Country Update on Energy Storage for Japan

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ABSTRACT
This article provides an overview of the number of installations of water thermal storage systems, representative of sensible heat storage systems and ice heat storage systems as latent heat storage systems, in Japan till the year. In addition, recent results regarding the introduction of a ground source heat pump system are reported. Moreover, the effective use of chemical heat storage at a relatively high temperature is explained. Finally, details on the stationary battery, which is currently being propagated across Japan, will be introduced.

1. INTRODUCTION
The last 40 years have been a period of high economic growth for Japan, with its energy consumption doubling. By sector, the energy consumption of the industrial sector has remained constant at 0.8 times, while that of the transport and civilian sectors has grown 1.7 times and 2.2 times respectively, which shows that the increase in the transportation and civilian sectors has contributed significantly to Japan’s economic growth. The expansion of the transportation sector is mainly due to the increase in passengers, the increase in the building floor area, and the spread of office automation (OA) equipment in the civilian sector. In the Paris Agreement, Japan has declared that its CO₂ emissions will be reduced to 26% in 2030 compared to 2013. Therefore, each sector is promoting energy conservation and low carbon initiatives. In order to realize this goal, the industrial sector must achieve 7% reduction, the transport sector, 28%, and the civilian sector, 39% reduction.

In addition, the Japanese government has launched the Basic Energy Plan in 2014, in which the basic policy is to stabilize energy supply and demand initially, improve economic efficiency, and adapt to the environment. After the Great East Japan Earthquake in 2011, along with energy conservation and low carbon, Japan has made a conscious effort to stabilize energy supply and demand with the Business Continuity Plan (BCP).

In order to promote the spread of renewable energy, the Feed-in-Tariff (FIT) mechanism has been introduced and operated since 2012. With the introduction of this mechanism, electric power utilization, produced by renewable energy sources such as solar power generation and wind power, has been promoted to a great extent. However, the
improvement of the electricity transmission network has not been up to par, while the effective use of surplus electric power is a future task. In addition to countermeasures such as pumped-storage hydroelectricity and battery introduction, the possibility of thermal storage technology has attracted more attention to this solution. Furthermore, efforts are being made to promote the use of heat utilization from renewable energy sources, such as solar thermal heat utilization and ground thermal heat source utilization.

This article provides an overview of the water thermal storage system as a sensible heat utilization system, ground source heat pump system, and the ice thermal storage system as a latent heat utilization system. In addition, it introduces the current situation regarding the chemical thermal storage system. Finally, it discusses the recent situation regarding the stationary battery, while providing a roadmap for future development.

2. SENSIBLE ENERGY STORAGE

In this chapter, the water thermal storage and ground source heat pump are described as sensible energy storage systems in Japan. Initially, the water thermal storage is introduced, which is mainly used for cooling, because the climate in Japan is hot and humid, except in Hokkaido.

The use of sensible energy storage systems has become widespread because they can level the thermal demand, achieve high efficiency by improving the operational load factor of the heat source equipment, and have demonstrated lower capacity requirements for heat source equipment. In recent years, it is expected to respond to the business continuity plan (BCP), which uses water in the water thermal storage tank at the time of disaster, to further utilize it as a source of absorption of surplus electric power by renewable energy.

The water thermal storage tank is mainly used by connecting a fully mixing storage and a temperature stratified-type storage. In general, non-residential buildings have earthquake-resistant pits in the basement of the building, which are utilized as thermal storage tanks. The cycle of charge and discharge of heat is one-day long, with the heat being charged during night time (from 22:00 to 7:00 on the following day), while being discharged during the day time. An air source heat pump is used as a heat source equipment. The outside air temperature, which is low compared with that during the daytime, could improve the efficiency of the heat source equipment operation.

Figure 2.1 shows the number of cumulative installed water thermal storage system units between 1990 and 2016. Approximately 1,246 installations had been reported by 1990, which increased to approximately 2,900 by 2016.

Figure 2.2 shows the cumulative heat storage volume of the water thermal storage system. It was approximately 897,000 m³ in 1990, while the introduction storage volume has increased to over 2,000,000 m³ in the 2010s.
Figure 2.3 shows the amount of contribution to electric power peak shift by using water thermal storage system, assuming a water temperature differential usage of 5 K, thermal storage efficiency of 0.85, and 10 h of discharge process per day. It was approximately 0.4 GW in 1990. However, as of 2016, the contribution to the peak shift was approximately 1.1 GW, which was nearly three times as large as 20 years ago.

Figure 2.3 Potential of electric power peak shift by using water thermal storage system

Subsequently, the situation in Japan with regard to geothermal heat utilization has been reviewed. The Japanese government launched the Basic Energy Plan (2014.4) by taking the geothermal heat into consideration for policies such as improving energy supply and demand structure, dissemination of distributed energy systems, and promotional support. In addition, the movement for the promotion of heat utilization as an application of renewable energy source is encouraging the usage of geothermal source.

Figure 2.4 shows the number of installations by the type of geothermal heat utilization system. Among the 6,877 cases in total, the air circulation system constitutes 1,919 cases, accounting for 27.9%. Direct use by water circulation accounts for 25.9% or 1,781 cases, while the ground source heat pump system accounts for 2,230 cases or 32.4% of the total.

Among the 2,230 cases of ground source heat pump utilization, the largest portion (1,946 cases) used the closed loop method and the open loop method was used in 270 cases, while hybrid utilization, which included both types, was used in 14 cases.

Figure 2.4 Number and percentage of installations of geothermal utilization units

Figure 2.5 Number of installations of ground source heat pump systems
Figure 2.5 shows the number of ground source heat pump systems installed. From 1981 to 1990, the number of installation units was low. However, it increased dramatically after 2000. In addition, closed loop systems showed a large growth rate, indicating that the total number of installations has been increasing.

Figure 2.6 shows the number of ground source heat pumps installed by the applied building types. Of the total, the largest portion of 991 cases is in the housing, with 254 offices, 157 public properties, and 119 department stores. The systems installed for this application account for approximately 68.2% of the total.

Currently, vertical buried geothermal heat exchangers are mainly used in Japan, as opposed to the horizontal type of installation. Research and development efforts are actively underway for cost reduction related to the excavation and installation of ground source heat exchangers. In addition, a subsidy program and R&D support project have been launched by the government and municipalities. For instance, the Ministry of the Environment has been working for the Independent Promotion Project for both, renewable electric power and thermal energy. The Ministry of Economy, Trade, and Industry has launched an R&D project for the cost reduction of renewable thermal energy utilization, such as geothermal utilization.

3. LATENT ENERGY STORAGE

Figure 3.1 shows the cumulative introduction of the ice thermal storage system. The ice thermal storage system, coupled with the central heat source HVAC system and the packaged type of system to form the so-called Eco-ice mini, is shown separately. In 1990, there were 209 cases of ice thermal storage systems of the central heat source system, with 19 cases of Eco-ice mini. Since 1998, the number of Eco-ice Mini installations was 2,753, which was added to the total. The ice storage with central-type HVAC system showed a moderate increase by 2016, whereas the packaged-type has significantly increased the number of installations. As of 2016, the Eco-ice mini over 28 kW amounts to approximately 16 thousand units, while the Eco-ice mini accounts for approximately 12 thousand units.
Figure 3.2 Cumulative thermal capacity of ice thermal storage

Figure 3.2 shows the cumulative installation capacity of the ice thermal storage system. The total capacity of the above-mentioned ice storage system, coupled with the central heat source HVAC system and Eco-ice system, is shown. From 1990, it increased significantly in the 2000s up to 15,000 m$^3$. In addition, the introduction of new systems decreased sharply after 2011. It is considered to have significantly influenced the social situation with respect to energy supply and demand after the 2011 Great East Japan earthquake.

Figure 3.3 Potential of electric power peak shift by using ice thermal storage system

Figure 3.3 shows the transition of power demand peak shift potential due to the ice thermal storage system. The peak shift potential due to the ice thermal storage system was 44.8 MW in 1990, which expanded to 0.8 GW in 2016.

4. THERMAL CHEMICAL STORAGE

Thermochemical heat storage (TCES) has potential for application in high-temperature thermal storage. After the Great East Japan Earthquake and Fukushima Daiichi nuclear power plant accident in 2011, it was enhanced to introduce renewable energy as alternatives to nuclear and fossil fuel thermal power plants. Unstable power from renewable energy can deteriorate the quality of electricity, causing serious confusion in the electricity power grid. The southern and northern parts of Japan have already faced this problem. Therefore, energy storage technology is becoming more important. TCES is expected to have a high potential for high-temperature heat storage, with high energy density.

Hydration reaction is a key reaction family. Hydration TCES systems, operated at low temperatures of less than 100 °C, are available for low-quality thermal heat recovery and cooling by thermal driving operation. The hydration reactions of calcium chloride (CaCl$_2$·6H$_2$O; Hirata, 2003), calcium sulphate (CaSO$_4$·0.5H$_2$O; Ogura, 2009), and strontium bromide (SrBr$_2$·H$_2$O·5H$_2$O; Kobayashi, 2016) have been well-studied for the utilization of low-temperature heat. Magnesium oxide/water (MgO/H$_2$O) TCES has been studied for the utilization of exhaust heat at a medium temperature of approximately 200–400 °C from an internal combustion engine and industrial processes (Kato, 1996).

$$\text{MgO (s) + H}_2\text{O(g)} = \text{Mg(OH)}_2, \Delta H = -81.0 \text{ kJ mol}^{-1}$$ (1)
The planned application of TCES on automobile catalyst heating is shown in Figure 4.1. The internal combustion engine in automobiles emits exhaust gas containing nitrogen oxide (NO$_x$), which is a toxic gas. NO$_x$ should be reduced into nitrogen and oxygen by an on-board catalytic reactor at 300 °C. At the start of the engine each day, the catalyst should be initially heated up to the active temperature from the atmospheric temperature. The heating operation requires additional fuel. MgO/H$_2$O TCES could assist in the supply of heat to the reactor by storing the surplus heat from the exhaust gas under normal operation on the previous day (Figure 4.2). Material developments of the MgO/H$_2$O system are discussed for the enhancement of TCES performance. Lithium chloride-modified magnesium hydride (Ishitobi, 2013) and lithium bromide-modified magnesium hydride (Myagmarjav, 2014) show higher TCES performance than authentic magnesium hydride due to their water absorption enhancement effect on the surface of the MgO particle. Although the Mg(OH)$_2$ pellet has high reactivity, the thermal conductivity enhancement of the material is important for efficient heat exchange. The packed bed of Mg(OH)$_2$ pellets is characterized by a low effective thermal conductivity, of approximately 0.2 W m$^{-1}$ K$^{-1}$. Expanded graphite (EG) is a good candidate for thermal conductivity enhancement. Mg(OH)$_2$ composite mixed with EG, called EM, was developed in some previous works (Kim, 2011; Zamengo, 2013). In comparison with pure Mg(OH)$_2$, EM has moldability, which means the capability of easily being shaped into a specific form by compaction in a mold. Measurements of thermal conductivity of EM tablets showed higher effective thermal conductivity of up to 2.0 W m$^{-1}$ K$^{-1}$. The mixing mass ratio of 8:1 between Mg(OH)$_2$ and EG showed optimal performance compared with the others, based on a packed bed reactor experiment (Zamengo, 2014). Carbon nanotube-based hybrid materials for MgO/H$_2$O were also developed for reactivity enhancement by the heat transfer enhancement effect of the carbon nanotube (Mastronard, 2016).

Thermal energy storage is useful for solar thermal system and other high temperature industrial processes for stable thermal energy supply to meet the demand. TCES at 700 °C is required for a concentrated solar power system.

A lithium orthosilicate/carbon dioxide (Li$_2$SiO$_4$/CO$_2$) reaction system has been proposed for use in TCES and chemical heat pump (CHP) systems at approximately 700 °C (Takasu, 2017). The carbonation of Li$_2$SiO$_4$ exothermically produces lithium carbonate (Li$_2$CO$_3$) and lithium metasilicate (Li$_2$SiO$_3$).

\[
\text{Li}_2\text{SiO}_4(s) + \text{CO}_2(g) = \text{Li}_2\text{CO}_3(s) + \text{Li}_2\text{SiO}_3(s), \quad \Delta H = -94.0 \text{ kJ mol}^{-1}
\]  

CO$_2$ storage is a key issue. Zeolite is a potential candidate for CO$_2$ adsorbent.

\[
\text{Zeolite}(s) + \text{CO}_2(g) = \text{Zeolite}&-\text{CO}_2, \quad \Delta H = -60 \text{ kJ mol}^{-1}
\]  

Decarbonation of these products is used for heat storage, while carbonation is used for heat output in a TCES system. An Li$_2$SiO$_4$/CO$_2$/Zeolite TCES system in chemical heat pump operation for a concentrated solar power plant is shown Figure 4.3. With the change in zeolite bed temperature, CO$_2$ moved between Li$_2$SiO$_4$/CO$_2$ reactor and Zeolite/CO$_2$ reactor. When the zeolite bed temperature in heat output mode is higher than that in heat storage mode, with the CO$_2$ pressure in the former also being higher than that in the latter, then the heat output temperature of Li$_2$SiO$_3$ carbonation is higher than that of the heat storage operation. This heat pump function is unique to TCES, in comparison with conventional sensible and latent heat storages. The reactivity of the Li$_2$SiO$_4$ composite and some metal oxides have been discussed with regard to reaction temperature changes and material cost reductions.
Figure 4.3 $\text{Li}_4\text{SiO}_4$/CO$_2$/Zeolite TCES system in chemical heat pump operation for a concentrated solar power plant. (a) Heat storage mode, (b) Heat output mode.

Generally, electrical battery continues to be a popular candidate for stable energy storage of renewable energy output. However, TCES costs as less as 1/10th of the battery storage system (Forsberg, 2017). Recognition of the availability and benefit of TCES, compared with battery, would be required for the realization of low-carbon society.

5. ELECTRICAL ENERGY STORAGE

Figure 5.1 shows the number of shipments of a lithium-ion stationary battery. Note that the lithium-ion battery shown here indicates a stationary battery that supplies the generated electric energy by an oxidation-reduction reaction that occurs when lithium ions move between the electrodes. The number of shipments was 1939 in 2011, which reduced to 34,569 units in 2016. As of 2016, the cumulative shipment volume had reached 120 thousand units. The shipment capacity was 11.8 MWh in 2011, 237.9 MWh in 2016, while the cumulative capacity as of 2016 was approximately 932 MWh.

Figure 5.2 shows the roadmap of the stationary storage battery issued by the New Energy and Industrial Technology Development Organization (NEDO). For the supply side and demand side, it has set an approximate target value of battery life and cost for 2020 and 2030. The battery life of each application is planned to be extended to approximately 20 years by 2030. Regarding the cost of the battery for the adjustment of long-term fluctuations in the grid, the current 50 to 100 thousand yen per kWh is assumed to be reduced to 23 thousand yen per kWh (equivalent to pumped-storage power generation) by around 2020. Moreover, the other costs related to the battery are also to be reviewed to achieve further cost reduction.
Table 5.1 Characteristics of Storage Battery for Buildings in Japan

<table>
<thead>
<tr>
<th>Type</th>
<th>Lead battery</th>
<th>Nickel hydride battery</th>
<th>Natrium Sulfur battery (NaS)</th>
<th>Redox flow battery</th>
<th>Lithium-ion battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Density (Wh/kg)</td>
<td>35</td>
<td>60</td>
<td>100</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>Cycle Efficiency (%)</td>
<td>75</td>
<td>90</td>
<td>75</td>
<td>70</td>
<td>95</td>
</tr>
<tr>
<td>Life Cycle (times)</td>
<td>3,000</td>
<td>2,000</td>
<td>4,500</td>
<td>&gt;10,000</td>
<td>3,500</td>
</tr>
<tr>
<td>Lifetime (year)</td>
<td>17</td>
<td>5 – 7</td>
<td>15</td>
<td>6–10</td>
<td>6–10</td>
</tr>
<tr>
<td>General Capacity</td>
<td>Several kWh to several MWh</td>
<td>Less than several MWh</td>
<td>Over several hundred kWh</td>
<td>Over several hundred kWh</td>
<td>Several kWh to 1 MkWh</td>
</tr>
<tr>
<td>Cost</td>
<td>$450/kWh</td>
<td>$900/kWh</td>
<td>$350/kWh</td>
<td>-</td>
<td>$1,800/kWh</td>
</tr>
<tr>
<td>Feature</td>
<td>○ Reasonable</td>
<td>○ Large-scale discharge</td>
<td>△ Requires high temperature for operation</td>
<td>○ Long life cycle</td>
<td>○ High efficiency △ High cost</td>
</tr>
<tr>
<td>Advantage</td>
<td>Can be recycled</td>
<td>Suitable for car use</td>
<td>Suitable for large-scale project</td>
<td>Suitable for large-scale project</td>
<td>Suitable for car use and middle-size project</td>
</tr>
</tbody>
</table>

Figure 5.2 Roadmap for Stationary Battery

6. CONCLUSIONS

A water thermal storage system and a ground source heat pump system, as a sensible heat storage system, were described. In addition, the current state of the ice thermal storage system and chemical heat storage system was reviewed. With regard to storage batteries, the current status of stationary batteries was introduced. Currently in Japan, further utilization of thermal storage technology is expected to be promoted in the future because of efforts related to energy conservation, low carbon, and required measures for surplus electric power from renewable energy and the promotion of heat utilization from renewable energy.

*1 The data presented in this figure refer to stationary lithium-ion energy storage systems, which are intended for peak cut (peak shift) and rapid charging. Such systems are not used in vehicular (electric motorcycles, automobiles, construction machinery, automatic conveyor, etc.) and industrial (robot, uninterruptible power supply (UPS)) applications. Although this system can serve as a backup power supply for railroads (for example) as well as stationary power storage, the object (portable storage system for portable storage) that can be moved after use is included.
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