Technology Development of Energy Management System Beneficial for Carbon Neutral Era

YUSUKE ISOBE[*1] **MASAYUKI MORIHARA**[*2]

MASAYUKI HASHIMOTO[*3] **TAKEHIRO NAKA**[*3]

MASATO MITSUHASHI[*3] **YU KOBAYASHI**[*4]

In order to achieve carbon neutrality, the environment surrounding energy demand and supply management in the industrial field has been changing dramatically. Mitsubishi Heavy Industries, Ltd. (MHI) has developed an energy management technology that could serve as a means to achieve carbon neutrality, and has constructed a system that places the cost incurred during the life cycle of each piece of equipment at the center of control from the unique perspective of an equipment manufacturer. We installed a photovoltaic power generation system and a battery energy storage system, which are decarbonized power sources, in our plant, and are currently validating the functions required for on-site power generation and off-site power generation for self-consignment. We will continue to enhance functions including the control of cooling and heating equipment while validating the technology we have developed, thus providing carbon-neutral solutions to our customers.

1. Introduction

In October 2020, the Japanese government set a goal of achieving a decarbonized society and virtually zero greenhouse gas emissions by 2050, and MHI Group has declared the goal of carbon neutrality by 2040. In the industrial field as well, carbon neutrality or decarbonization is an urgent long-term strategic theme, and we aim to contribute to the achievement of carbon neutrality through the early establishment of decarbonization technologies and the social implementation of these technologies, and products and services based on them.

Against this background, many energy consumers in the industrial field require proposals of actual carbon neutrality measures and of solutions in line with their energy usage conditions. In particular, there are many cases of introducing decarbonized power sources such as photovoltaic power generation equipment for the purpose of self-consumption as a "real solution" to carbon neutrality. However, photovoltaic power generation and other variable power sources are subject to changes in their power generation depending on weather conditions, and the amount of electricity they generate needs to be suppressed to meet the demand characteristics in some cases. Thus, it is difficult to say that the adoption of such variable power sources is taking full advantage of the benefits of decarbonizing power sources.

Therefore, we developed a unique-to-equipment manufacturer carbon-neutral energy management technology that takes into account the component characteristics and life cycle costs of distributed resources such as photovoltaic power generation equipment and battery energy storage system that absorbs fluctuations. We have actually installed photovoltaic power generation and battery energy storage system in the Yokohama Hardtech Hub (YHH), a co-creation space in the Honmoku Plant of MHI Yokohama Dockyard & Machinery Works, to validate the functionality

*1 Deputy General Manager, Carbon Neutral Strategy Office, Business Intelligence & Innovation Department, Mitsubishi Heavy Industries, Ltd.

*2 General Manager, Carbon Neutral Strategy Office, Business Intelligence & Innovation Department, Mitsubishi Heavy Industries, Ltd.

*3 Research Manager, Power Electronics Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.

*4 Chief Staff Researcher, Power Electronics Research Department, Research & Innovation Center, Mitsubishi Heavy Industries, Ltd.

of this technology. We have also started validation tests using actual equipment to predict the return on investment based on the life-cycle costs of the equipment, and to establish the control of the components and the operation of the equipment based on the monitoring results. We are planning to confirm the effectiveness of the developed functions through a long-term demonstration test in fiscal 2022.

2. Concept of carbon-neutral energy management and value provided thereby

With an eye toward achieving carbon neutrality, our concept of energy management by energy consumers in the industrial field, such as factories, and the value provided to customers created by the use of our energy management technology are as described in the following sections.

2.1 Concept of carbon-neutral energy management

For energy consumers, when their goal is to achieve carbon neutrality in the wide variety of energy they use, the suitable management of the equipment for energy supply and demand is one of the effective ways to achieve the goal, and this is the essence of energy management.

We have defined this energy management for the purpose of carbon neutrality as "carbon-neutral energy management", the concept of which consists of the following three elements to support the energy consumers' PDCA (Plan-Do-Check-Action) cycle to achieve carbon neutrality as shown in **Figure 1**.

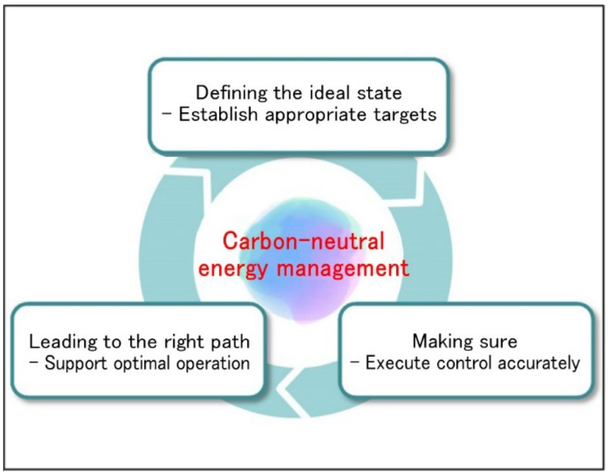

Figure 1 Concept of carbon-neutral energy management

(1) Defining the ideal state - Establish appropriate targets

Set the ideal state that is expected to be able to operate efficiently at that point in time, according to the conditions for both decarbonization and economic efficiency set by the equipment managers and operators.

(2) Making sure – Execute control accurately

Establish an operation plan according to the characteristics of the supply and demand equipment to be controlled so as to achieve the target defined in (1) above, and execute the control according to the plan. This operation plan and control execution reflect our knowledge of energy equipment as an equipment manufacturer.

(3) Leading to the right path - Support optimal operation

Visualize the discrepancy between the operation plan and control execution described in (2), and present the operator with a means of correcting the discrepancy, taking into account the impact of the discrepancy on the life cycle cost of the equipment to be controlled.

2.2 Value provided to customers

By utilizing the energy management technology developed this time as a tool for achieving carbon neutrality, we aim to ultimately provide our customers with the value presented below.

(1) Implementing unique-to-equipment manufacturer features

We have a wide range of products and related technologies that play a central role in energy supply and demand, including private power generators for electric power supply, air-cooled chillers for cold/heat supply, and cogeneration systems for combined heat and power

(CHP) supply. Utilizing this unique-to-equipment manufacturer knowledge and expertise, the energy management technology implements control algorithms that reflect the operating characteristics of the equipment, life cycle costs, and the diversity of the equipment to be controlled.

(2) Supporting decarbonized power supply equipment

To achieve carbon neutrality, on-site or off-site photovoltaic power generation is an indispensable source of decarbonized power that consumers can manage on their own. In addition, the combined use with battery energy storage system is also effective from the viewpoint of diversifying means in order to utilize the decarbonized power from photovoltaic power generation, which is a variable power source, internally without surplus. In developing the energy management technology, we actually installed the decarbonized power supply equipment, validated the functional effectiveness, and made the equipment practical.

(3) Managing predicted and resulted effects through simulation

When energy equipment is installed or renewed, it is common to make planning in consideration of the return on investment, but after the equipment is installed, the operation is often determined solely on the basis of maintenance and operation costs. Since the operating environment changes from that at the time of planning, it is desirable to reflect the degree of influence of environmental changes in the operation plan as needed. Thus, it becomes possible to improve the accuracy of predicting the return on investment at the time of planning by predicting the situation ahead from the point of change through simulation with use of the technology presented in this report and managing the actual results of costs and decarbonization effects.

(4) Evaluating with key performance index from life cycle perspective

It is rare for energy equipment to maintain the component performance and equipment utilization rate set originally at the time of installation planning until the time of abolishment. In addition, it is easy to imagine that costs, especially maintenance and operation costs, may change from those at the time of installation planning due to changes in the environment. Therefore, we have developed a control algorithm based on an index that takes into account the life cycle, which is represented by the levelized cost of electricity (LCOE), such as changes in component characteristics over time and fluctuations in maintenance and operation costs, which cannot be captured by an index at a certain cross-sectional level. This enables the index to be updated in real time and realizes the evaluation of the overall optimization in the latest state.

3. Configuration of energy management technology

As described in chapter 2, operation and energy management after installation of equipment generally target the reduction of the maintenance and operation costs. However, for achieving carbon neutrality, it is important to use the decarbonized power equipment fully as planned. In order to realize this, LCOE is introduced in this development as an index for operational determination. In the case of battery energy storage system, an expression levelized cost of storage (LCOS) is generally used, and evaluation in the same system as LCOE can be made by considering charging costs, etc.

The flow of energy management using LCOE is as follows.

(1) Making LCOE plan (prior to start of operation)

In the installation of equipment, the LCOE at the time of planning is calculated based on the expected fuel cost and the amount of electricity generated during the operation period. This is defined as the LCOE to be achieved from the life cycle perspective.

(2) Monitoring resulted LCOE (during operation period)

The amount of electricity generated by various types of equipment changes depending on operating methods, environmental conditions and other factors. Fuel costs, electricity prices, etc. also change with market trends. The resulted LCOE is calculated by reflecting these changes and the difference from the planned LCOE is monitored.

Figure 2 schematically shows the management of predicted and resulted LCOEs and the selection of the operation scenario based on LCOE. The management of predicted and resulted LCOEs calculates the resulted LCOE of the target equipment from the start of operation to the present and predicts the LCOE for each operation scenario based on the past results and future predictions. The selection of the operation scenario based on LCOE starts the operation in order of decreasing predicted LCOE in principle, and then evaluates differences in the future LCOE of the target equipment for each operating scenario to select an operating scenario with the optimal future LCOE.

The operation method of the target photovoltaic power generation equipment can be categorized as output power limitation, and the operation methods of the target battery energy storage system can be categorized as peak-shaving operation, Load leveling, surplus power charging operation, and so on. These operation methods are prepared in advance as operation scenarios and the selection of an operation scenario is made based on the LCOE.

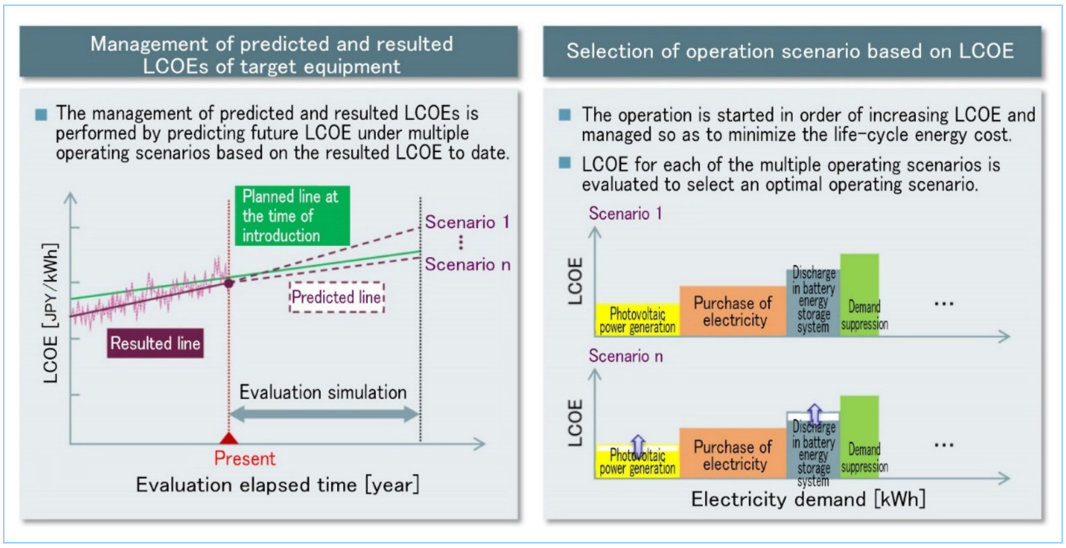

Figure 2　Schematic diagram of management of predicted and resulted LCOEs and selection of operation scenario based on LCOE

4. Functions and benefits of energy management technology

Figure 3 shows the summary of the main functions of the energy management technology developed this time. The outline and benefits of each function are as follows.

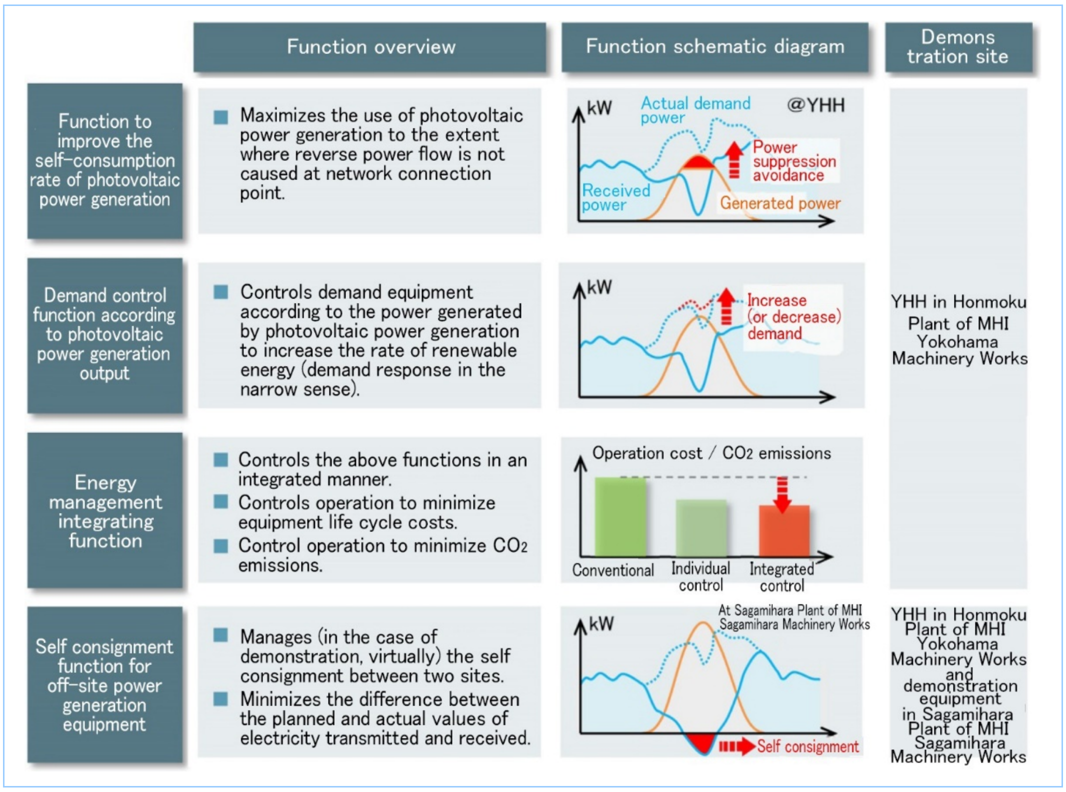

Figure 3　Function summary of developed energy management technology

(1) Function to improve the self-consumption rate of photovoltaic power generation

It monitors the power at the network connection point to maximize the use of photovoltaic power generation and limits the output of photovoltaic power generation when there is a possibility of reverse power flow.

(2) Demand control function according to photovoltaic power generation output

It controls demand equipment (increases/decreases the demand) according to the power generated by photovoltaic power generation.

(3) Energy management integrating function

It combines the operation of battery energy storage system operation (Load leveling, peak shaving, surplus power charging, etc.) with (1) and (2) to perform integrated energy management and utilizes the results of photovoltaic power generation and electricity demand predictions to perform operational control based on criteria such as LCOE and CO_2 emissions. Energy storage equipment also has a function to individually control power converters according to the charge rate and degradation state with the aim of aligning the degradation state for multiple groups of battery energy storage system is included.

(4) Self consignment function for off-site power generation equipment

It manages (in the case of demonstration, assumes) the self consignment between two sites by creating planned values of the amount of power transmitted and received for self consignment based on predictions of photovoltaic power generation and power demand to perform 30-minute planned value simultaneous equivalence control so that compliance with the planned values is ensured.

5. Validation of basic functions using actual equipment

We validated the basic functions of the energy management technology described in chapter 4 by using the demonstration system installed at YHH. **Figure 4** shows the configuration of the demonstration system. In the cloud-side system (TOMONI®), an operation plan is formulated by utilizing our proprietary AI demand prediction engine (ENERGY CLOUD®) to predict photovoltaic power generation and power demand in the TOMONI environment. TOMONI is a collective term for a variety of digital energy-related products and services, and here it refers to the system infrastructure that supports them.

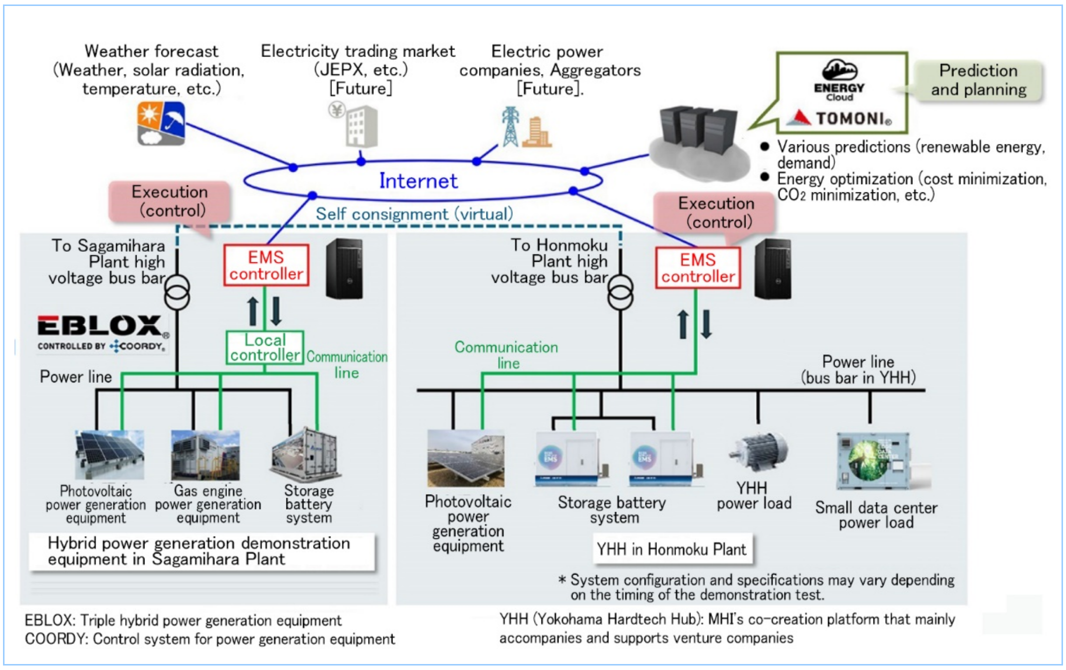

Figure 4 Demonstration system configuration

The edge systems (energy management system controllers, hereinafter referred to as "EMS controllers") are installed at two sites: YHH and the hybrid power generation equipment (EBLOX®) demonstration equipment in MHI's Sagamihara Plant. At YHH, we newly installed photovoltaic power generation equipment, a energy storage system, and an EMS controller. The

EMS controller controls the equipment according to the operation plan and operation mode selection policy developed by the cloud. At the Sagamihara Plant, we newly installed only the EMS controller and built an interface with the local controller of the existing hybrid power generation demonstration equipment. By connecting the two sites via TOMONI, a function assuming self consignment between YHH and the Sagamihara Plant was realized.

As examples of the results of validation of basic functions using the demonstration equipment, **Figure 5** shows an example of the energy management integrating function and **Figure 6** shows an example of the self consignment function. It was confirmed that the energy management integrating function shown in Figure 5 was able to reduce the amount of electricity purchased from the power company by utilizing the photovoltaic power generation equipment while charging and discharging the battery energy storage system, and that the self consignment function shown in Figure 6 was able to operate the battery energy storage system to compensate for errors in the planned value of the power received based on the prediction results, which resulted in a similarity between the planned value and the resulted value, albeit for a limited period of time.

After these basic operation tests, we started a long-term demonstration test in June 2022, in which we will validate and enhance the performance of the energy management technology we have developed, and to visualize the CO_2 emissions reducing effect.

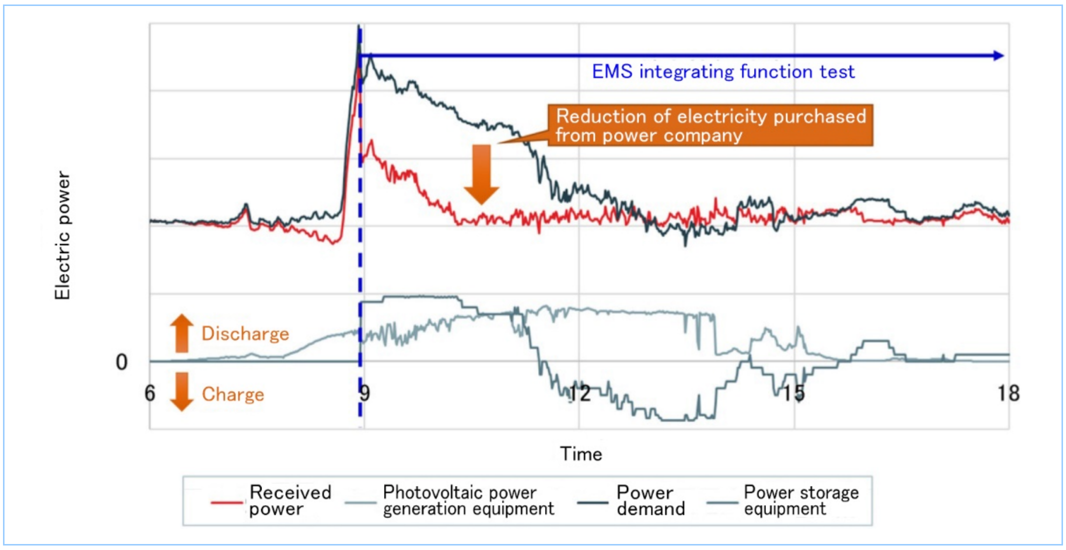

Figure 5 Example validation result of integrating function

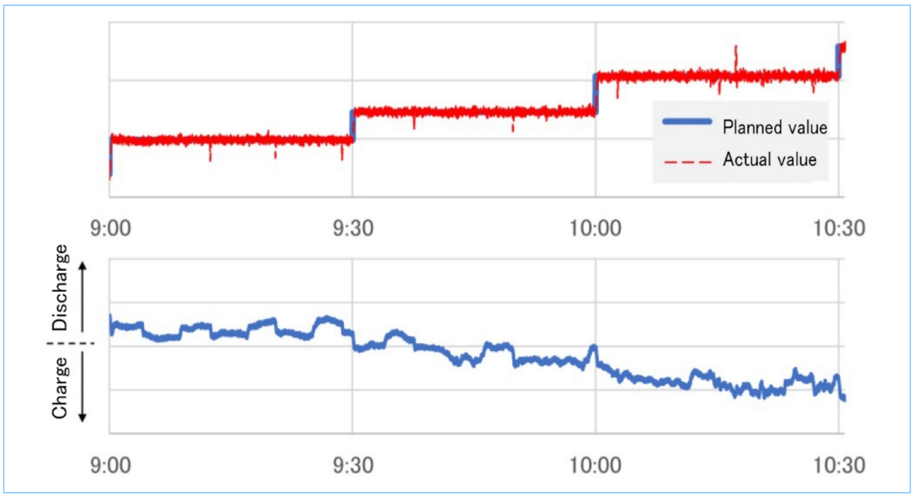

Figure 6 Example validation result of self consignment function

6. Conclusion

MHI Group has developed energy management systems that can serve as a tool for achieving a decarbonized society through the entire value chain, from the unique-to-equipment manufacturer perspective. The main feature of this technology is to control, operate and manage distributed resources such as photovoltaic power generation equipment and battery energy storage system, which are believed to be a realistic solution for decarbonizing power sources, based on the life cycle costs. We are still working on long-term evaluations and logic enhancement, including the construction of prediction simulations.

This report presented energy management mainly for electric power equipment, which is the main focus for carbon neutrality. However, for energy consumers in the industrial field, such as factories, cold/heat supply equipment is also an important factor in considering carbon neutrality in Scope 1. As shown in **Figure 7**, we will expand the functionality of the energy management technology developed this time by applying it to cold/heat supply equipment and will develop this technology as carbon-neutral solution services for customers.

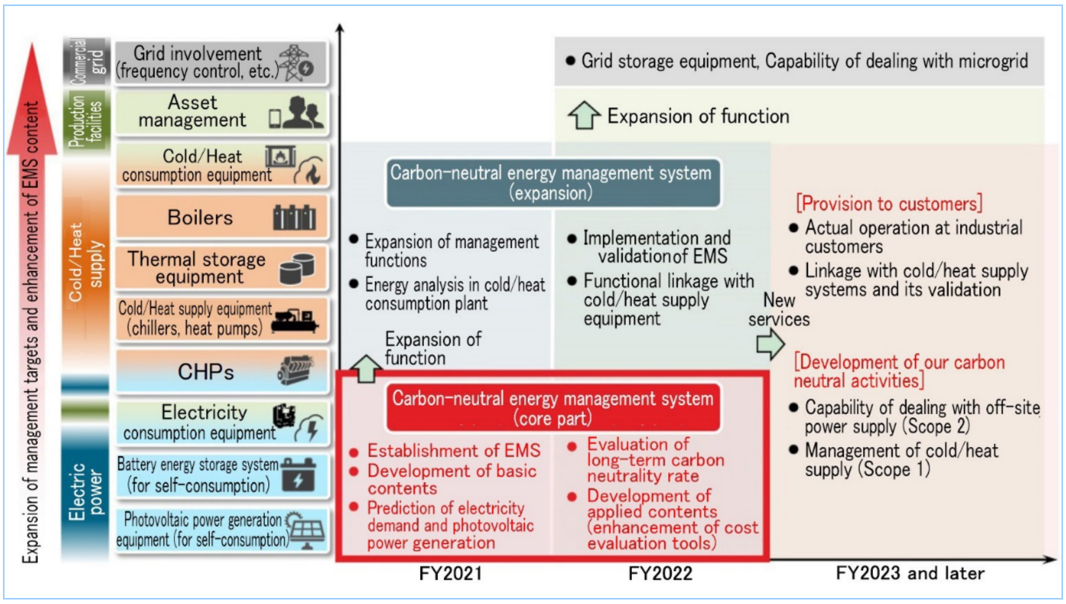

Figure 7 Expansion of energy management functions and contents

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