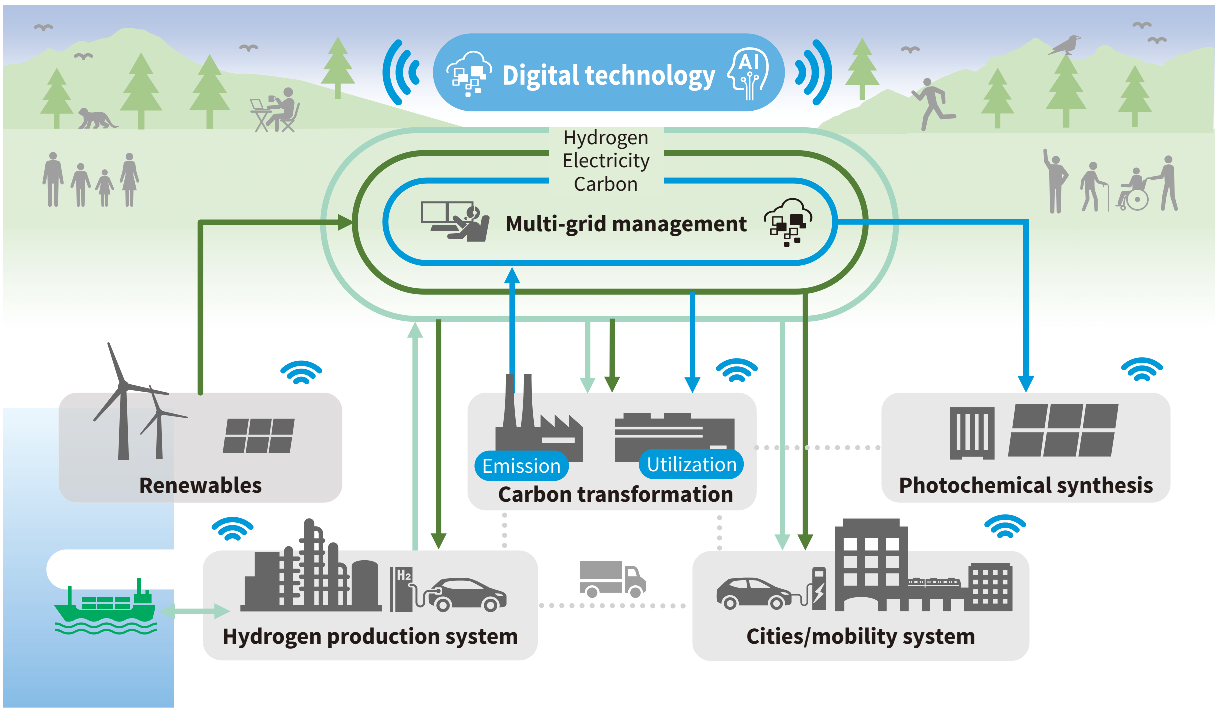
Innovation for Addressing Future Challenges



AI: artificial intelligence

1 Innovation for a carbon-neutral society

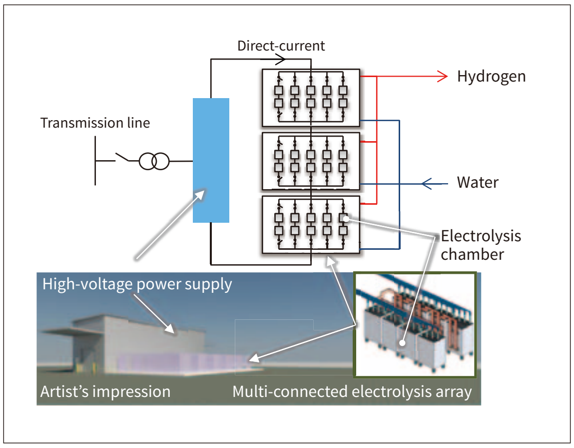
1 Innovation for a Carbon-neutral Society

Addressing wide-ranging issues to achieve prosperous societies within the planetary boundaries is an important element in Hitachi's Research & Development Group. Its research to address climate change is based on a "fore-casting" approach, which focuses on immediate societal issues and their solutions, including the electrification of mobility, the promotion of non-fossil fuels, and the use of digital transformation (DX) to improve energy efficiency. On the other hand, a "backcasting" approach is also employed to focus on a vision of a social system in 2050 to help identify potential long-term opportunity areas, including the hydrogen value chain for achieving carbon neutrality and delivering other innovations for carbon-negative systems.

One example is the multi-grid management technology: it is being developed to address the issue of temporal and spatial mismatches of supply and demand for hydrogen and other renewables, ensuring that clean energy is stable and reasonable. To address the loss of biodiversity, Hitachi also seeks to develop technologies to transform carbon dioxide (CO_2) into production materials for food, clothing, and shelter, while building an ecosystem to enable collaborations among universities, national research institutions, and startup companies.

2 High-voltage Electrolysis System for Energy Storage and Supply

The production of hydrogen using electricity derived from non-fossil renewable sources of energy such as photovoltaics, wind, and hydro has attracted attention as one way to go about the decarbonization of society. Hitachi has been working on the development of a world-first* high-voltage electrolysis technique for producing hydrogen in high volume using minimal resources and electric power. Hitachi already has technologies for insulation, electrochemical device control, and high-capacity power conversion from its past work. The objective now is to



2 High-voltage electrolysis system

reduce the size and resource requirements of large electrolysis systems by leveraging these technologies to build arrays of electrolysis stacks that can utilize high voltages and to develop high-voltage management and control techniques.

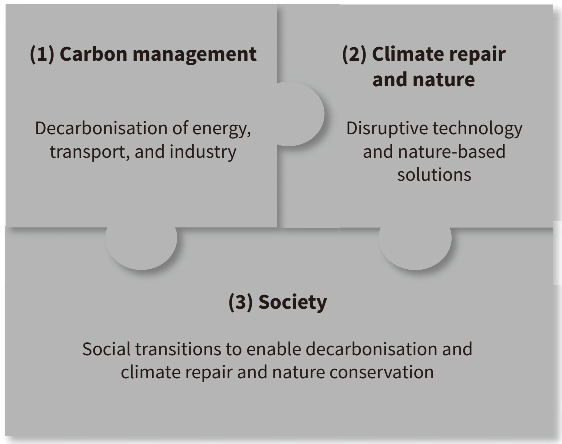
Along with plans to verify the benefits of a demonstration system that utilizes these technologies, Hitachi also intends to play its part in smoothing the transition from fossil fuels to hydrogen in Japan and elsewhere by supplying total solutions that also cover processes upstream of hydrogen production. These include developing ways of providing the necessary clean water and practices for operating these systems at sites suitable for photovoltaic, wind, or hydro power generation.

* Based on research by Hitachi, Ltd.

3 Hitachi-Imperial Centre for Decarbonisation and Natural Climate Solutions

A new research centre has been created in partnership with Imperial College London to address the largest sustainability challenges facing society today. Rapid decarbonisation is essential to avoid the worst impacts of climate change, which will require the transformation of industry sectors and lifestyles. Natural environmental systems must also be protected as they provide essential services, such as food production, clean water, and removing CO_2 from the atmosphere.

In response, the centre focuses on two key areas, decarbonisation and climate repair. Four initial research projects have initiated and will be delivered collaboratively with Hitachi colleagues in Europe and Japan. The projects will evaluate pathways for reducing CO_2 emissions, including direct air capture (DAC), optimising nature conservation, and identifying the necessary transition to be made by society.



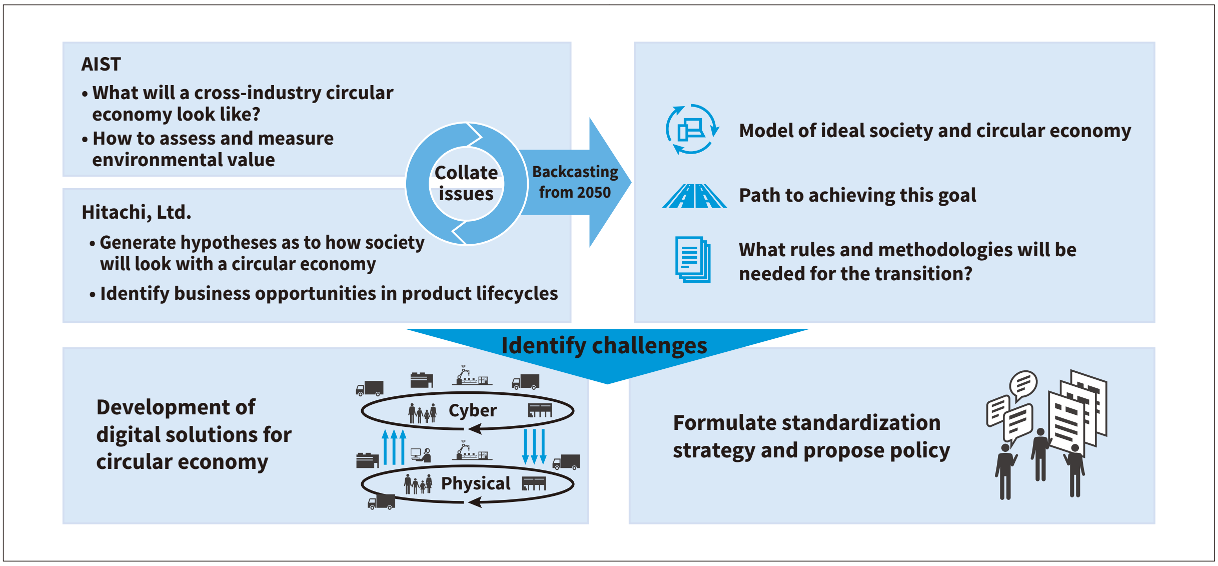
3 Projects within the centre focus on three main pillars of research

Hitachi intends to utilise the centre to build new relationships with industry, government, and academia and to ensure that Hitachi's research and development in sustainability is at the forefront of global themes to benefit society.

4 Hitachi–AIST Laboratory: Establishment of Joint Research Facility to Achieve Circular Economy

In October 2022, Hitachi, Ltd. and the National Institute of Advanced Industrial Science and Technology (AIST) jointly established the Hitachi–AIST Circular Economy Cooperative Research Laboratory at AIST Tokyo Waterfront. The laboratory will host about 40 specialists from Hitachi and AIST who will engage in joint research into what sort of society will be needed for a future circular economy that makes highly efficient use of resources across entire value chains through multiple industries. They will also study topics such as what rules should apply to this circular economy and measures for overcoming challenges.

The three-year joint research program involves drawing a grand design for a circular economy that lays out what such a society will look like, the path to reaching this goal from where we are now, and what form the rules and methodologies for making the transition will take. It will also develop digital solutions that utilize environmental and other data such as CO_2 emissions for corporate environmental reporting and for generating production schedules that have a low environmental impact. In relation to how data is collected and used, the laboratory also intends to produce policy proposals and participate in Japan's contribution to rule-making and standardization.

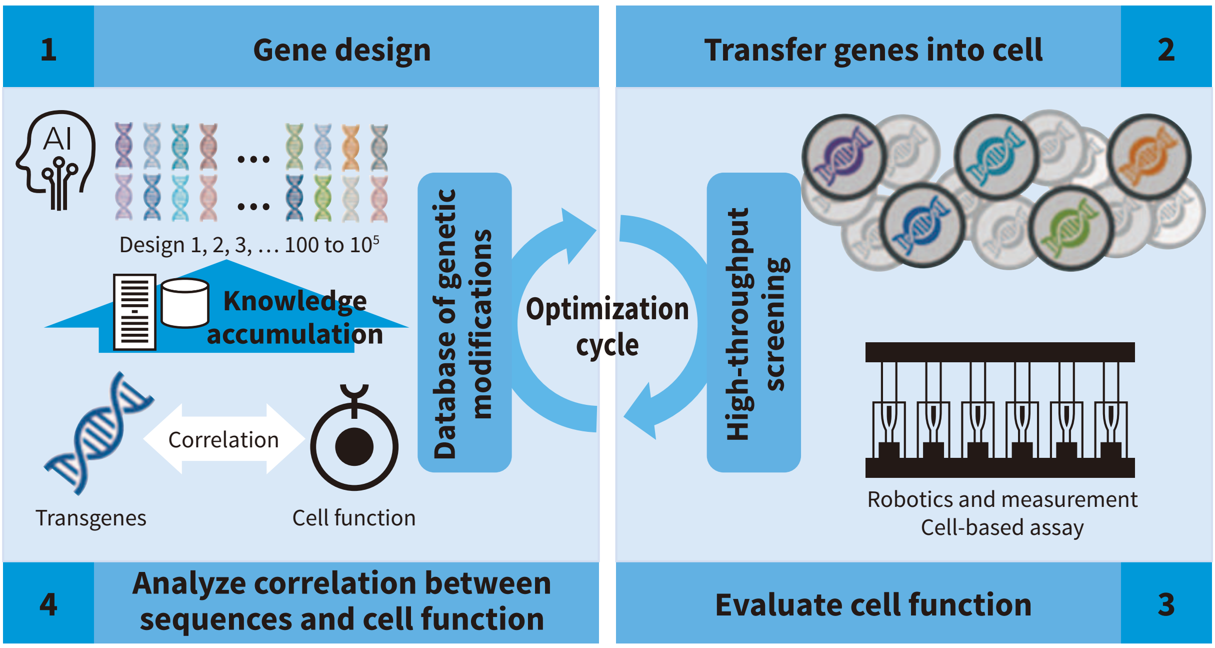


4 Formulation of a grand design for a circular economy

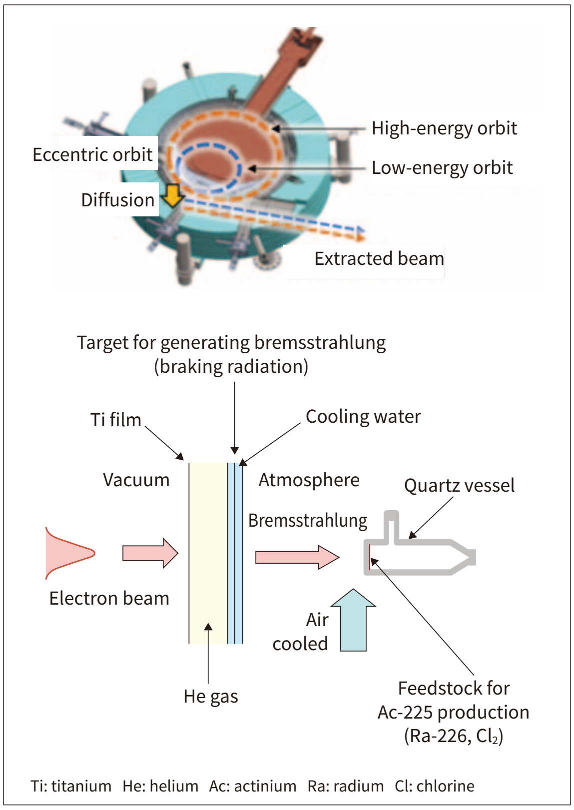
5 Designed Cell

Cell-based gene therapy, which involves the administration of genetically modified cells, is expected as a way to overcome diseases that are considered difficult or impossible to treat. One example is chimeric antigen receptor (CAR) T-cell therapy, which has already been approved for the treatment of certain cancers where it has demonstrated remarkable efficacy. With the use of genetic modification, it holds the potential to treat a wide variety of other diseases. CAR T-cell therapy has been an active topic of research and development since its initial approval in the USA in 2017. However, due to a lack of maturity in the relevant research and development practices, it cannot be said that this potential has been adequately realized yet. The work is also very costly and time-consuming.

In response, to support the research and development of CAR T-cell and other cell-based gene therapies, Hitachi has started working on a development platform for cell design that features a system for massively parallel gene design and cell function analysis. Work on the analysis of the next-generation CAR T-cell therapy conducted as part of this development was published in August 2022 in Frontiers in Immunology, an international journal.



5 Development platform for cell design



6 Diagram of new accelerator for particle beam therapy (top) and system for trial production of Ac-225 in MBq-range quantities (bottom)

6 New Accelerator for Particle Beam Therapy and Technique for Producing Actinium 225

Hitachi has developed a new accelerator that helps to reduce the burden on patients undergoing particle beam therapy and a technique for producing actinium 225 (Ac-225), an isotope used for targeted alpha-particle therapy.

Particle beam therapy is a form of radiotherapy that works by accelerating a beam of charged particles, such as protons or carbon ions, up to an energy that is chosen based on the depth of the target in the patient's body. The new accelerator currently under development works by offsetting the eccentric beam orbit toward the outlet and diffusion by high-frequency voltage to deliver a high beam current regardless of the target depth. Past work has confirmed beam extraction using an electromagnetic field distribution chosen for ease of fabrication and this is now a subject of detailed analysis to prepare it for practical deployment.

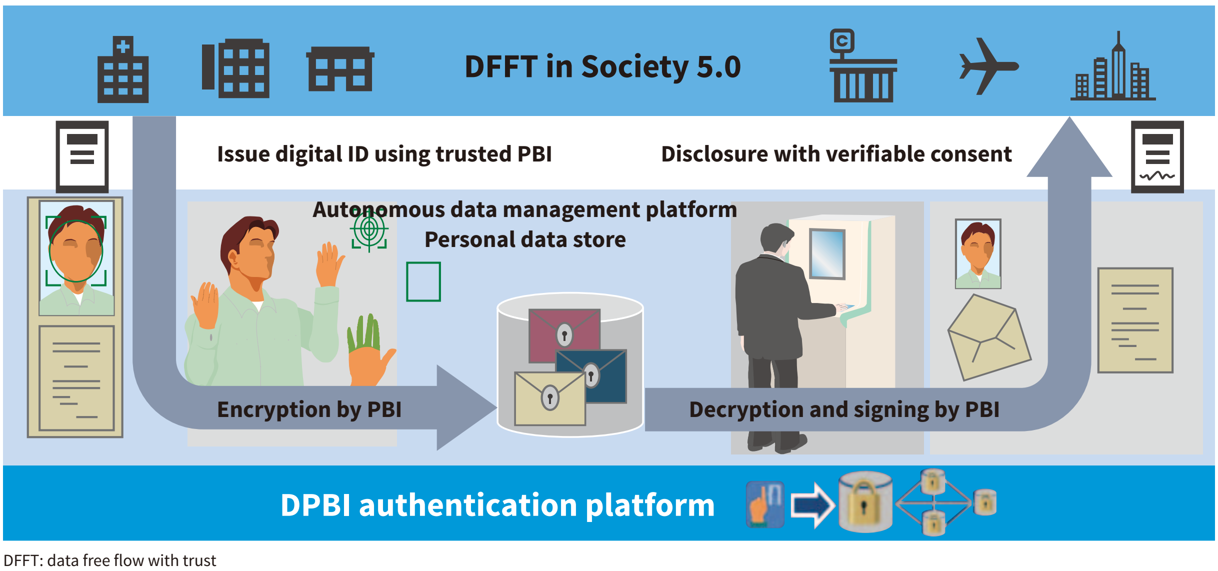
Targeted alpha-particle therapy is a new technique that attacks tumor cells from inside the body. It works by dosing the patient with a medication that is selectively taken up by tumor cells, but also contains radionuclides that emit alpha particles to destroy the cells. As Ac-225 is an effective choice of radionuclide for this therapy, Hitachi has been developing a manufacturing technique that uses an electron linear accelerator to produce this isotope with high levels of quality and efficiency. Working in partnership with Tohoku University and Kyoto University, the new technique was successfully used to produce Ac-225 in quantities measured in the MBq-range, a world-first*.

Future plans include detailed system studies aimed at high volume production and evaluation of its suitability for use as a medication.

* Based on research by Hitachi, Ltd.

7 DPBI Digital Identity Platform for Web3

While advances in the web have made the Internet an essential part of people's daily lives, the rising dominance



DFFT: data free flow with trust

7 Concept behind digital identity platform for Web3 of a small number of large platforms has come to be seen as a problem. While the sort of decentralized services that have come to be known as Web3, such as the trading of non-fungible tokens (NFTs) and crypto assets, have attracted a lot of attention over recent years, security issues (such as fraud and hacking) that arise from the lack of a central authority have also emerged.

With a view to the full-scale deployment of Web3, Hitachi has been working on the development of a digital identity platform that improves privacy and convenience while at the same time preventing fraud and hacking and helps to ensure the authenticity of NFT creation in the trading of NFTs and crypto assets. The core technology is a decentralized public biometric infrastructure (DPBI) for the generation of encryption keys from biometric information and the distributed management of authentication and identifiers (IDs). By linking the cyberspace presence of individuals or organizations to their real-world selves, the DPBI enables the delivery of Web3 services that can be used with confidence.

8 Silicon Quantum Computing

Quantum computers are recognized as a new computing paradigm that can solve problems that are intractable using conventional computers. As they unfortunately still lack the number of qubits (the basic building block of a quantum computer) required to solve meaningful real-world problems, the challenge for the future is to find ways of combining qubits numbering in the millions.

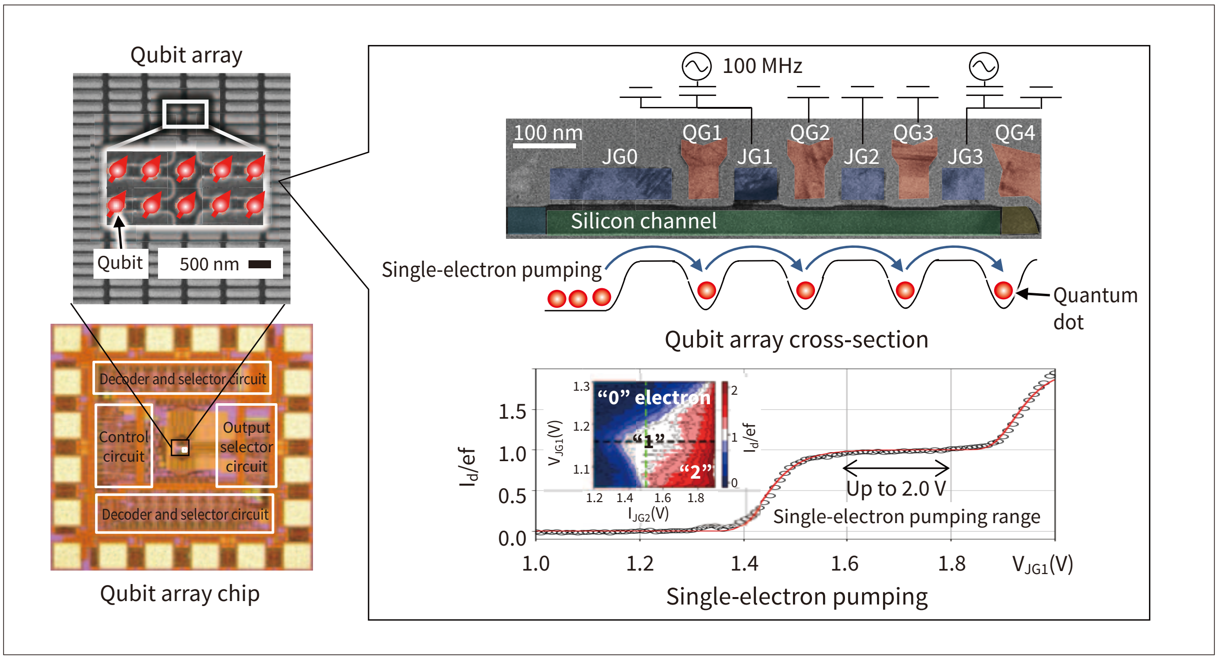
To this end, Hitachi has leveraged silicon integration in the development of a silicon quantum computer. To perform quantum computation, this requires the delivery ("pumping") of electrons into an array of qubits fabricated using large-scale integration to create quantum dots (the physical manifestation of a "particle in a box," the particle being an electron) and initialize their state. To achieve this, Hitachi has worked with the Tokyo Institute of Technology to develop a precise, high-speed single-electron pumping technique that can supply electrons individually to each quantum dot in the qubit array at a rate of 100 MHz. This is an important development required for the scaling of large arrays.

Future plans include establishing a way to initialize the entire qubit array and test quantum operations. The ongoing work on large-scale integration was recognized by an SSDM* Paper Award that was presented at the 2022 conference.

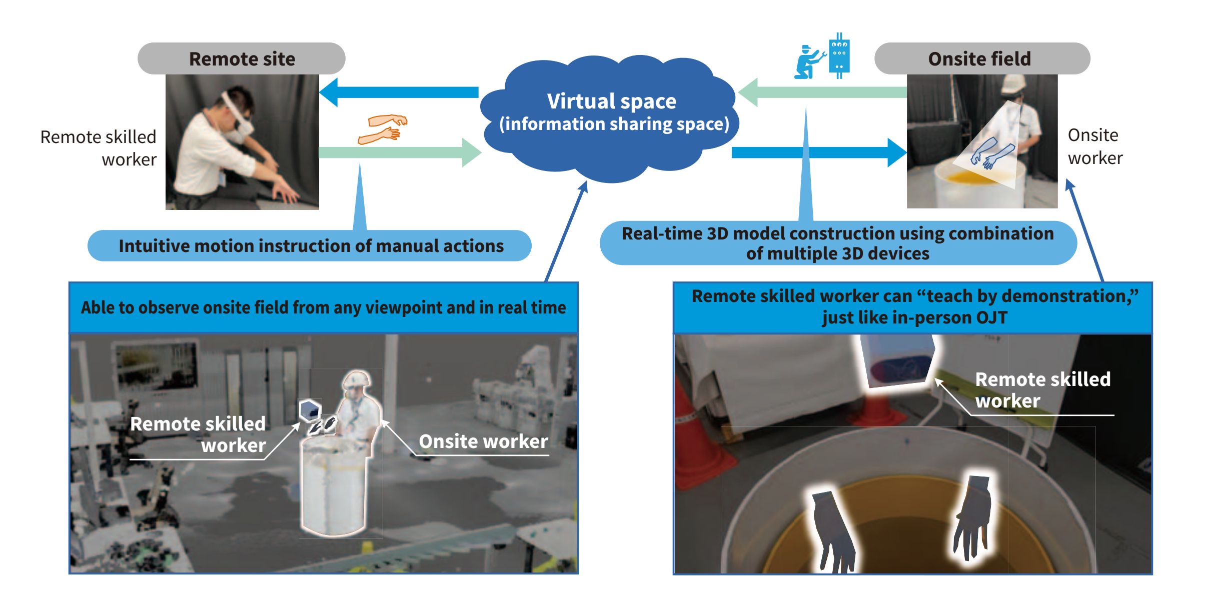
As it works to expedite the practical deployment of quantum computers, Hitachi has participated in open innovation, including involvement in the Moonshot Research & Development Program of the Japan Science and Technology Agency (JST), and collaboration with the Hitachi Cambridge Laboratory to develop not only quantum computing systems, but also quantum algorithms and error correction systems.

This work was funded by grant number JPMJMS2065 of the JST Moonshot Research & Development Program.

* International Conference on Solid State Devices and Materials



8 Precise, high-speed single-electron pumping technique using qubit array



9 Overview of prototype telepresence work support system

9 Telepresence Work Support

Labor saving in onsite field work is one way to improve the productivity of the field work and overcome shortages of skilled workers. To make this possible, Hitachi has developed a way to support remote work that allows remote skilled workers to observe a work field from any viewpoint in real time through a virtual space that replicates the work field, and to use hand motions to show onsite workers how to perform onsite tasks that would be difficult to explain verbally.

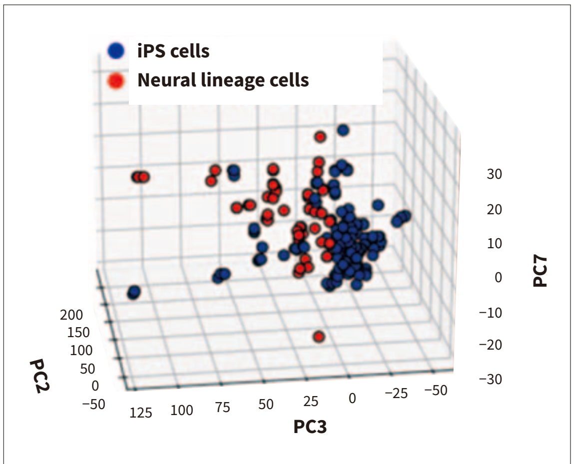
This combines three-dimensional sensing with technologies for virtual reality (VR) and augmented reality (AR) to replicate the work field in virtual space and in real time, allowing someone at a remote site to observe it from any viewpoint using VR goggles. The system can also provide virtual demonstrations of how to perform workplace tasks without the instructor being physically present. This is done by capturing the instructor's hand motions and having an avatar replicate them to the onsite worker wearing AR glasses.

With the metaverse expected to become more commonplace in the future, Hitachi is also looking to deploy the above technology in solutions that use this new medium. This will form part of its efforts to further improve the productivity of field work and address the shortage of skilled workers.

10 Hitachi Kobe Laboratory: Regenerative Medicine

Hitachi launched its ACC-200, automated cell culture equipment for commercial cell manufacturing in 2019 to help make regenerative medicine more widely available by producing the required cells with more reliable quality and lower production costs. The ACC-200 was supplied to a plant for cell therapies operated by Sumitomo Pharma Co., Ltd. and its first clinical application was in investigator-initiated clinical trials conducted by Kyoto University on the transplantation of neural lineage cells differentiated from induced pluripotent stem (iPS) cells to treat Parkinson's disease.

To ensure more reliable cell production, Hitachi has been developing a technique for the non-invasive



10 Plot of principal component of Raman signal due to extracellular vesicles in culture supernatant monitoring of cells during culturing based on cell morphology and culture supernatant constituents. In particular, by looking at the extracellular vesicles secreted by cells into the culture supernatant, it was found that the expression of micro ribonucleic acid (miRNA) and proteins included in extracellular vesicles was indicative of cell quality*. In addition, Hitachi investigated the application of Raman spectroscopy for real-time evaluation of extracellular vesicles during cell culturing. As a result, it was found that iPS cells and neural lineage cells differentiated from iPS cells could be distinguished based on Raman signal patterns derived from each vesicle. This demonstrated the possibility for non-invasive monitoring of cell differentiation states during culturing.

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

* H. Saito et al., Journal of Bioscience and Bioengineering, 132, 381–389, 2021, the 30th Excellent Paper Award of the Society for Biotechnology, Japan

11 Hitachi-UTokyo Laboratory: Policy Proposal and Hosting of Open Forum

Policy development work at Hitachi-UTokyo Laboratory aimed at realizing Society 5.0 has included the publication of a policy proposal and the hosting of an open forum.

The Habitat Innovation Project has presented methodologies for the sustainability of people-centric smart cities to the Cabinet Office. Hitachi-UTokyo Laboratory has also hosted its third Habitat Innovation Forum entitled, "Creating People-centric Super-smart City—Five Key Factors for Sustainable Smart City" where a consensus on the gist of the proposal was forged through discussion between relevant stakeholders from industry, academia, and government.

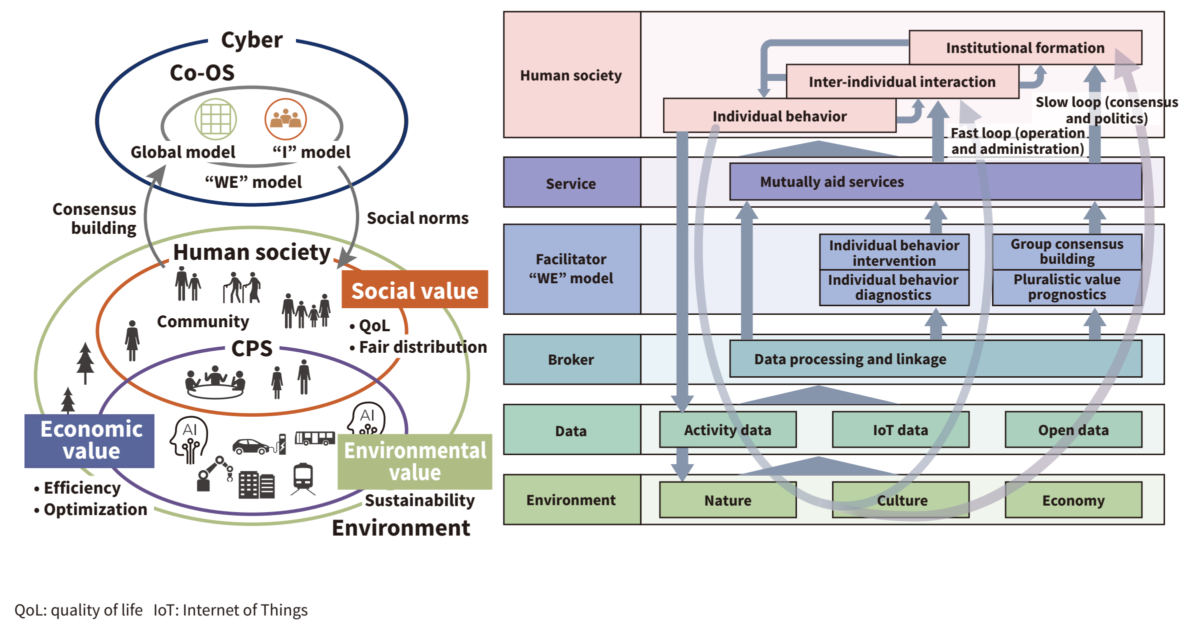
With its Energy Project, meanwhile, Hitachi-UTokyo Laboratory has hosted the fourth Industry-Academia Collaboration Forum, "Toward Realizing Energy Systems to Support Society 5.0—Achieving a Sustainable Carbon-neutral Society in Terms of Universal Participation." Along with a deep dive into the use of backcasting to validate society and its policies and systems, this also involved the publication of a fourth version of their energy proposal.

Following on from summing up the phase 2 activities that will finish at the end of FY2022, work will next start on the new phase 3 initiatives planned for FY2023 onwards.

12 Hitachi Kyoto University Laboratory: Cyber-Human Social Co-Operating System

Along with debate about what is meant by a super-smart society (Society 5.0) that is based on human values and made possible by cyber-physical systems (CPSs),

11 Habitat Innovation Forum (held online) (left) and cover of energy proposal (version 4) (right)



12 CHSS concept and Social Co-OS architecture

technology is also being developed for the "wellbeing society" (as described in the book "Beyond Smart Life" from Nikkei Business Publications) that lies beyond that, one that cannot be achieved by smart technologies alone.

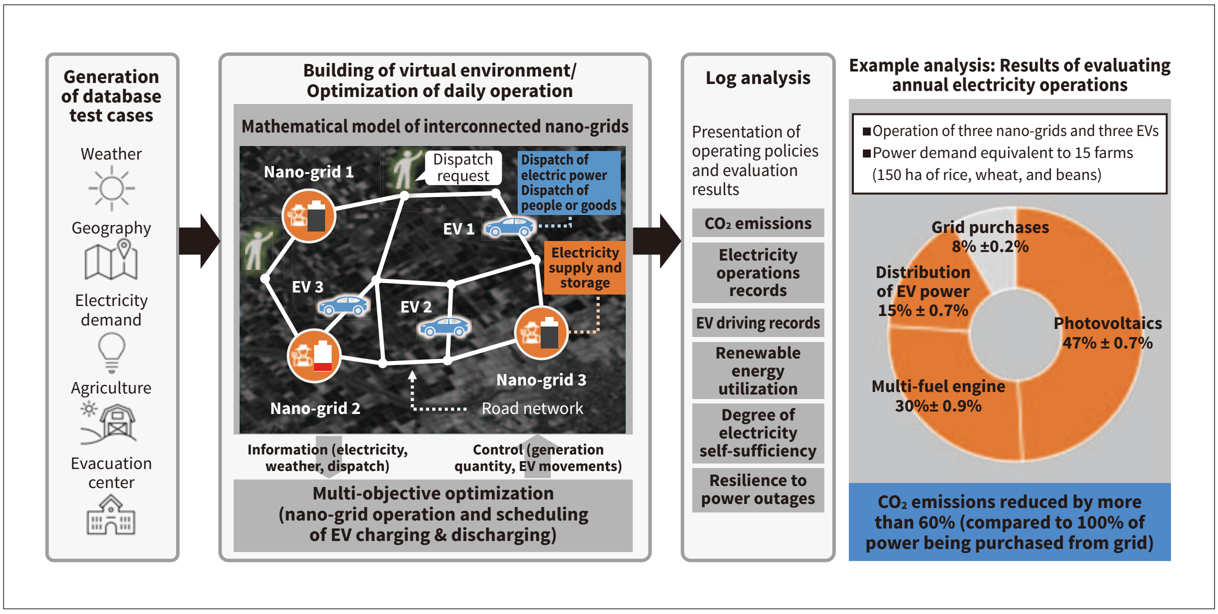
In pursuit of a "mixed-life society" that combines individual freedom and collective solidarity across diverse people, Hitachi Kyoto University Laboratory has proposed the new concept of a cyber-human social system (CHSS) that incorporates constructions from human society into CPSs to support prosocial behavior by individuals and consensus building among groups. To accompany this, it has also developed the cyber-human social co-operating system (Social Co-OS) as an architecture for putting this concept into practice. In the Social Co-OS, the cyber system and human society cooperate through a fast loop (operation and administration) consisting of individual behavioral diagnostics and intervention, and a slow loop (consensus and politics) consisting of pluralistic value prognostics and consensus building for groups.

In the future, there will be an expectation for contribution in the establishment and trouble-free operation of mutual aid communities and platform cooperatives. Accordingly, the laboratory will be partnering with Kyoto University in two national projects from FY2022, the Japan Society for the Promotion of Science's (JSPS) Topic-Setting Program to Advance Cutting-Edge Humanities and Social Sciences Research, and the Japan Science and Technology Agency's (JST) Responsible Innovation with Conscience and Agility (RInCA) program for addressing ethical, legal, and social implications/issues (ELSI).

Details of this work have been published in the September 2022 edition of IET Cyber-Physical Systems: Theory & Applications, an international academic journal.

13 Hitachi Hokkaido University Laboratory: Support Model for Low-carbon Agriculture Using Locally Sourced Energy

Hitachi Hokkaido University Laboratory has been developing a self-sustaining local energy system with the aim of setting up an electric power system that can supply locally sourced low-carbon electric power and maintain electricity supplies during disasters. The system is made up of small self-sustaining nano-grids providing electricity services that would not be possible on a single grid. It has the ability to distribute power from sources such as electric vehicles (EVs) between these nano-grids so as to avoid over- or under-supply while also using excess power for the transportation of people and goods. To facilitate system implementation, the laboratory has also developed a self-sustaining local energy system simulator that can optimize multiple objectives covering the operation of electricity and transportation services on the basis of local needs and circumstances while also allowing for the uncertainties of the weather and demand for those services. When the simulation was run for agricultural activities in Iwamizawa City, the results indicated that



13 Structure of self-sustaining local energy system simulator and example analysis

the system could reduce CO_2 emissions by more than 60% compared to sourcing electricity from the grid.

The aim for the future is to leverage collaboration between industry, academia, government, and communities to establish local industry models with a low environmental footprint that utilize locally sourced energy, and to provide communities with safe and secure foundations for their way of life.