THERMAL ENERGY STORAGE DEVELOPING FOR A DECARBONIZED SOCIETY

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SUMMARY

- Due to the spread of renewable energy and seasonal factors, more power is generated than demand, causing the surplus power problem. This has caused a need for mechanisms and technologies to store electricity power without throwing it away.
- There are various technologies such as batteries for storing power, and they each have their own appropriate scale and scope of use. Power generation using thermal energy storage is a technology suitable for large-scale energy storage over long periods of time made up of a combination of existing technologies, and is characterized by its high reliability and low cost.
- A shift is taking place from battery-based power storage in the past to practical application of thermal energy storage and hydrogen energy storage in the future. Energy business operators need to consider combinations of optimal power storage technologies from perspectives such as storage time and capacity, cost, demand and transmission grids, and location.

WHY ARE ENERGY STORAGE AND POWER STORAGE NECESSARY?

With the spread of renewable energy (renewables), power generation using renewables sometimes exceed demand temporarily when there are favorable conditions, which are ample sunlight for photovoltaic power generation and continuously moderate wind for wind power generation. This results in surplus power, which destabilizes power grids and can cause power outages. For the purpose of stabilizing power grids so that power surpluses may not arise, restrictions are applied in the form of power limits to suspend photovoltaic and wind power generation.

Even in Europe, where power grids are linked among multiple countries, output limits are applied when there is a power surplus. Renewables that should normally contribute to the reduction of CO_2 are not effectively utilized, and subsidies for renewable energy business operators also became an economic problem; for example, those reached 700 million euros in Germany.

Renewables can only generate power when the sun is shining or the wind is blowing, and power generation cannot be adjusted according to power demand in the same way as oil or gas power generation. While being a trump card in the reduction of CO_2, the weakness of renewables is being power that cannot be adjusted. A large volume of surplus power is expected to be generated as renewables spread in the future. With such a trend, there is an urgent need to establish power storage facilities capable of storing surplus power and supplying the necessary volume when it is required.

THERMAL ENERGY STORAGE GAINING ATTENTION AS A POWER STORAGE TECHNOLOGY

Power storage technologies include the thermal energy storage covered in this paper, in addition to a variety of technologies in practical application or under development, such as batteries, pumped storage hydropower, compressed air energy storage, and hydrogen energy storage (Figure 1). Batteries are a technology that stores electricity as electricity, and have practical applications in a variety of devices such as personal computers and mobile phones. In addition, it is a widely used power storage technology such as being seen in some households with photovoltaic power generation installed. In contrast to this, there are methods that store electricity by converting it into other forms of energy. A typical example is pumped-storage hydroelectricity using dams. A large volume of water is pumped into dams using surplus power to be temporarily stored, and the water is dropped to generate hydropower when it is required. Pumped-storage hydroelectricity is a power storage facility that stores electricity by converting it into potential energy. Other methods are compressed air energy storage creating compressed air using electricity (physical energy conversion), and hydrogen energy storage performing electrolysis on water to create hydrogen to be stored (chemical energy conversion).

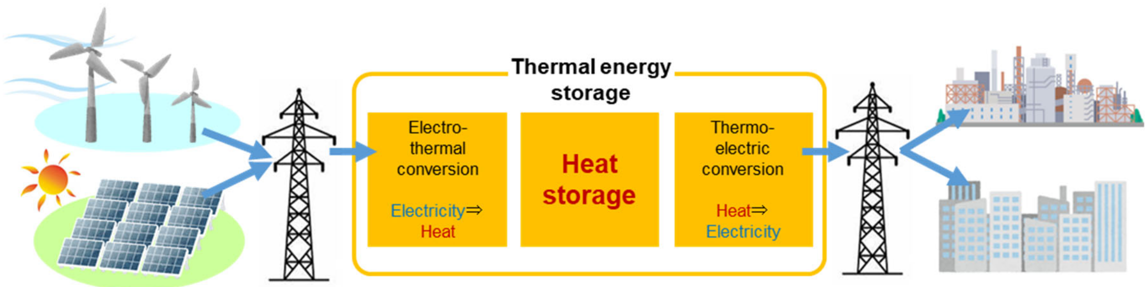
Figure 1. Examples of Power Storage Technology

Power Storage Technology	Overview of Technology	Technical Issues
Batteries	Storage using chemical energy. Lithium-ion, flow, etc. Effective for fluctuations in comparatively short periods. Approximate power storage time: Minutes to hours.	Reducing cost and extending lifespan. Difficulty to leverage economies of scale in large volumes over a prolonged period.
Pumped Storage Hydropower	Storage using potential energy of water. Output is large and variable. However, input time (pumping time) cannot be significantly adjusted even when variable pumping is used. Approximate power storage time: Hours to days (supporting night-time power surpluses from nuclear power).	Costs are dependent on terrain, and few suitable locations remain.
Thermal Energy Storage (TES)	Material heat storage. Includes sensible heat, latent heat and chemical heat storage. The thermal storage part is low-cost at $15/kWh. Electrothermal conversion, heat storage and thermoelectric conversion can be designed separately. Approximate power storage time: Hours to days.	The speed of changes in output is slow. Heat loss at the time of power generation is significant.
Compressed Air Energy Storage (CAES)	Storage in compressed air in underground cavities or tanks. Includes the LNG method, the method generating power by compression and expansion of air without using fuel, and the type using stored heat when compressing and expanding. Approximate power storage time: Minutes to hours.	Commercialized plants use underground cavities. Suitable locations are limited.
Hydrogen Energy Storage	Storage as hydrogen by performing electrolysis on water. Storage uses high-pressure tanks, liquefaction, hydrogen storing alloy, etc. Hydrogen transportation and store are also possible using hydrogen compounds (such as ammonia). Approximate power storage time: Days to weeks.	Reducing cost of hydrogen production, improving overall system efficiency, necessity of large-scale system continuity verification tests.

Source: Prepared by MGSSI based on materials from the Institute of Applied Energy

Power generation using thermal energy storage is also a power storage technology. Its basic concept is that electricity is converted into heat when there is a power surplus caused by renewables, temporarily stored as heat, and converted back into electricity to supply power when needed during an increase in power demand (Figure 2). In recent years, heat storage technology has progressed, and numerous verifications have been conducted in demonstration plants. Such progress in development aimed at commercial-scale application is bringing attention to the technology.

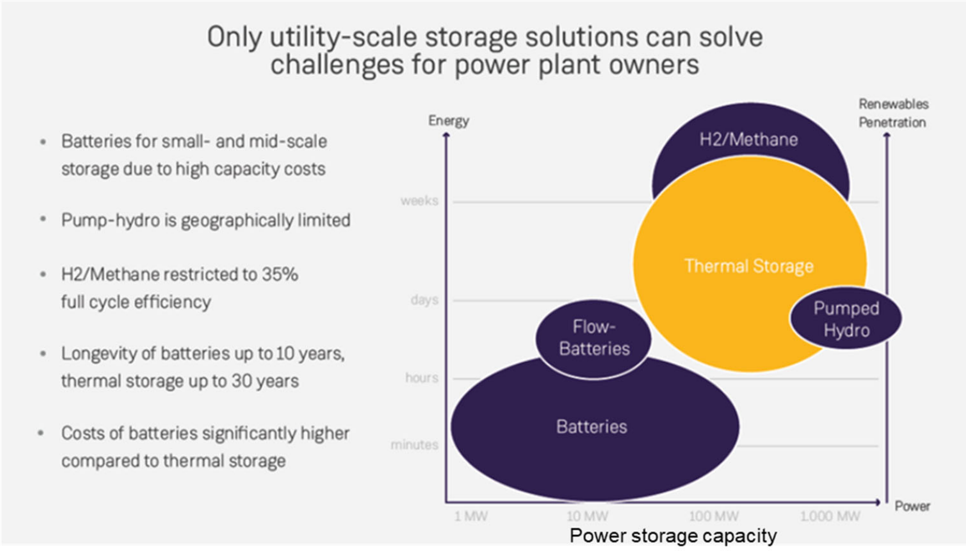
Figure 2. Overview of Thermal Energy Storage



Source: Prepared by MGSSI based on materials from Hokkaido University Graduate School

Power storage technologies have differences in the power storage capacity and power storage time. Siemens Gamesa, which is one of the developers and manufacturers of thermal energy storage systems, has positioned the power storage technologies as shown in Figure 3.

Figure 3. Capacity and Power Storage Time of Various Power Storage Technologies



Source: Siemens Gamesa materials

The appropriate scale for batteries is a small to medium storage capacity (up to 100MW[1]) and power storage time is up to several hours. Thermal energy storage, pumped-storage hydroelectricity, and hydrogen energy storage are able to store larger capacities (100-1,000MW) than batteries. The available storage time is evaluated to range from several hours to several days using pumped-storage hydroelectricity for storing surplus nuclear power at night, several hours to several days using thermal energy storage, and several days to several weeks using hydrogen energy storage. Heat storage, pumped storage, and hydrogen storage are considered to be suitable for long-term storage of large volumes of power. On the other hand, there are issues such as difficulty securing suitable sites for the construction of dams used for pumped storage, and concerns about the high cost of hydrogen because the technology is still in the development phase. Meanwhile, power generation using thermal energy storage has excellent features: Its system is able to store large volumes of power for extended periods and to be built using existing technologies, while having moderate geographical restrictions. It also has the potential to lower costs compared to hydrogen, which is also a promising form of power storage at the same scale.

MECHANISM OF POWER GENERATION WITH THERMAL ENERGY STORAGE

This section introduces the basic principles of thermal energy storage and the configuration of equipment using the thermal energy storage system under development by Siemens Gamesa as an example (Figure 4). Thermal energy storage is made up of three elemental technologies in the form of (1) “electrothermal conversion” converting electricity into heat, (2) “heat storage” storing heat, and (3) “thermoelectric conversion” converting heat into electricity. The Siemens Gamesa facility converts electricity into heat by using an electric heater to heat air, and the heated air is blown against the stone heat storage material (crushed igneous rock) to heat it. The stored heat is drawn out as heated air when necessary, used to create steam using a heat exchanger, and converted into electricity using a steam turbine.

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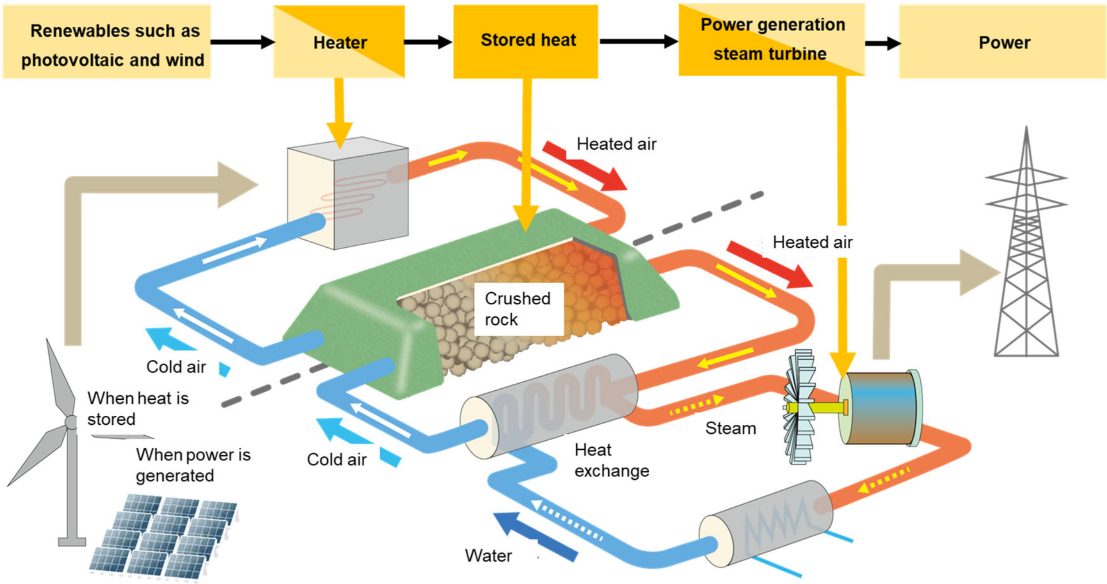
1 MW (megawatts) are a unit of energy (power). 1MW indicates the power required by approximately 250 households. MWh indicates the amount of energy in MW units that can be supplied in one hour. Similarly, MJ (megajoules) and kcal (kilocalories) are also the amount of energy, where 1MWh=3,600MJ=860,000kcal.

Figure 4. Example of a Thermal Energy Storage Configuration



Source: Prepared by MGSSI based on materials from Siemens Gamesa and the Institute of Applied Energy

Even in other examples, industrial heaters that are widely used in petrochemical plants, etc. in the same was as Siemens in (1) “electrothermal conversion.” The heater uses the same principle as a dryer, which is the simple principle of heating air by passing it through an element heated by electricity. In (3) “thermoelectric conversion,” like Siemens, there are many cases using steam turbines commonly used in power plants. However, a variety of technologies are being developed for (2) “heat storage.” These can be generally categorized into the two methods of “sensible heat storage” storing heat in stone, bricks and molten salt, and “latent heat storage” using the heat stored in the phase transition from solid to liquid in chemical compounds and alloys (Figure 5).

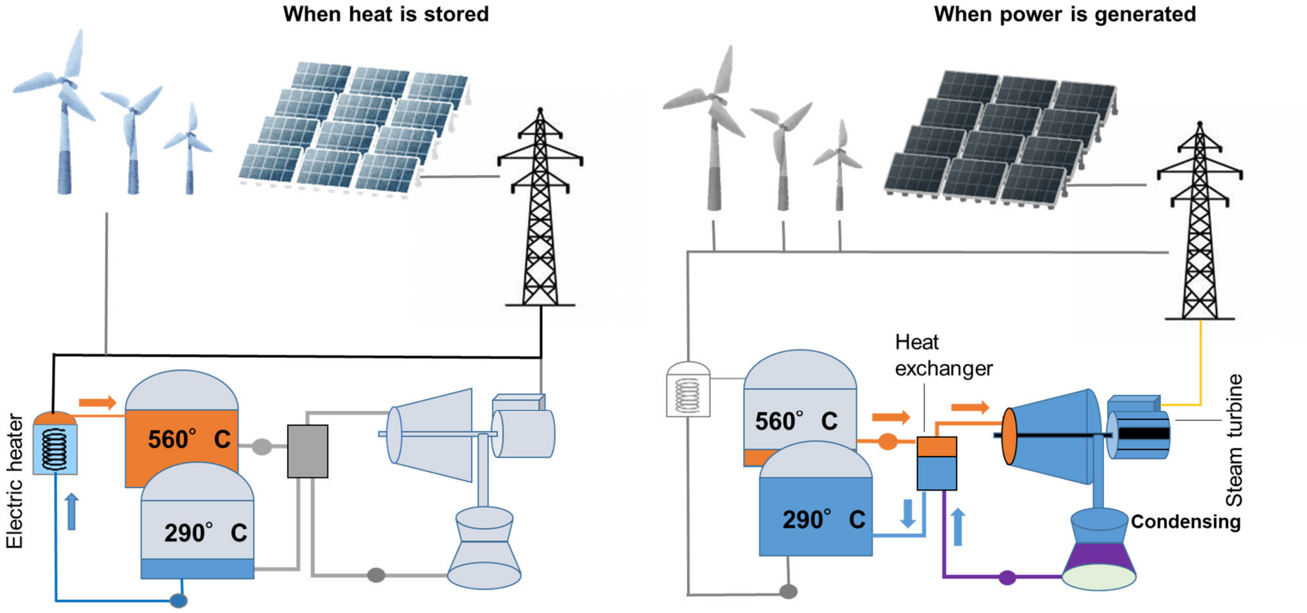
Figure 5. Overview of Heat Storage Methods

Heat Storage Method	Overview of Technology	Practical Examples	Practical application in thermal energy storage
Sensible heat storage	Uses heat stored in a solid or liquid. (no phase transition)	Use of the stored heat temperature difference of water, bricks, concrete, etc. Heating of bricks in furnaces, ceramic heating using waste gas from regenerative burners, etc.	There have been results with liquid using molten salt (nitrate) in concentrated solar power generation. Solids are in development using stone (such as igneous rock), concrete, etc.
Latent heat storage	Solid⇔Liquid Uses heat stored in phase transition. Amount of heat storage is greater than sensible heat storage.	No practical examples of heat storage using heat. There are examples of using storage of cold in ice made with power at night for cooling during the day.	Under development. Applied research is being conducted on the phase transition of salt hydrates, paraffins, organic compounds, molten salt, and alloys.

Source: Prepared by Mitsui & Co. Global Strategic Studies Institute based on materials from the Institute of Applied Energy

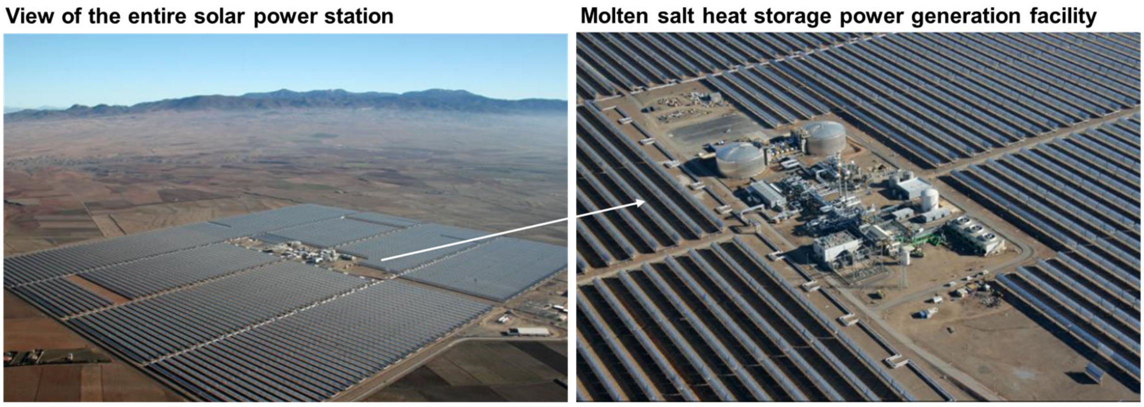
With sensible heat storage, heat storage using stone like in the example of Siemens Gamesa is under development, but heat storage using molten salt is already in practical application in concentrated solar power generation. The molten salt used for heat storage often uses a mixture of sodium nitrate and potassium nitrate. The fact that thermal energy storage is a comparatively cheap power storage method was mentioned above, and the nitrate salts used here are low-cost materials that are readily available. Nitrates are solid at room temperature, but become liquid at approximately 220°C, and can maintain liquid state up to 600°C. Using this property, heat can be stored between 200°C and 600°C. Figure 6 shows an image of power generation and heat storage using molten salt. Here, molten salt acts to repeatedly store heat and generate electricity through two tanks. When heating, molten salt is heated to 560°C using an electric heater and stored inside the tank. When generating power, the 560°C molten salt is used to generate steam through a heat exchanger, and a steam turbine generates electricity. When the temperature of the molten salt falls to 290°C after generating steam, it is reheated through the tank to store heat and the cycle is repeated. This technology is yet to be used for power storage of surplus renewables, but molten salt thermal energy storage directly using solar heat is in practical use (Figure 7). Meanwhile, latent heat storage is expected to be developed in the future because it stores more heat than sensible heat storage and the heat storage equipment can be made smaller.

Figure 6. Image of Power Generation and Heat Storage Using Molten Salt



Source: Prepared by MGSSI

Figure 7. Andasol Concentrated Solar Power Station in Spain
(100MWe heat storage 2,000MWht)



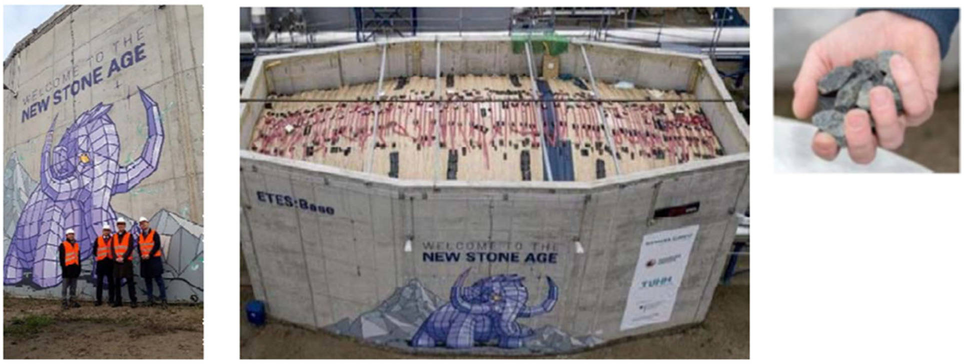
Source: SENER Energy website. Explanations added by MGSSI

GLOBAL EXAMPLES OF THERMAL HEAT STORAGE DEVELOPMENT

Thermal heat storage using igneous rock：Siemens Gamesa

The thermal heat storage under development by Siemens Gamesa generates power stored as heat in crushed igneous rock as shown in Figure 4. The company operates a demonstration plant in Germany, which is capable of heating approximately 1,000 tons of crushed igneous rock to 480°C and storing the heat for 24 hours (Figure 8). Power is supplied using a 1.5MW steam turbine, and the overall efficiency of converting electricity into heat and then back to electricity is 25%. In the future, the goal is to increase the heat storage temperature to 600-700°C to achieve overall power generation efficiency of 45%. The system is made using existing technologies and inexpensive materials, such as using an industrial heater for electrothermal conversion, using inexpensive igneous rock as the heat storage material, and generating power with a proven steam turbine. For this reason, facility cost can be kept to one tenth that of batteries, according to Siemens Gamesa. In the future, after verification in a 30MW pilot plant with five times the heat storage scale, the company plans to build a commercial plant capable of storing approximately 100MW in around 2025.

Figure 8. Thermal Energy Storage Facility and Igneous Rock Used as a Storage Medium by Siemens Gamesa

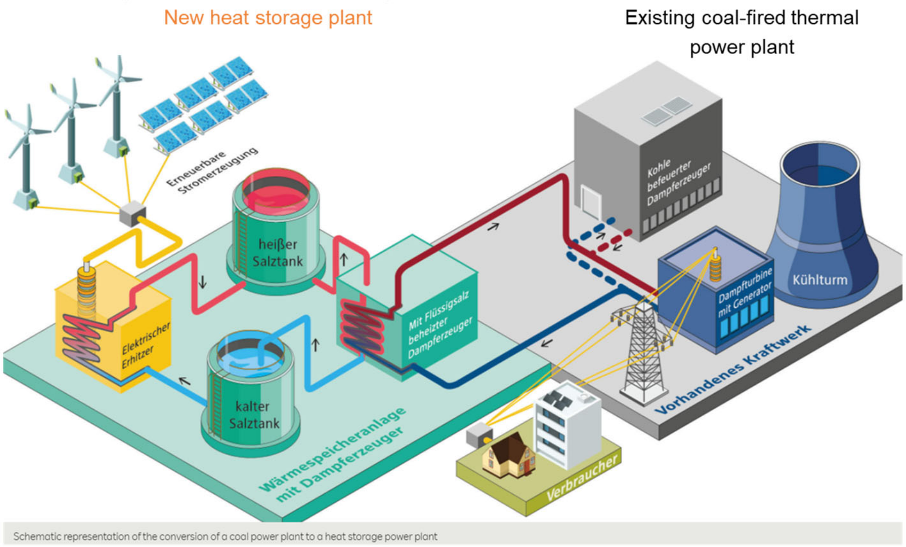


Source: Siemens Gamesa

Combination of coal-fired thermal power plant and thermal storage: RWE, RWTH Aachen University

German power company RWE and RWTH Aachen University are proceeding with an attempt to reduce CO_2 by combining heat storage with an existing coal-fired power plant (Figure 9). Surplus renewables are used to heat molten salt, and this heat along with the heat from burning coal are used to create steam for generating power. Surplus renewables can be effectively utilized, and the power produced using heat stored from renewables is treated as producing zero CO_2 emissions, lowering the overall CO_2 emissions of the coal-fired thermal power plant. RWE has positioned combination with heat storage as a measure for reducing CO_2 until coal-fired thermal power generation ceases, and is drawing up a plan to convert the plant into a complete thermal energy storage plant once coal-fired thermal power generation has been abolished.

Figure 9. Combination of an Existing Coal-fired Thermal Power Plant and Heat Storage at RWE in Germany



Source: RWE materials. Explanations added by MGSSI.

Compact heat storage facility: Eco-Tech Ceram

In France, Eco-Tech Ceram is developing a compact heat storage facility using waste heat. (Figure 10) A plant's waste heat that is normally released into the atmosphere through a chimney is recovered as heat stored in ceramic, and reused as a heat source within the plant. The heat storage temperature is 600°C, and up to 2MW can be stored. In addition to thermal uses, the company also has a concept enabling power generation by installing multiple heat storage devices. Although large projects are the mainstream in the development of thermal heat storage facilities absorbing surplus renewables, development is also being carried out on compact heat storage facilities using waste heat such as this. 40% of primary energy being discarded as heat is an important issue for improving the efficiency of energy usage, and it is believed that waste heat storage facilities will be a trend that gains attention in the future.

Figure 10. Heat Storage Solution Used by Eco-Tech Ceram in France

Source: Eco-Tech Ceram materials. Explanations added by MGSSI.

SUMMARY

National governments and businesses are setting goals for zero emissions, and the introduction of renewables will continue to expand to achieve these goals. In the future, it will be necessary to effectively utilize surplus renewables rather than discarding them as in the present, and power storage will become increasingly important. At present, batteries are the major technology used for power storage, but there will be more understanding that batteries are suitable for storage of small volumes of power for short periods, and that thermal energy storage is effective for storage of large volumes of power for extended periods. Energy business operators need to consider combinations of power storage technologies optimized from perspectives such as storage time and capacity, cost, demand and transmission grids, and location as power storage shifts from primarily using batteries in the past to practical application of thermal energy storage and hydrogen energy storage in the future.

Thermal energy storage, and particularly latent heat storage materials, are technologies still under development, and the reduction of costs through the maturity of technology will depend on future technological development, but the promotion of such technologies warrants continued attention.