Value-based Innovation: Environment

Hitachi was the first Japanese company to be appointed a Principal Partner for the 26th United Nations Climate Change Conference of the Parties (COP26) held in November 2021 in Glasgow, UK. With climate change posing a challenge for all of humanity, Hitachi intends to use its capabilities for innovation to help societies decarbonize and achieve a more sustainable future. Four key initiatives are needed to achieve decarbonization, namely for society as a whole to move to electrification and electric transportation together with the large-scale adoption of renewable energy, and for energy efficiency and resource recycling to be adopted across entire product life cycles. In pursuit of these initiatives, Hitachi is working on research and development in fields such as power electronics that enable innovation in the charging and driving of EVs, energy management for the reliable supply of electric power in distributed grids, the energy-efficient control of mobility using digital technology, and process optimization and condition monitoring to accelerate the recycling of plastics and batteries.

1 Large-capacity, Space-efficient Multiport Charging to Boost Uptake of EVs

Along with making electric vehicle (EV) charging systems smaller and lighter, Hitachi has developed more flexible ways of adjusting charging capacity and the number of charging ports. It has also produced a prototype 350-kW multiport EV charging system.

To reduce the size of the bulky transformer, Hitachi utilized silicon carbide (SiC) power electronics to develop a solid-state transformer (SST) with an operating frequency increased to 50 kHz. This achieved world-leading small size and light weight (as of October 2021, based on research by Hitachi, Ltd.), with a reduction of approximately 40% in installation footprint and 70% in weight.

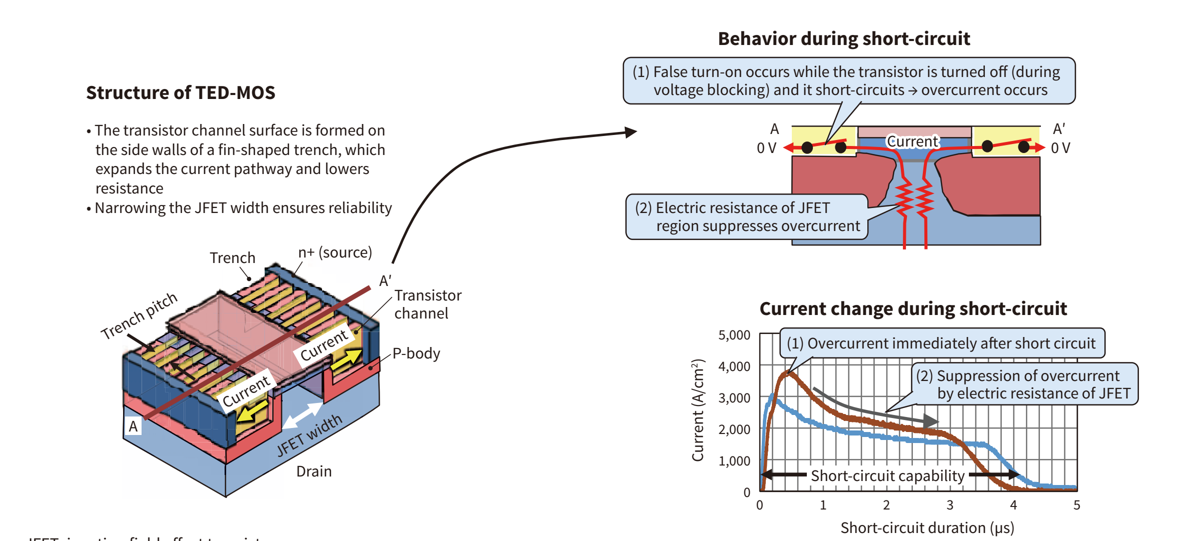
A multi-level circuit was also developed that divides the 6.6-kV input voltage by arranging the power conversion units fitted with SST into blocks of seven connected in series. The charging system has three of these blocks for a total of 21 power conversion units, with output controlled by a switch that provides the flexibility to adjust the charging capacity and number of ports as required to meet user needs. When configured as 50-kW fast chargers, for example, the system can charge seven EVs at a time. Alternatively, the switch can also configure the system as a 350-kW ultra-fast charger for the rapid charging of an EV equipped with the large-capacity batteries that will likely become more common in the future.

1 New 350-kW multiport EV charging system

2 Design Technique for SiC TED-MOS Power Devices that Help Achieve Decarbonization

A trench-etched, double-diffused, metal-oxide semiconductor (TED-MOS) is an SiC power device that was developed and further enhanced by Hitachi to help achieve decarbonization. Hitachi has now established a design technique for these devices that takes advantage of their structural characteristics.

While SiC power devices offer better energy efficiency than their silicon predecessors, they have issues with short-circuit capability (a reliability parameter). This calls for improvements to the associated trade-off between power saving and reliability. In response, a detailed analysis of how much different device parameters influence short-circuit capability and modeling of the short-circuit failure mechanism have led Hitachi to devise a way to design the devices for improved durability. Device prototyping, meanwhile,



JFET: junction field effect transistor

2 Structure of TED-MOS and physical model for short-circuit characteristics

has verified that the tradeoff can be overcome through the optimization of trench dimensions, one of the structural features of TED-MOS devices.

By utilizing this technique to supply power devices that suit diverse customer applications, Hitachi plans to contribute to decarbonization through lower power consumption in social infrastructure products and reduced carbon dioxide (CO_2) emissions.

3 In-wheel Direct EV Drive System

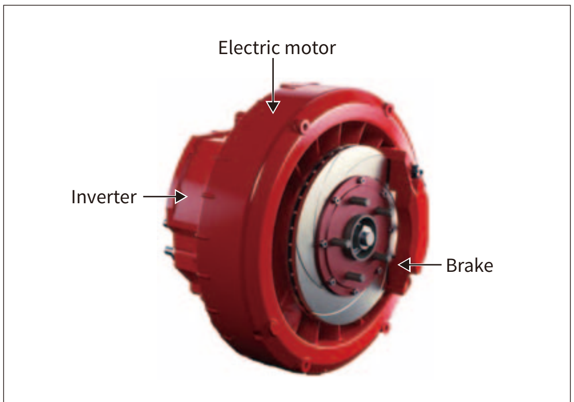
For EVs, which are becoming widespread toward the realization of a decarbonized society, larger vehicle cabins and wider battery space are needed in order to provide further comfort and range. An in-wheel type EV with motors mounted inside its wheels is widely known as a technology to solve these issues. However, an increase of the wheel weight and modification of brakes and existing parts become technical issues.

Therefore, Hitachi has developed a small and lightweight direct-drive[*1] system that integrates a motor, an inverter, and a brake. This system exploits the company's technologies in railway and elevator applications.

In terms of the motor technology, Halbach-array[*2] magnets enhance the driving force by increasing the effective flux at each pole, and the high-density layout of the flat coils realizes a lighter weight. The inverter technology improves the plumbing space by being integrated into the motor, with direct cooling of the power semiconductor by dielectric oil. With these original technologies, the developed drive system has realized world-class power density and significant weight reduction. And, it also can be mounted inside wheels without major modifications to the suspension.

In the future, based on the developed direct-drive system and the vehicle control technology, Hitachi aspires to globally expand EV products with a wider lineup.

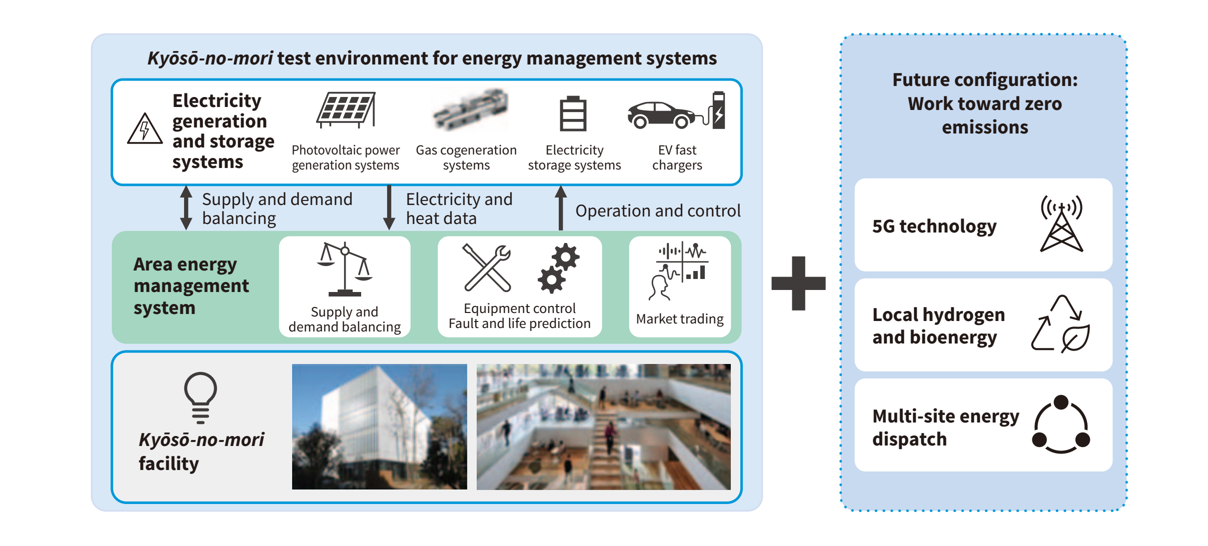
*1 The driving force of an electric motor is directly coupled to the wheel.
*2 By rotating the north pole of magnets by 90°, a high magnetic flux density is generated in each pole of the motor.



3 Direct-drive system

4 *Kyōsō-no-mori*: Co-creation Environment for Working with Customers on Energy Management Systems for Distributed Grids

At its *Kyōsō-no-mori* research and development facility in Kokubunji, Tokyo, Hitachi has established a test environment for energy management systems targeting a wide range of industries where energy-consuming equipment is found, including commercial or residential areas, factories, buildings, and data centers.



4 *Kyōsō-no-mori*: Test environment for energy management systems

The test environment has three key features, each of which was developed by the Hitachi's Research & Development Group.

(1) Control techniques for electricity generation systems that utilize semiconductor technology and can predict faults and equipment life quickly and with high precision

(2) Control algorithms for precise matching of energy supply and demand and resolving imbalances in electric power supply

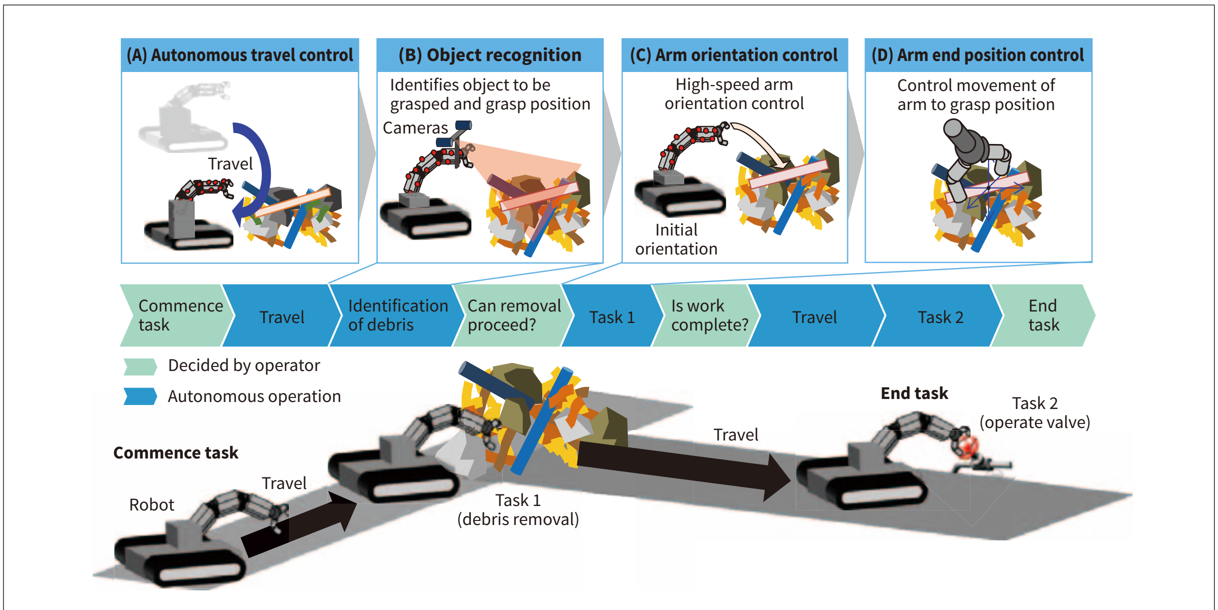
(3) Systems for trading energy and environmental value using artificial intelligence (AI)

For customers seeking to achieve zero emissions and the reliable, efficient, and economic operation of renewable energy, the test environment provides the facilities needed for testing, including the flexibility to combine different equipment and systems as needed.

In the future, Hitachi intends to further develop the test environment to work with customers on the co-creation of new energy solutions and the achievement of zero emissions, including local hydrogen and biotech, fifth-generation (5G) telecommunications, and energy dispatch technologies for coordinating across multiple sites.

5 Autonomous Control of Work Robot for Fukushima Daiichi Nuclear Power Plant Decommissioning

Hitachi has developed autonomous control that supports the sequence of processes whereby remotely operated robots used for decommissioning travel to their work area and undertake their designated tasks, the aim being to complete



5 Block diagram of autonomous control of remotely operated robot

Research & Development　Value-based Innovation: Environment work more quickly by reducing operator workloads.

This combines a travel control technique that enables the crawler to travel along an assigned route based on robot location estimates, learning-based recognition for identifying objects involved in the work and their relative position using images from robot-mounted cameras, learning-based orientation control that rapidly positions the robot arm next to target objects, and arm position control for positioning the end of the arm relative to the target object based on the object's position relative to the robot. The operator only needs to start and stop robot operation and decide whether particular tasks need to be performed.

The autonomous control was implemented on the prototype of a hydraulically driven robot being considered for use in decommissioning and trialed on the sort of debris removal work that would be required in practice. A comparison of the time taken to perform tasks autonomously and by an operator using manual operation found that use of the new control method could shorten work times by 30%.
(Hitachi-GE Nuclear Energy, Ltd.)

6 Energy-saving Driver Advisory System for Trains

As a solution for achieving both punctuality and energy savings in railway operations, Hitachi has developed a driver advisory system (DAS) that provides advice based on the operational status of the train.

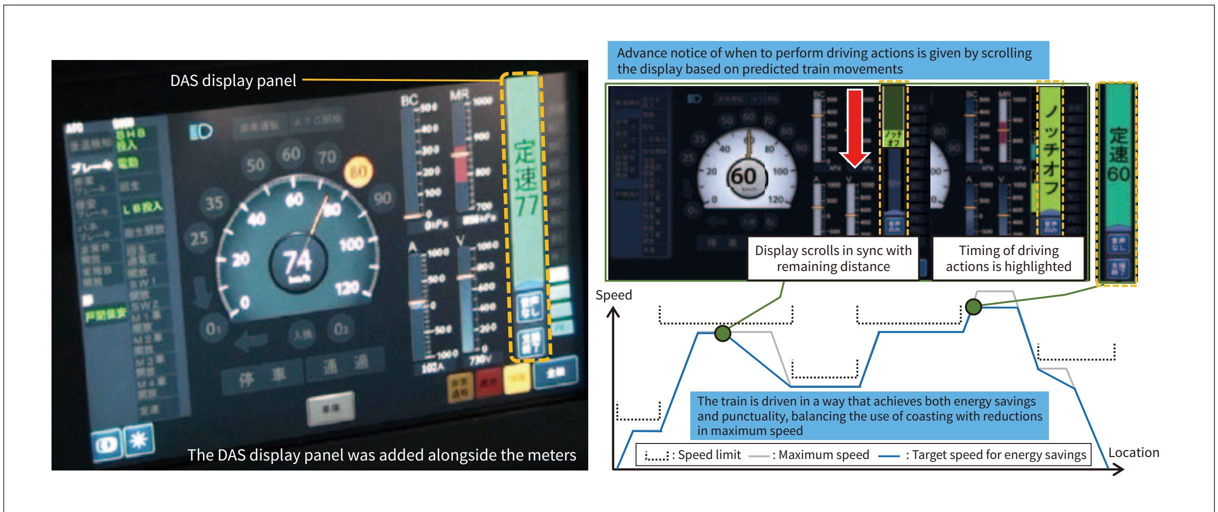
The DAS runs on the existing onboard hardware, forming part of the train control and monitoring system (TCMS), using train position, speed, and target travel time to generate advice on how to drive in a way that saves energy while keeping the train on time. The recommended actions and when to perform them are displayed on the driver's screen and provided in the form of audible notifications. In operational testing, following the advice of the DAS reduced power consumption by more than 10%.

The new DAS commenced operation in the 10000 series rolling stock of Tokyo Monorail Co., Ltd. in July 2021 where it is collecting data under actual operating conditions. By taking advantage of its features, which include major energy saving gains achieved at low cost, requiring only a software upgrade to the existing system, the DAS will help the railway industry reduce its load on the environment.

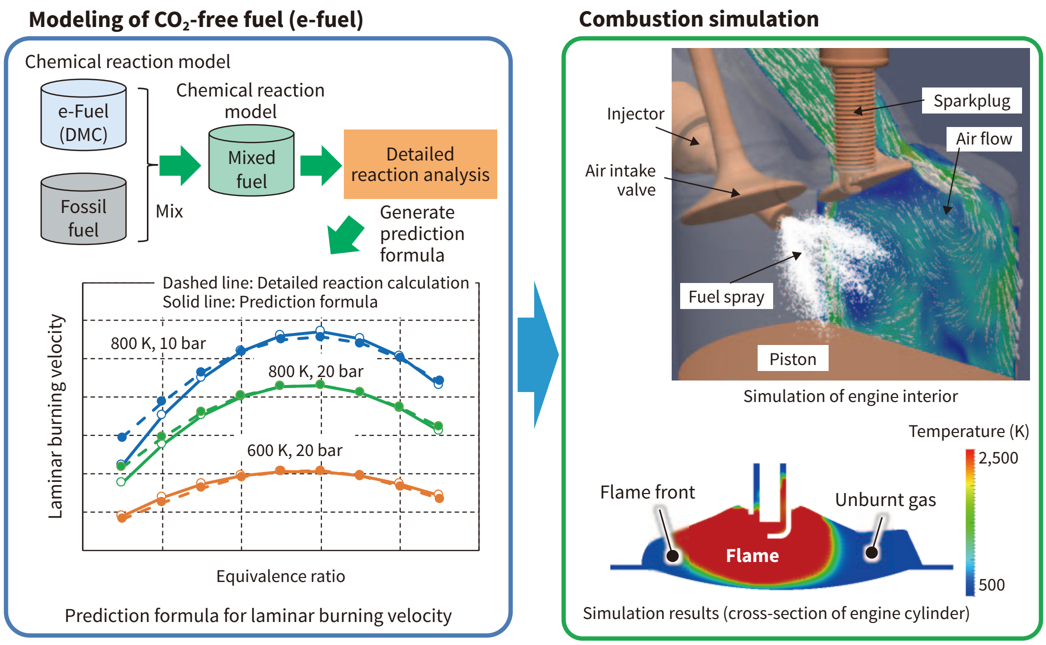
7 Combustion Simulation of CO_2-free Fuels to Help Achieve Decarbonization

With various countries and regions having set significant reduction targets for the CO_2 emitted from vehicle engines, this has prompted investigations into the use of new synthetic e-fuels. These are carbon neutral fuels synthesized using electricity derived from renewable sources. As they use CO_2 from the atmosphere or industrial emissions as a feedstock, this offsets the CO_2 produced during combustion. By mixing with existing fuels, they have the potential to achieve significant CO_2 emission reductions.

E-fuels' properties are different from existing fuels, however, making it necessary to understand what effect these differences have if they are to be used in engines and other existing combustion systems. Moreover, as numerical analysis can provide a view of those phenomena that are not amenable to experimental study, this provides a way to identify efficient combustion systems, control methods, and operating practices. Accordingly, Hitachi has developed a technique for e-fuel combustion analysis.



6 DAS display on driver's screen of Tokyo Monorail 10000 series (left) and example advice provided by the system (right)



DMC: dimethyl carbonate

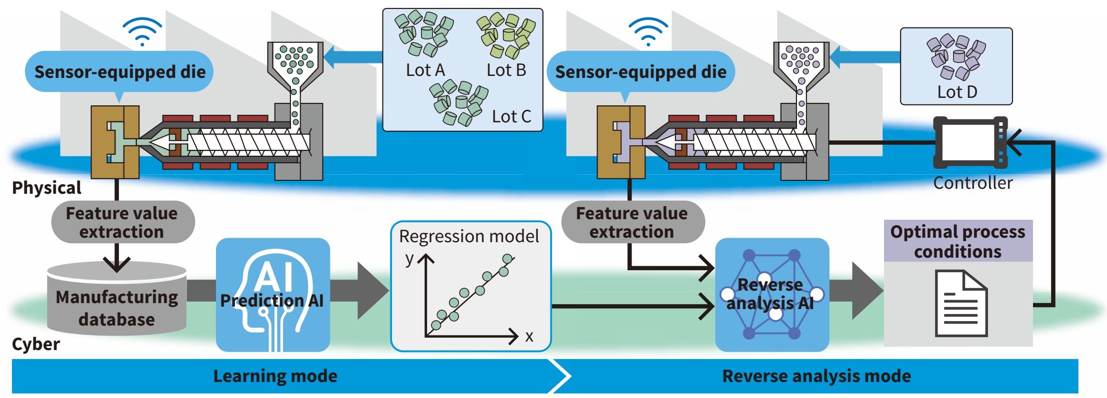
7 Fuel modeling and simulation results

This involves elucidating the e-fuel chemical reactions and using the results to develop prediction formulae for the rate of e-fuel combustion in the combustion chamber that incorporate functions for temperature, pressure, and equivalence ratio (an indicator of the concentration of fuel in the fuel-air mixture). This provides a rapid and accurate way to predict the rate of e-fuel combustion in the combustion chamber. The model was implemented on a combustion analysis platform developed by Hitachi to enable the numerical analysis of e-fuel combustion in the combustion chamber. In the future, Hitachi intends to use this technique to assist with the development of combustion systems that burn alternative fuels as well as the associated control.

8 Process Optimization AI to Accelerate Plastic Recycling

Making the most of limited resources is an urgent task for society if it is to achieve sustainability. In particular, there is a strong need for the recycling of plastic given that it has a large impact on ecosystems and is derived from finite oil resources. Being manufactured from collected waste, recycled materials tend to suffer from considerable lot-to-lot variability in material properties, such that achieving reliable product quality is one of the challenges posed by recycling.

In response, Hitachi has developed an AI that can automatically determine the optimal process conditions for achieving reliable quality. It uses a sensor located inside the



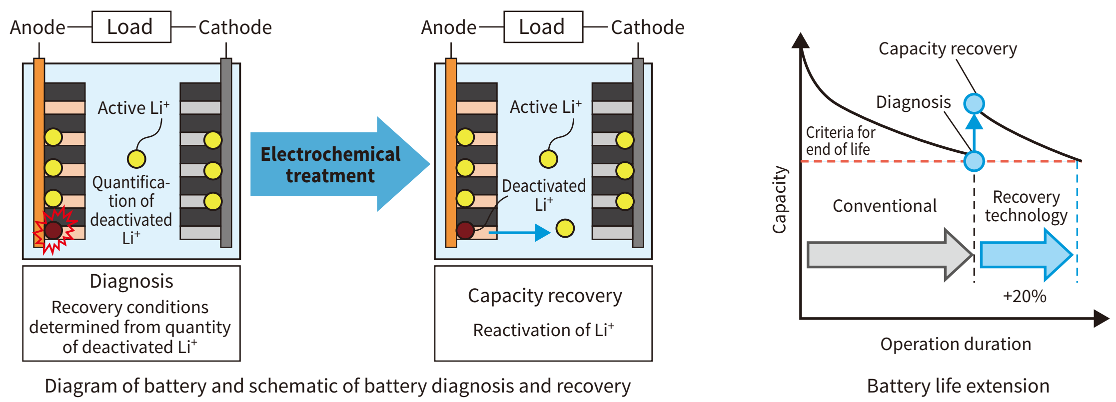
8 Block diagram of process optimization AI die and works by identifying feature values that represent variations in material properties. The core AI is made up of a learning mode and reverse analysis mode. The former generates a regression model that predicts quality from the feature values and forming conditions, while the latter determines optimal process conditions using the regression model and the feature values for the current lot. Use of the AI reduces lot-to-lot weight variability in plastic products formed from recycled material by 70%. Future plans include creating solutions for ensuring reliable quality that make use of the AI.

9 Non-destructive Diagnosis and Capacity Recovery Technology for Lithium-ion Batteries

Growth in the use of energy storage systems based on lithium-ion batteries (LiBs) is being driven by the electrification of mobility and greater use of renewable energy as a major source of electric power. While replacement of the batteries in these systems becomes necessary once the degradation that occurs over their operating life results in inadequate system capacity, the installation of new batteries brings increased CO_2 emissions due to the associated increase in resource usage and energy consumption.

To reduce this burden on the environment, Hitachi has developed technologies for extending LiB life cycles by means of non-destructive diagnosis and capacity recovery. The non-destructive assessment of battery condition is done using battery operation data, while the parameters for the electrochemical treatment used to restore battery capacity are determined using a proprietary analysis process. This enables reactivation of the lithium (Li) ions in the battery that have become deactivated, without any damage to the battery materials. When used on LiBs with a graphite anode and a cathode made of Li, nickel (Ni), cobalt (Co), and manganese (Mn) oxides, and degradation to 80% of their initial capacity, the diagnosis and recovery process succeeded in recovering some of this capacity and extended battery life by 20%.

By extending the operating life of energy storage systems, reducing maintenance costs, and enhancing the value of used LiBs, this new technology will help enhance the performance of businesses such as electricity transmission and distribution companies or electric mobility operators and thereby achieve a decarbonized society.



9 Non-destructive diagnosis and capacity recovery for lithium-ion batteries