021 issue of ACS Synthetic Biology, an international journal.

5 Hitachi Kobe Laboratory: Next-generation CAR T Cell Therapies

Chimeric antigen receptor (CAR) T cell therapies have demonstrated remarkable efficacy against certain types of cancer. Because of their scalability, it is anticipated that CAR T cell therapies will also be applied to various types of cancers and other diseases. The scalability of CAR T cell therapies is based on rapidly progressing techniques that genetically modify patient-derived cells. Hitachi's overarching goal is to develop next-generation CAR T cell therapies to provide benefits to larger numbers of people.



5 Recognition of target cell by human CAR T cells

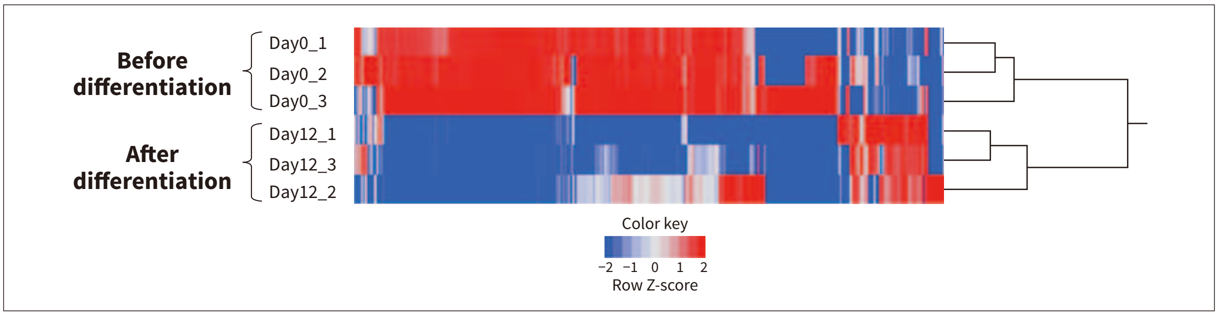
To achieve this goal, Hitachi has commenced the improvement of the CAR T cell manufacturing process using a new gene transfer technique, the development of CARs that can recognize new therapeutic targets, and the enhancement of a therapeutic protein production system from CAR T cells. Details of the improvements to the CAR T cell manufacturing process were published in 2021 in Mammalian Cell Engineering (Springer), a scientific journal.

Note that some of the work described in this article was assisted by the Leading Initiative for Excellent Young Researchers (LEADER) of the Japan Society for the Promotion of Science (JSPS).

6 Hitachi Kobe Laboratory: Regenerative Medicine

Regenerative medicine is an innovative medical practice that uses regenerated cells or tissue to treat the loss of bodily functions due to injury or illness. While the manufacture of cellular medications for regenerative medicine has in the past been done manually by experienced technicians, raising problems of how to reduce costs and ensure reliable quality. To overcome these problems, Hitachi released its iACE2 automated cell culture systems for commercial manufacturing in 2019. The iACE2 was also involved in a physician-led clinical trial of a nerve grafting treatment for Parkinson's disease using induced pluripotent stem (iPS) cells that was conducted by Kyoto University and Sumitomo Dainippon Pharma Co., Ltd. It was the first automated cell culture system intended for the commercial manufacturing of cells for medical use to have entered clinical use.

Hitachi is also looking at new cell culture monitoring practices that can play a part in the next generation of techniques for automated cell culturing. Using the



6 Expression data for exosome-derived miRNA secreted from iPS cells (microarray)

culturing process for the initial differentiation of iPS cells into nerve tissue as a model, this involved analyzing correlations with cell quality, looking at indicators of quantitative and qualitative changes in exosomes that have been secreted by the cells into the culture supernatant and the nucleic acid and proteins they contain, such as micro ribonucleic acid (miRNA). A correlation with these was found. Details of this work were published in the September 30, 2021 issue of the Journal of Bioscience and Bioengineering, an international journal.

Note that some of the work described in this article was undertaken through Japan Agency for Medical Research Development (AMED) project JP21be0404010.

7 Hitachi-UTokyo Laboratory: Online Closed Workshop Held for Energy Project

Phase two of an energy project at the Hitachi-UTokyo Laboratory that commenced in FY2020 involved formulating scenarios for achieving a net-zero society. International moves to achieve carbon neutrality are accelerating, and achieving Japan's ambitious target of a 46% reduction in CO_2 emissions in 2030 relative to FY2013 will require active participation by all of the stakeholders involved.

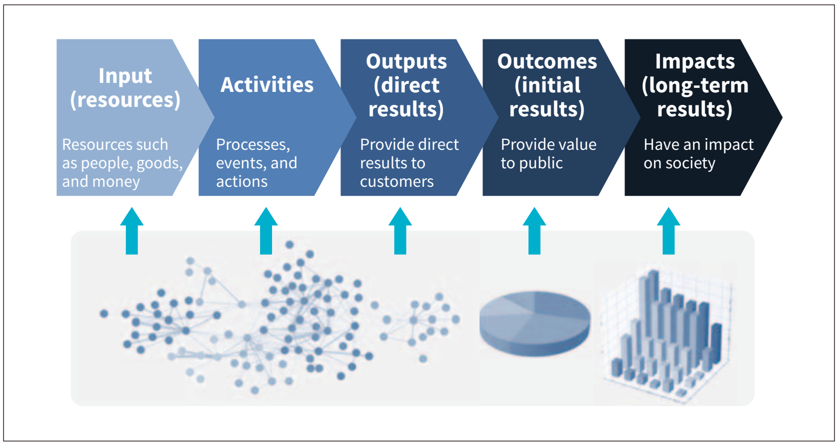
With participation by panelists from a wide range of sectors, including energy supply, industry, and consumers, the closed workshop provided for a frank exchange of opinions about how to go about achieving the common goal of creating a sustainable energy system and what such a scenario might look like. Four areas identified as being of particular importance were: (1) discontinuous innovation, including cost, (2) international coordination through decarbonization innovations, (3) attention to lifecycle assessment considerations, and (4)evaluation systems that support local activity.

Hitachi-UTokyo Laboratory has collated a policy statement based on discussions at the workshop and intends to publicize it through open forums.

8 Hitachi Kyoto University Laboratory: Social Impact Assessment Using Logic Models

Societies are facing a variety of challenges, including climate change, natural disasters, and consequences of the COVID-19 pandemic that include constraints on economic activity and the fragmentation of communities. While a range of social programs are being undertaken by national and local governments and the private sector to overcome these societal challenges, it is becoming more

7 Workshop opening by Teruo Fujii, President of The University of Tokyo (left) and Toshiaki Higashihara, Chairman & CEO of Hitachi, Ltd. (right)



8 Social impact assessment using logic models

difficult to measure their outcomes using the conventional approach to program evaluation that only measures the direct results of investment. This is because societal challenges are becoming more complex and because of the growing difficulty of determining how the deployment of different resources will ultimately impact on society.

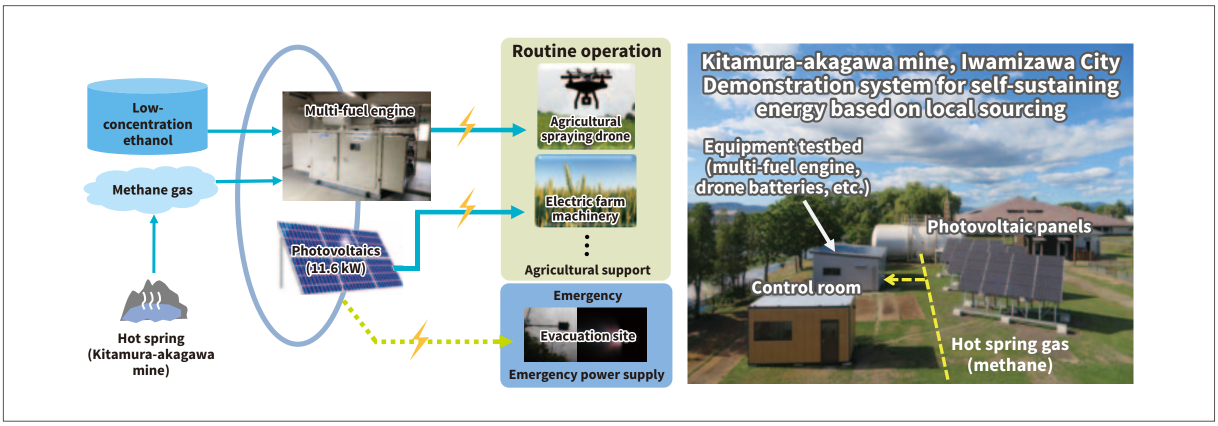
Hitachi Kyoto University Laboratory is developing a technique for assessing social programs using a logic model featuring a graphical representation of what sequence of deployed resources will logically lead to the desired social impacts. Future plans include coupling this technique with a quantitative simulator to extend its scope to cover quantitative social impact assessment.

9 Hitachi Hokkaido University Laboratory: Development of Self-sustaining Energy System Based on Local Sourcing to Help Achieve Sustainable Communities

Hitachi Hokkaido University Laboratory is working with Hokkaido University and a number of other stakeholders to pursue coexistence regional development with interoperation between infrastructure for health, food, and agriculture, and energy to help achieve sustainable communities and overcome the societal challenges faced by Hokkaido, which include depopulation, aging demographics, and a low birthrate.

With the aim of providing a locally sourced low-carbon electricity supply and a distribution network that can maintain supplies during emergencies, Hitachi has worked with Iwamizawa City to build a prototype self-sustaining energy system based on local sourcing. This demonstration system is helping to reduce carbon emissions in agriculture by utilizing electric power generated from unused local resources or photovoltaic panels to power equipment such as self-piloting drones. As the system is capable of standalone operation, without relying on the wider grid, it is also helping to strengthen the region against disasters by providing an autonomous power supply during emergencies.

In addition to accelerating the field testing and technical development of this system through collaboration between industry, academia, government, and communities, and contributing to the sustainable progress of local industry using locally sourced energy, future objectives also include providing communities with safe and secure infrastructure for living.



9 Block diagram of autonomous energy system based on local sourcing