What Would Be the Most Suitable Battery for Utility-scale Energy Storage?
- Redox Flow Battery Has Great Potential -

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Introduction

In recent years, many economies including advanced ones have declared the target of achieving carbon neutrality by 2050, veering in the direction of a decarbonized society. In response, every corner of the world anticipates an age of massive renewable energy production, indicating that the importance of stationary batteries for large-scale energy storage would increase further. Especially, redox flow battery has been gathering much higher expectations among them. This paper analyzes the background to the growing importance of stationary batteries for utility-scale energy storage and outlines the structure, operating principles and technological characteristics of redox flow batteries. Furthermore, it checks the market size and cost for redox flow batteries, Japanese companies' position in the competition for the development of these batteries in the world and specific cases in which these batteries have been introduced, before spelling out challenges to be resolved toward the further diffusion of these batteries.

1. Growing importance of batteries for utility-scale energy storage

(1) Responses to power grid problems accompanying the expansion of solar and wind power generation

Renewable energy power generation including solar photovoltaics and wind power generation represents variable power sources where output varies depending on weather conditions. Therefore, the following problems unique to variable renewables must be addressed:

Surplus electricity

Surplus electricity comes when renewable power generation increases in seasons or time zones for smaller electricity demand. As renewable power generation capacity has expanded in recent years, surplus electricity and its fluctuations have gradually increased.

Duck curve problem

As renewable power generation, particularly solar photovoltaics, expands, the fluctuation velocity of apparent demand[1] in the morning and evening increases, surpassing the limit velocity for increasing or reducing output from generators, triggering the so-called "duck curve" problem[2].

Frequency regulation capacity shortage

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[1] Apparent demand is total electricity demand minus renewable electricity production. Power grid operators adjust supply and demand in the entire electricity system to balance the apparent demand with electricity production.

[2] The problem is called such because the curve of fluctuations in net electricity demand that represents daily electricity demand minus solar PV production looks like a duck.

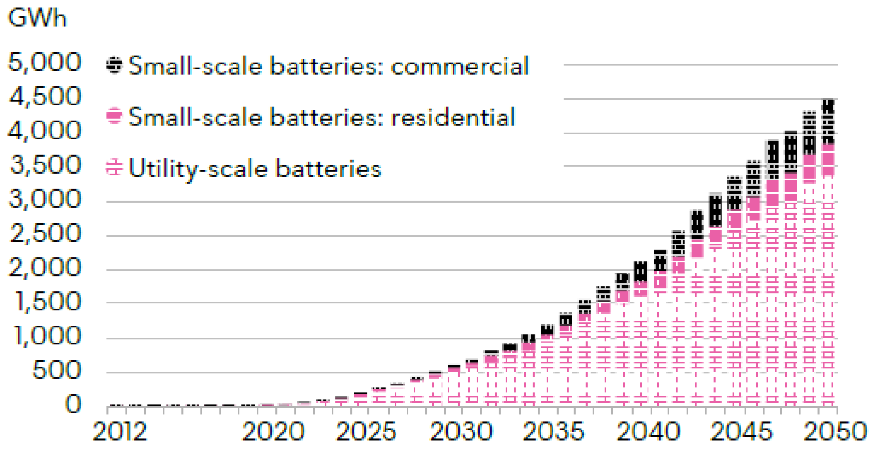
As renewable output fluctuations can disturb the grid frequency, power utilities must keep the frequency at an adequate level. In the past, fossil thermal, hydro or pumped storage power generation had been used to regulate the frequency. Under the current priority power supply rule, however, output from fossil thermal power plants that have frequency regulation capacity is preferentially curtailed when renewable electricity production increases. Therefore, how to secure the frequency regulation capacity becomes a much more challenging issue.

There are various technological measures to these problems. Among them, the charge and discharge of energy storage systems (stationary batteries) can cover power generation, transmission/distribution and consumption sectors and feature high cost-effectiveness, as shown in **Table 1** below. A forecast indicates that installed stationary storage battery capacity would rapidly penetrate from the mid-2020s and reach 4,500 GWh in 2050. Utility-scale batteries are expected to account for more than three quarters of the total capacity (**Figure 1**).

Technological measures	Power generation		Power transmission and distribution	Power consumption
	Large-scale, centralized	Distributed		
Improving balancing capacity for centralized power sources	✔			
Improving renewable output forecast accuracy	✔	✔		
Demand response				✔
Charge and discharge of energy storage systems	✔	✔	✔	✔
Controlling (curtailing) renewable power generation	✔	✔		
Wide-area supply and demand control			✔	

(Source) New Energy and Industrial Technology Development Organization (NEDO) TSC Foresight vol.20 as modified by the author

Table 1　Measures to electricity demand issues emerging from renewable power expansion



(Source) Bloomberg New Energy Finance, “2019 Long-Term Energy Storage Outlook”[3]

Figure 1 Global cumulative energy storage installations (commercial, residential & utility sectors)

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[3] BloombergNEF (July 2019), https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/

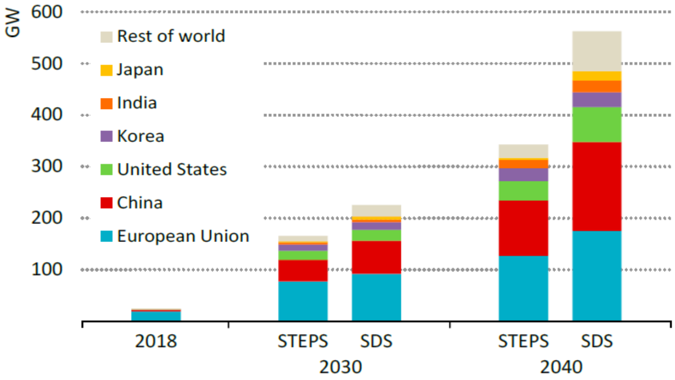
Offshore wind power generation, planned to sharply expand, is expected to aggravate these problems unique to renewable power generation. In 2020, numerous economies declared net-zero emission targets for 2050 or 2060, including three (China accounting for 39% of global CO_2 emissions, Japan for 3% and Korea for 2%)[4] among the 10 largest CO_2 emitters. The realization of a decarbonized society will require not only the power sector but also the industry, transportation and manufacturing sectors to be electrified as much as possible and electricity must be required to be free from carbon. European and other countries that already feature renewables' high energy mix shares are planning to expand offshore wind power generation to further penetrate renewables. Offshore wind power generation capacity targets for 2050 in the European Union, the United Kingdom, the United States, China and Taiwan total more than 500 GW, equivalent to the capacity of 500 nuclear power plants (**Table 2, Figure 2**). Massive wind power generation is a reasonably realistic measure to help realize a decarbonized society. However, wind power generation depends heavily on natural conditions. When wind is too strong, massive electricity generated may be abandoned. Therefore, utility-scale stationary batteries suitable for charging and discharging electricity generated by large offshore wind farms in long-time cycles will have to diffuse.

Region	2050 offshore wind capacity targets
EU	2030: 60 GW, 2050: 300 GW
U.K.	2030: 40 GW, 2050: 100 GW
Germany	2040: 40 GW
United States	2030: 30 GW (*)
China	2020: 5 GW
Taiwan	2025: 5.5 GW, 2035: 15.5 GW
Japan	2030: 10 GW, 2040: 30-45 GW

* Reported on March 29, 2021

(Source) Prepared by the author from "Offshore Wind Industry Vision" (Agency for Natural Resources and Energy)

Table 2 2050 offshore wind capacity targets



(Source) Offshore Wind Outlook 2019 (IEA, November 2019)

Figure 2 Installed capacity of offshore wind by region and scenario

Economic incentives are working for installing stationary batteries. Western countries have terminated feed-in tariffs for the initial-phase promotion of renewable energy. Instead, they have developed a mechanism in which renewable power generators are preferentially allowed to be connected to the grid and sell electricity in a timely manner in electricity exchange markets. The United Kingdom has introduced the Contract for Difference (CfD) in which the government covers the difference between a strike price fixed through auctions and a market reference price. Germany has set up the Feed-in Premium (FIP) to provide premium (subsidies) on renewable power generators' sales at market prices. California obliges electricity utilities to procure energy storage technologies (under State Law AB2514) while allowing utility-scale stationary batteries to take part in the electricity exchange market. This arrangement has prompted renewable power generators to positively generate revenue by charging batteries in time zones for lower electricity prices and discharging them (selling electricity) in the evening and nighttime when electricity prices rise with the supply-demand balance tightening (**Figure 3**). In California, battery systems have

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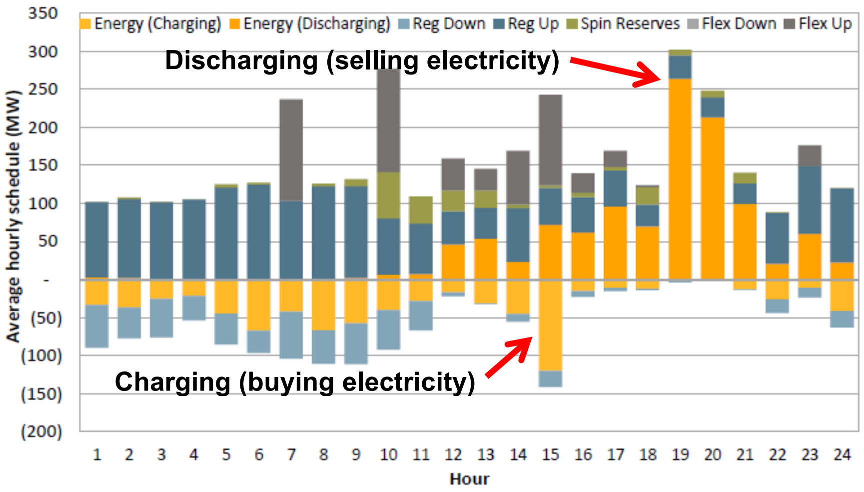
[4] Shell LNG Outlook 2021

increasingly participated in the electricity market, with their total capacity in the market standing around 400 MW at the end of the third quarter 2020[5].



(Source) CAISO, Q3 2020 Report on Market Issues and Performance

Figure 3　Average real-time battery schedules in California (September 5 and 6, 2020)

(2) Fading fossil thermal power plants

Providers of balancing capacity are changing. While decarbonization speeds and approaches differ from region to region in the world, arguments are growing for curtailing output from and capacity of fossil thermal power plants that have undertaken regulation and for fading out fossil thermal power plants from the viewpoint of environmental friendliness, as noted earlier. The European Commission in June 2019 published the EU taxonomy that dropped natural gas-fired power plants without carbon capture and storage (CCS) and coal-fired power plants with CCS as well as nuclear power plants from a list of technologies for sustainable finance. The EU taxonomy, though having no binding power, represents a great trend towards decarbonization. Fossil thermal power plants are destined to be faded out and replaced by utility-scale stationary batteries as balancing capacity.

As noted above, demand is expected to further grow for utility-scale stationary batteries suitable for energy storage. Among such batteries, I pay attention to redox flow batteries (RFBs) in which Japanese companies are well positioned in fierce competition. The following outlines the structure, operating principles and technological characteristics of RFBs and a global RFB development trend.

2. Redox flow batteries

(1) Structure and operating principles

Batteries are broadly classified into three categories: consumer batteries built into smartphones and personal computers, vehicle batteries mounted on automobiles and stationary batteries for stabilizing power grids and storing electricity. RFBs are exclusively used as stationary batteries. An RFB is an electrolyte-circulation (flow) battery. It uses pumps to circulate electrolyte stored in external tanks to positive and negative electrodes separated with an

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[5] CAISO (February 4, 2021), “Q3 2020 Report on Market Issues and Performance,” http://www.caiso.com/Documents/2020ThirdQuarterReportonMarketIssuesandPerformance-Feb4-2021.pdf, pp.125-126

ion-exchange membrane to generate ion oxidation and reduction reaction to control charging and discharging. Positive and negative electrodes are made of thin cellular carbon material and use the same electrolyte (**Figure 4**). As the electromotive force per cell is limited to 1.4 V, cells are connected in series and laminated into a stack to get a practical voltage (**Figure 5**). In addition to the conventional plant type, a container type has been developed and commercialized to reduce the transportation and construction cost and save space (**Figure 6**).

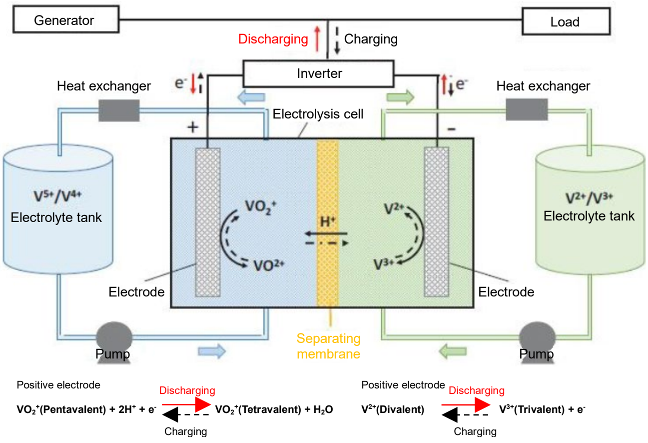

Figure 4 Operating principle of RFB[6]

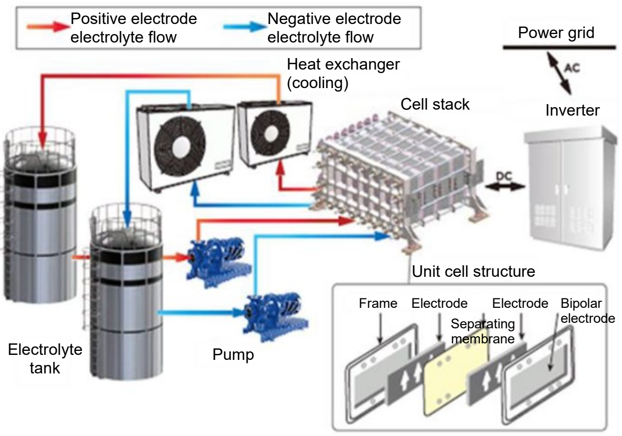

Figure 5 Cell stack configuration details[7]

Plant Type **Container Type**

Figure 6 Exterior appearance of RFB systems (Plant and Container Types)[8]

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[6] (Center for Low Carbon Society Strategy (March 2017) "Proposal for Making Innovation Policy Based on Quantitative Scenario of Technology, Economy and Society towards Realizing Low-carbon Society," Technology Development, Storage Battery System (Vol. 4) - Redox Flow Battery System Configuration Analysis and Cost Assessment -

[7] Sumitomo Electric Industries, Ltd., Redox Flow Battery Catalogue, https://sei.co.jp/products/redox/pdf/Redox_Flow_Battery.pdf

[8] Sumitomo Electric Industries, Ltd., Products Information, https://sei.co.jp/products/redox/

(2) Technological characteristics of RFBs (Table 3, Figures 7 and 8)

Table 3 below compares the technological characteristics of RFBs and other batteries. RFBs have the following excellent characteristics.

Battery Type	**Redox flow (Vanadium electrolyte solution)**	**Lithium ion**	**Sodium-sulfur (NaS) battery**	**Lead battery**
Active material (Positive/negative electrodes)	V ion / V ion	Metal composite oxide containing lithium ion / Carbon	Sulfur / Sodium	Lead oxide / lead
Theoretical energy density (Wh/kg)	100	392-585	786	167
Durability	◎ (Over 20 years) Highly durable to irregular charging and discharging	○ (about 10 years) (7,000 charging and discharging cycles)	○ (about 10 years) (4,500 charging and discharging cycles)	◎ (15-17 years) (3,000 charging and discharging cycles)
Safety	◎ (No fear of ignition, flame-resistant electrolyte)	× (Flammable)	× (Operating at high temperatures (300℃))	× (Dilute sulfuric acid and lead are harmful)
Expandability	◎ (Most expandable) (Output and capacity can be designed independently)	○ (Expandable) (Output and capacity increase linearly)	○ (Expandable) (Output and capacity increase linearly)	× (not expandable)
Charge and discharge time	◎ Available for long time (Available for 24-hour storage and discharging)	△ Available for high-speed, high-output charging/discharging	○ Positioned between RFBs and lithium ion batteries	× Short time
Output	◎Some 10 times as much as rated output can be discharged in a short time	◎ （High output）	◎ (Long time / high output)	◎(Short time / high output)
Charge/discharge efficiency	△ Battery alone: 75% System: 70%	◎ 95%	◎ Battery alone: 85% System: 75%	◎ 80-90%
Major accessory	Circulation pump	Nothing particular	Heater	Nothing particular
Resource constraints	△ (Vanadium)	× (Lithium)	◎(Not Applicable)	◎ (Not Applicable)
Features (Advantage ○ /disadvantage ×)	○ Residual power is easy to measure ○ Electrolyte solution can be reused almost permanently ○ Highly safe, installable in urban areas × Electric current can be lost	○ Used frequently for consumer products ○ High energy density ○ High charge/discharge efficiency ○ Self-discharge is limited × Safety (flammable) × Unsuitable for enlargement × Vulnerable to over-charging/discharging	○ Frequently used for storing electricity ○ Capacity can be increased with space saved ○ No self-discharge ○ Low cost (needing no rare earths) × Ignition risk (must be kept at 300℃) × Power consumption for warming	○ Used frequently for vehicles × Large and heavy ×Harmful to humans × Self-discharge is possible

(Source) Prepared by the author from Shigematsu[9], NEDO TSE Foresight vol.20[10], etc.

Table 3 Comparing technological characteristics of utility-scale batteries for energy storage

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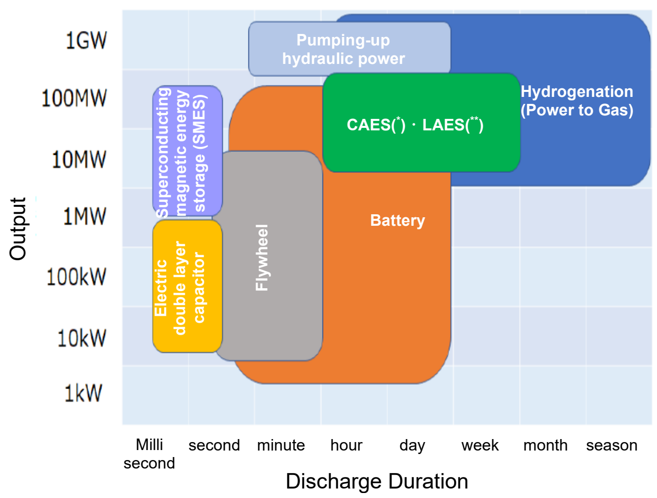
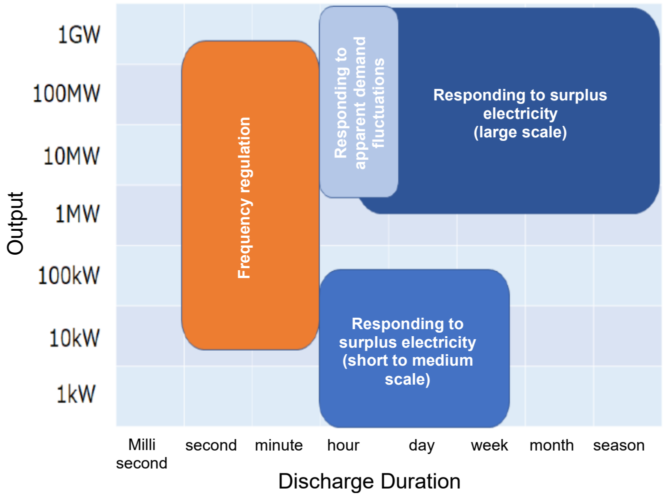
[9] https://sei.co.jp/technology/tr/bn179/pdf/sei10674.pdf
(T. Shigematsu, Redox Flow Batteries for Electricity Storage, July 2011, SEI Technical Review, Vol. 179)

[10] https://www.nedo.go.jp/content/100866310.pdf (New Energy and Industrial Technology Development Organization, TSC Foresight vol. 20 (July 2017), Towards Formulating Technology Strategy for Electricity Storage)





(Source) Prepared by the author from NEDO TSC Foresight vol.20 (July 2017)

Figure 7 Output and discharge durations for energy storage technologies

Figure 8 Output and discharge duration required for each application

Excellent durability

First of all, RFBs feature excellent durability. Vanadium electrolyte redox flow batteries (VRFBs)[11], the most popular among RFBs, **only change the valence of vanadium ions in an electrolyte solution when charging and discharging electricity, remaining free from the dissolution or precipitation of electrodes. Their degradation is limited, allowing them to remain in service for a long time, with the charging and discharging frequency being unlimited.** Thanks to the excellent durability, RFBs are more competitive in the lifecycle cost than other stationary batteries including lithium-ion batteries. **RFBs are also durable in terms of irregular charging and discharging, having a high affinity for power generation technologies plagued with wild and unpredictable output fluctuations, including offshore wind farms that are expected to diffuse massively in Japan. Moreover, the vanadium electrolyte solution would not degrade through charging or discharging but remain in service almost permanently. It can even be recycled**, meaning that users can reduce the initial RFB installation cost by leasing electrolyte solutions (classifying rents as operating expenses).

Extremely high safety

Lithium-ion and NAS batteries use flammable materials, having a high risk of ignition. In contrast, **RFBs have no such risk because their electrodes and electrolyte solution are inflammable or flame-resistant. They also operate at ordinary temperatures, featuring extremely high safety.** RFBs can charge and discharge electricity for a long time ranging from several hours to several days, being suitable for stabilizing grids connected to large-capacity renewable power plants. Thanks to the high safety, RFBs can be even securely installed in urban areas. In this way, RFBs have great potential to play key roles in a decarbonized society using massive renewable energy (see Chapter 6).

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[11] VRFBs account for about 58% of all RFBs in use, according to IDTechEx (June 2020), https://www.idtechex.com/en/research-report/redox-flow-batteries-2020-2030-forecasts-challenges-opportunities/723

High expandability (Figure 9)

The electrolyte solution tank capacity (kWh) and the cell stack output (kW) can be designed independently, meaning that the RFB capacity and output can be designed flexibly. While output increases linearly as capacity increases for other batteries, an RFB's capacity can be raised through the addition of electrolyte solution tanks with output kept unchanged. As its capacity is expanded to enable charging and discharging over a longer time above 8 hours, the RFB can increase its cost competitiveness against other stationary batteries including lithium-ion batteries. (If the lithium-ion battery that uses the rare metal lithium for electrodes expands its capacity, however, the material cost may increase substantially to the disadvantage of its cost competitiveness.)

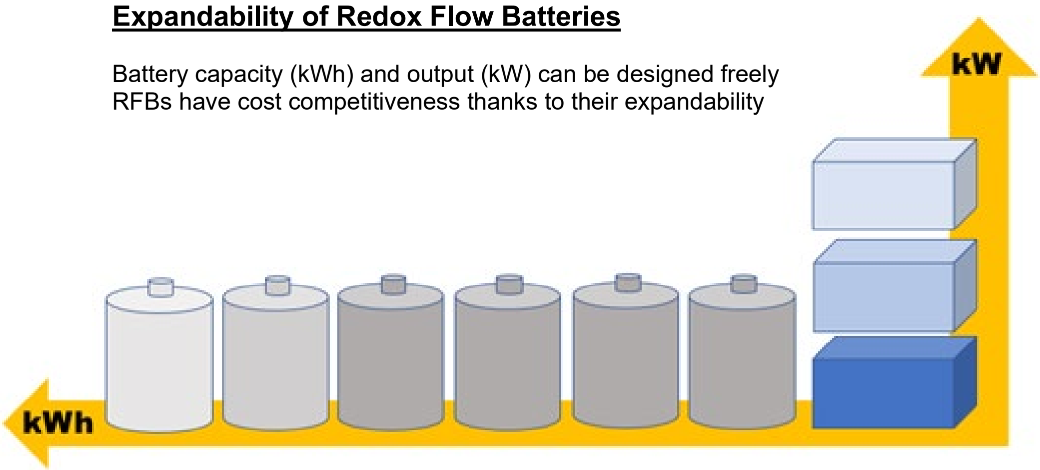


Figure 9 Conceptual diagram of RFBs' expandability

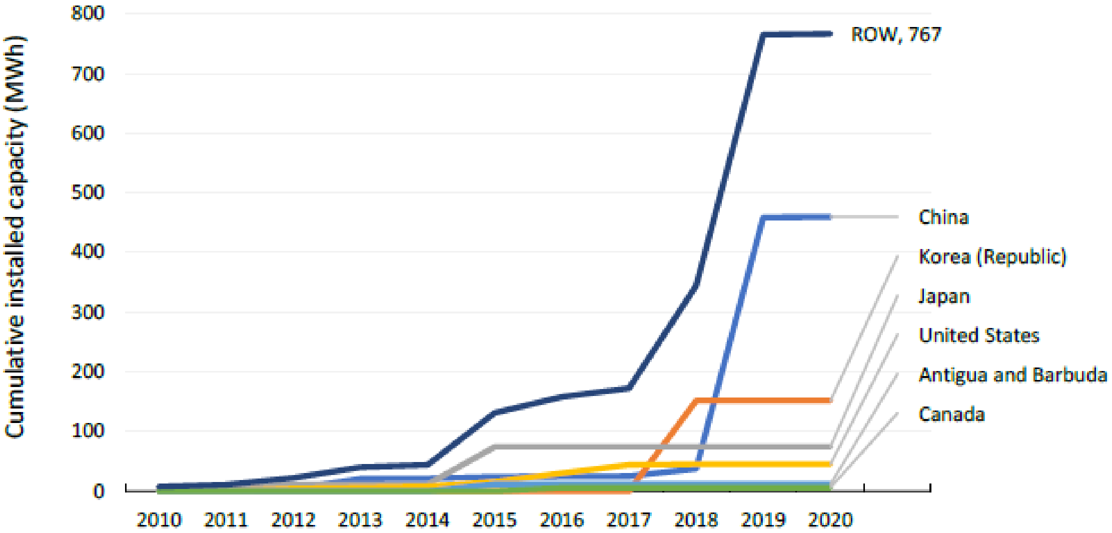
Long charge/discharge cycle and high output in milliseconds

Generally, lithium-ion batteries have strength in charging and discharging electricity in a short time of milliseconds. However, **an RFB can discharge 10 times as much as the rated output in milliseconds and has a long charge/discharge cycle such as 24 hours for charging before 24 hours for discharging,** being suitable for large-scale offshore wind and other renewable power generation for which long charge/discharge cycles are required. RFBs can also be used as backup power sources that are required to continuously charge and discharge electricity for a long time of 24 to 48 hours during an outage caused by natural disasters, which have recently tended to bring about huge damage. (In contrast, lithium-ion and NAS batteries are suitable for charge/discharge cycles of several hours due to their technological characteristics.) In addition to their safety, RFBs have particularly excellent technological characteristics for providing grid stabilization functions to be required when massive renewable power generation capacity is installed towards the 2050 carbon neutrality target.

Disadvantages for RFBs include a low energy density attributable to separated electrolyte solution tanks, a charge/discharge efficiency of some 70% lower than for other stationary batteries and the insecure supply of the rare metal vanadium. The low charge/discharge efficiency is attributable to losses from the circulation of electrolyte solution with pumps and can be raised to around 80% through better loss control. As for the vanadium resource constraint, initiatives are being implemented to develop a more efficient electrolyte solution including no vanadium and to secure a stable supply of vanadium at cheap prices irrespective of international commodity price fluctuations (see details in Chapter 5).

3. Market size, cost, Japanese companies' position in global development competition

(1) Market size

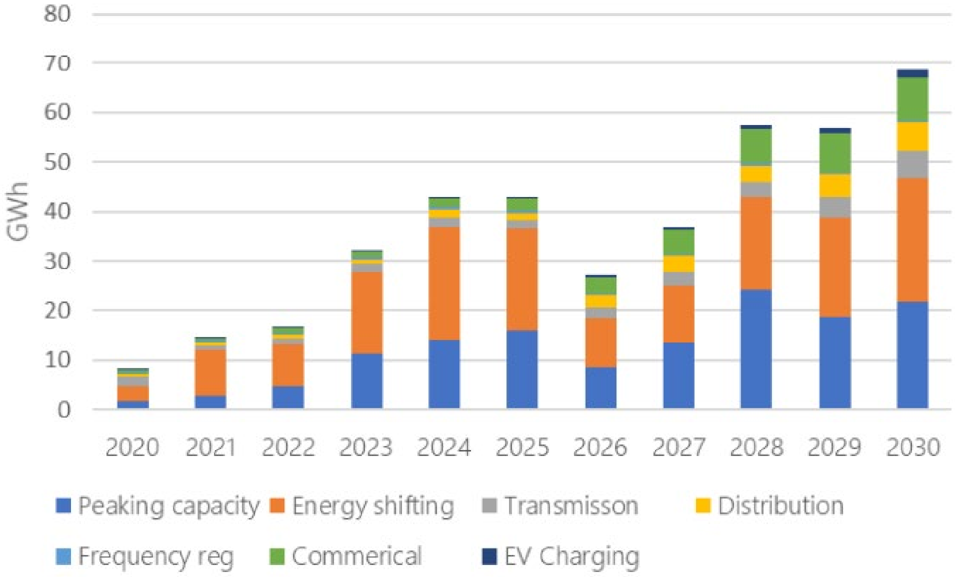


(Source) Bloomberg New Energy Finance (2020), "Storage Data Hub – Storage Assets"

(Note) ROW: Rest of the World

Figure 10 Cumulative installed RFB capacity (by country, 2010-2020)

First, I would like to check the penetration of RFBs. **Figure 10** above shows cumulative installed RFB capacity in the world. RFBs rapidly penetrated from 2018 to 2019, driven by China and Korea.



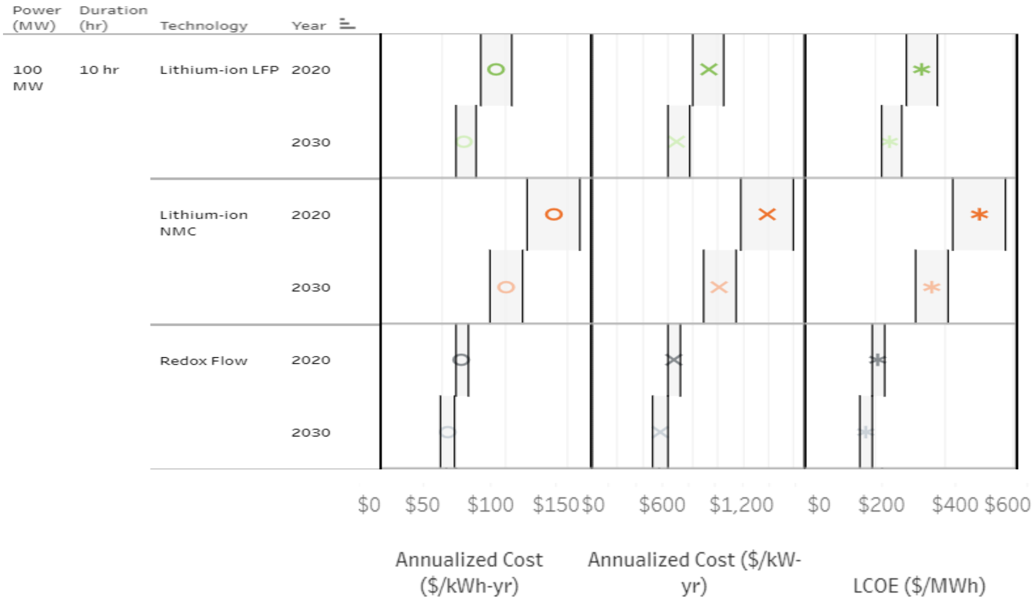
(Source) J. Frith, "Emerging Energy Storage Technologies," Bloomberg New Energy Finance (2020)

Figure 11 RFB market outlook (2020-2030)

Figure 11 above shows a long-term RFB market outlook. The RFB market is expected to continue growing, with a total capacity reaching around 70 GWh in 2030. Major RFB applications are predicted to include energy shifting and peaking capacity.

(2) Cost

The most critical factor behind RFBs' failure to penetrate is the high initial installation cost, but the cost has been lowered down to 1.2-1.3 times the levels for other utility-scale stationary batteries. The unit installation cost for a utility-scale RFB system for a long charge/discharge cycle above 8 hours and a long lifecycle can be 60,000 yen/kWh[12] including electrolyte solution. If electrolyte solution is leased in and excluded from initial investment, the cost may slip below 40,000 yen /kWh. A useful reference for a cost outlook towards 2030 is an analysis by the U.S. Pacific Northwest National Laboratory under support from the U.S. Department of Energy. It indicates that RFBs are fairly competitive in terms of the annualized cost ($/kWh, $/kW) and the levelized cost of electricity (LCOE, $/MWh) in comparison with other stationary batteries under the assumption of the system having an output at 100 MW and a charge/discharge cycle at 10 hours (**Figure 12**) [13].



(Note) The LCOE ($/MWh) was computed by dividing annualized cost by annualized output (kWh).

Figure 12 Utility-scale stationary battery cost outlook (2020 and 2030)

(3) Japanese companies' positions in global RFB development competition

Demand has been growing year by year for RFBs with excellent technological characteristics suitable for utility-scale stationary batteries. A number of RFB manufacturers reaches as many as 50 to 70 in the world. While their elimination and consolidation have actively made progress in recent years, Sumitomo Electric Industries (Japan), Invinity Energy Systems (U.K.), Schmid Group (Germany) and VRB Energy (China) have

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[12] According to a survey report on the impact of solar singularity, if the battery price slips below 60,000 yen/kWh, a storage parity in which the introduction of batteries becomes economically advantageous may be achievable.

[13] Pacific Northwest National Laboratory, "Energy Storage Cost and Performance Database," https://www.pnnl.gov/ESGC-cost-performance

ranked ahead of others in terms of system quality and sales. As stationary batteries become larger for large scale renewable power generation such as offshore wind, technology verification at installation sites is required more and more. Although hopes have recently been placed on the early commercialization of all-solid, all-polymer and other next-generation batteries, RFBs are fairly viewed as having a lead of three to five years over these next-generation batteries in that technology verification at installation sites has already made great progress. Particularly, Sumitomo Electric Industries features a long history of RFB development from the 1980s, RFB demonstrations at various sites in the world and massive deliveries of practical RFBs, boasting an advantageous position over competitors. On the other hand, many Chinese companies such as VRB Energy and Pongke Power have joined the market for RFBs as well as lithium-ion batteries in a manner to intensify competition (**Table 4**).

Manufacturer	Output	Capacity	Note
Sumitomo Electric Industries (Japan)	250 kW	750kWh (3hr)-1.5MWh (6hr)	Single module specification
Invinity Energy Systems (U.K.)	78 kW-10 MW	220 kWh - 40 MWh	Operational over more than 25 years
Schmid Group (Germany)	5-60 kW	30-200 kWh	Single module specification
Volterion (Germany)	2.5-15 kW	13 kWh	Operational over more than 20 years
VRB Energy (China)	250-500 kW	4-80 MWh	Developing GW-class RFBs (maximum output at 250MW, 10hr)

Table 4 Major RFB manufacturers and their products lineups

4. RFB installation cases

Large stational RFBs have diffused in China, the United States, Australia and Europe. Apparent factors behind the diffusion include growing needs for longer charge/discharge cycles (charge/discharge cycles have lengthened from 2-3 hours to 8-48 hours due to greater offshore wind farm capacity, RE100 (Renewable Energy 100% initiative) participants have increased globally and demand has grown for utility-scale stationary batteries for longer charge/discharge cycles through progress in BCP (business continuity planning) responses).

As an overseas case for the installation of an RFB, a deal for installing an 8 MWh VRFB made by Invinity Energy Systems at a 6 MW solar PV array in South Australia was announced in December 2020. Under 5.7 million Australian dollars in funding by the Australian Renewable Energy Agency (ARENA), the VRFB will be delivered in the second half of 2021[14] (**Figure 13**). Anticipating the future expansion of demand for VRFBs, Schmid Group announced in June 2020 that it would form a joint venture with Nusaned Investment (an investment subsidiary of Saudi Basic Industries Corporation) to establish a VRFB plant and a research and development center in Saudi Arabia. The plant will have an annual production capacity of 3 GWh, being among the biggest RFB production facilities[15].

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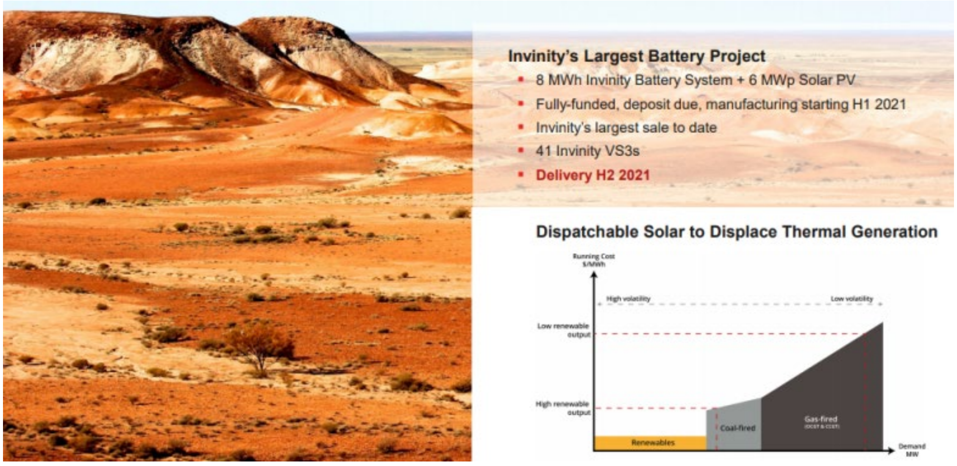
[14] ARENA (November 11, 2020, Press Release), “First grid scale flow battery to be built in South Australia,” https://arena.gov.au/news/first-grid-scale-flow-battery-to-be-built-in-south-australia/

[15] Schmid Group (May 6, 2020, Press Release), “Everflow JV to manufacture Vanadium Redox Flow Batteries (VRFB) in KSA,” https://schmid-group.com/en/schmid-group/news-events/press-releases/everflow-jv-to-manufacture-vanadium-redox-flow-batteries-vrfb-in-ksa/



Invinity's Largest Battery Project

- 8 MWh Invinity Battery System + 6 MWp Solar PV
- Fully-funded, deposit due, manufacturing starting H1 2021
- Invinity's largest sale to date
- 41 Invinity VS3s
- **Delivery H2 2021**

Dispatchable Solar to Displace Thermal Generation

(Source) Invinity Energy Systems[16]

Figure 13 Utility-scale VRFB in South Australia (Yadlamalka Solar + Storage Project)

In Japan, Hokkaido Electric Power Co., Inc. (HEPCO) and Sumitomo Electric Industries jointly installed a utility-scale RFB (with rated output at 15 MW and storage capacity at 60 MWh) at the Minami Hayakita electric power substation as part of the main grid system to demonstrate the performance of the RFB over three years between February 2016 and January 2019 as new regulation and balancing capacity responding to renewable energy output fluctuations and establish optimum control technology[17]. HEPCO used the demonstration data to consider introducing a utility-scale stationary battery to raise the capacity for accepting electricity from wind farms. In March 2017, it invited bids for a project for a 600 MW wind power generation facility on the premises of a 360 MWh battery to be installed under a joint funding scheme[18]. Following the demonstration, HEPCO ordered a VRFB system (with installed capacity at 510 MWh (170 MW x 3 hours) from Sumitomo Electric Industries in July 2020. It is planned to be completed by March 2022[19] (**Figure 14**).

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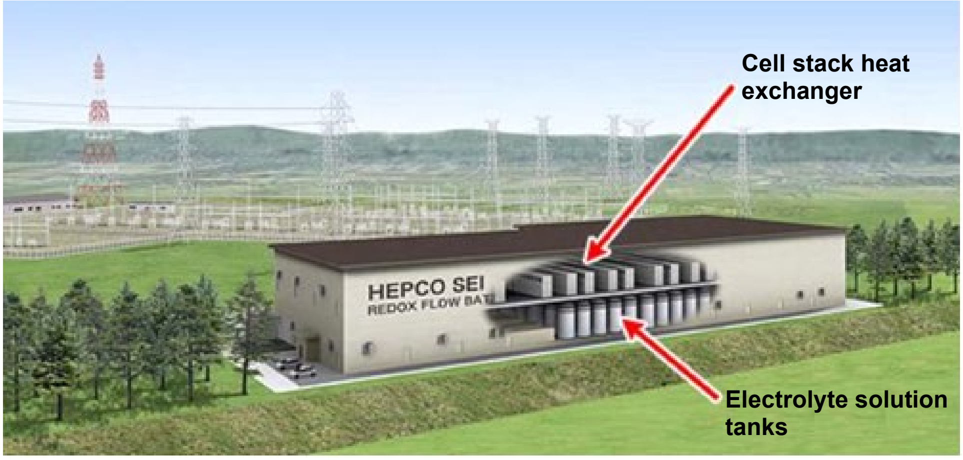
[16] Invinity Energy Systems (December 2020), "Production Flow Batteries," https://invinity.com/wp-content/uploads/2020/12/Invinity-Corporate-Presentation-Nov20_WEB.pdf

[17] (New Energy Promotion Council (February 2018) "Large Battery System Demonstration at Minami Hayakita Electric Power Substation") https://www.nepc.or.jp/topics/pdf/180320/180320_9.pdf

[18] (Nikkei Cross Tech (August 9, 2917) "Achievements of Large Redox Flow Battery Launched in Northern Japan") https://xtech.nikkei.com/dm/atcl/feature/15/415282/080700019/

[19] Sumitomo Electric Industries press release (August 7, 2020) "Sumitomo Electric awarded for Redox Flow Battery Systems from Hokkaido Electric Power Network" https://sumitomoelectric.com/sites/default/files/2020-12/download_documents/20200807Sumitomo%20Electric%20awarded%20for%20Redox%20Flow%20Battery%20Systems%20from%20Hokkaido%20Electric%20Power%20Network.pdf



(Source) Nikkei BP "Next-generation Batteries 2018"

Figure 14　Conceptual drawing of a large VRFB system to be introduced by HEPCO

5. Challenges

Cost reduction is the key to the further penetration of RFBs. Cost reduction measures include the improvement of battery efficiency (see 2. (2)) and the stable procurement of cheap vanadium. **Figure 15** below shows a breakdown of the VRFB cost and the electrolyte solution cost. Electrolyte solution accounts for about 40% of the total VRFB cost (electrolyte solution's cost share increases as a charge/discharge cycle lengthens). Vanadium, a main raw material for electrolyte solution, captures about 45% of the electrolyte solution cost. Producers of the rare metal vanadium are limited to China, Russia, the United States, etc. Japan must depend on imports from these countries for vanadium supply. Vanadium prices can rise easily in response to an increase in demand from the steelmaking industry that uses massive vanadium for specialty steel[20]. This is a reason why lithium-ion batteries that have diffused widely for vehicles and consumer products have been used for storing electricity from renewables.

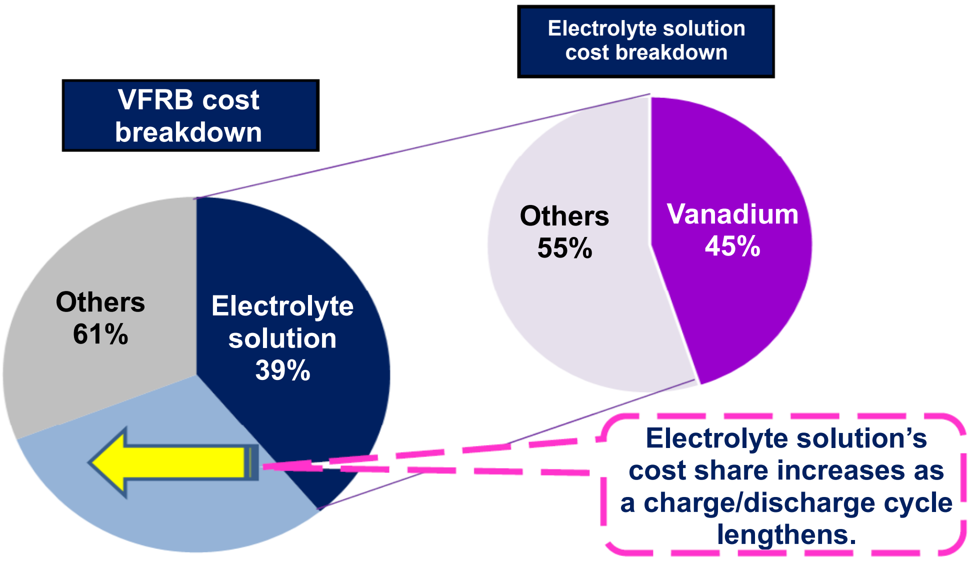


Figure 15　VRFB cost breakdown and electrolyte solution cost breakdown

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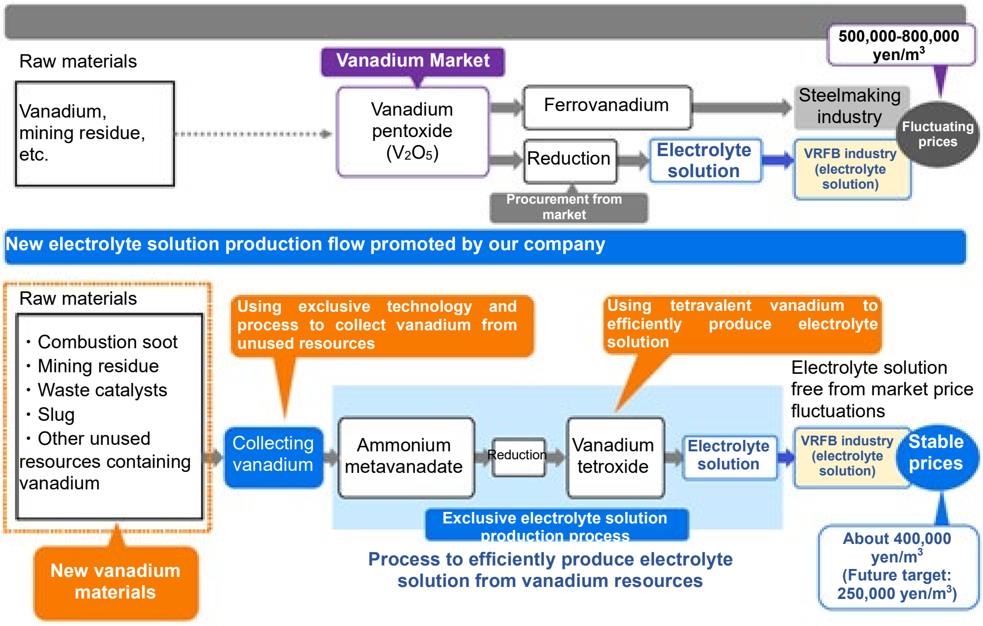
[20] In the past, market prices shot up to levels that were seven to eight times as high as normal levels.

To reduce the electrolyte solution cost, Sumitomo Electric Industries is developing RFBs using titanium or manganese instead of vanadium. If RFBs are expected to spread in a full-fledged manner, however, priority should be given to the stable procurement of vanadium for the established RFB technology. LE SYSTEM, a vanadium electrolyte solution production venture based in Kurume, Fukuoka Prefecture, has developed a technology to collect vanadium from oil coke, combustion soot from thermal power plants, iron-ore mining residue, waste catalysts, slug and other vanadium-containing wastes and unused resources and use collected vanadium for producing electrolyte solution efficiently. By partnering with other companies in Japan to collect vanadium free from international commodity price fluctuations, LE SYSTEM could halve vanadium electrolyte solution prices at 500,000-800,000 yen/kL[21] and stably provide vanadium electrolyte solution (**Figure 16**). LE SYSTEM has conducted domestic demonstration tests for the technology under funding by NEDO and is currently pursuing its commercialization. The company plans to complete a vanadium collection plant and an electrolyte production facility under construction in Namie, Fukushima Prefecture, by August 2021. The facilities will annually ship 5 million liters of electrolyte solution to domestic customers. In anticipation of renewable energy diffusion in Japan and other countries, LE SYSTEM plans to build plants in Yamaguchi and other prefectures to boost its electrolyte production capacity to 20 million liters per year by 2025. It is also preparing for a project to integrate vanadium collection and electrolyte solution production at overseas sites rich with untapped resources including mining residue. The LE SYSTEM technology could lower the RFB cost to 20,000-30,000 yen/kWh[22] paving the way for VRFBs to be used for solar PV. On the other hand, vanadium procurement from abroad has become difficult. International vanadium prices have begun to spike against the backdrop of growing global VRFBs demand. Particularly, competition to purchase mining residue with high vanadium contents has intensified, making it difficult for private companies to procure mining residue from abroad.



(Source) Presentation material for NEDO venture business matching meeting (LE SYSTEM)

Figure 16 Innovative vanadium electrolyte solution production flow

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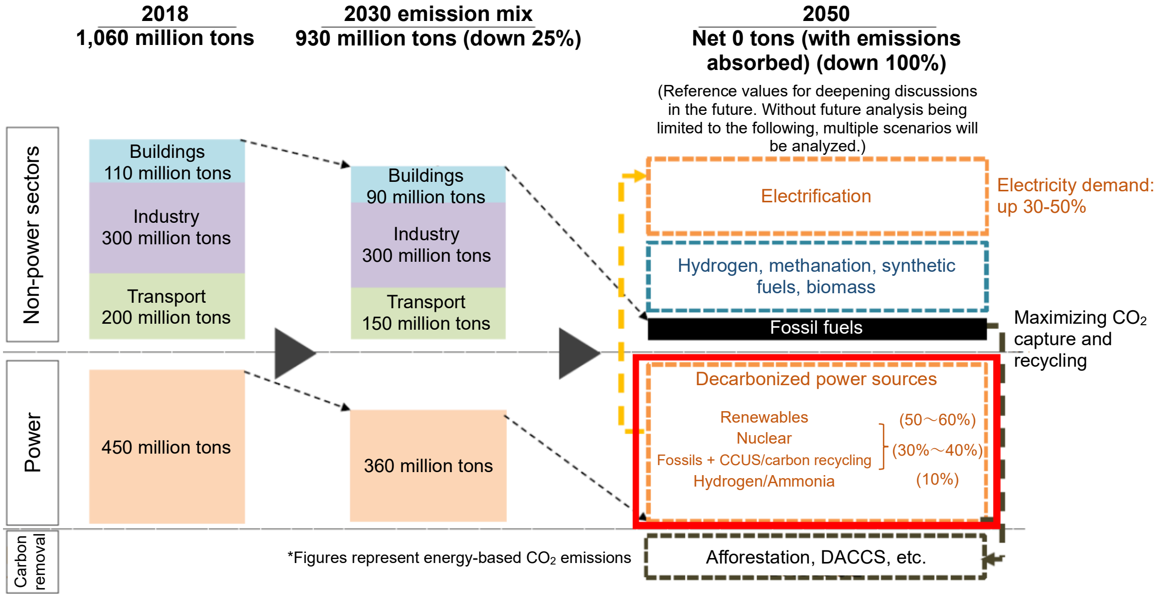
[21] (Nikkei Shimbun (April 16, 2021) “LE SYSTEM to commercially produce electrolyte solution for long-life, safe batteries in Fukushima) https://www.nikkei.com/article/DGXZQOJC089I60Y1A400C2000000/

[22] *Ibid.*

6. Realizing an RE100 decentralized model with a higher renewable energy share

Chapter 2 said that RFBs have great potential to play key roles in a decarbonized society using massive renewable energy. The 2050 carbon neutral target pursued by the Japanese government is difficult to achieve. **Figure 17** below indicates an image of a transition to carbon neutrality in 2050. A proposed decarbonized power mix for 2050 comprises renewable energy accounting for 50-60% of total power generation, nuclear energy and fossil fuels (with CCU/CCUS/carbon recycling) for 30-40% and hydrogen/ammonia for 10%. Given that the renewable energy share would have to be expanded if nuclear power plant replacement/restarting is difficult, the current centralized urban model focusing on fossil-fired power generation may have to be transformed into a decentralized model dominated by renewable energy through a bold change in the way of thinking.



(Source) Ministry of Economy, Trade and Industry, “Green Growth Strategy to Support Japan’s 2050 Carbon Neutral Goal” (December 2020)

Figure 17 Image of transition to 2050 carbon neutrality

In line with the 2050 Carbon Neutral Declaration, local governments are expected to formulate and publish their respective carbon zero plans. There may be numerous challenges to overcome. A potential option arising from a bold change in the way of thinking would be an RE100 renewable energy self-sufficiency model to be powered 100% by solar PV combined with utility-scale stationary batteries. Batteries being installed in urban areas would have to be extremely safe or free from the risk of ignition. From the viewpoint of emergency power sources for business continuity planning as well as renewable energy promotion, stationary batteries would have to have charge/discharge cycles as long as two to three days to maintain public services amid power outages caused by natural disasters. Given the abovementioned technological characteristics, VRFBs are highly adaptable to such emergency situations.

On the Japan Electric Power Exchange, electricity prices frequently fall to as low as 0.1 yen/kWh in spring, autumn and on weekends when electricity demand is lower. Batteries may be used for charging when electricity prices are low and discharging when such prices are high. In this respect, hopes may grow on VRFBs that can demonstrate a price advantage by storing electricity for a long duration.

From the viewpoint of sustainability, it is desirable for batteries to contribute to realizing a recycling-oriented society by recycling resources. RFBs' technological characteristics meet the desirability. Therefore, RFBs are fairly expected to play growing roles in realizing a decarbonized society.

Conclusion

Many economies in the world are veering in the direction of realizing net zero emissions by 2050. This trend will accelerate in the future, being irreversible. Although great hopes are placed on hydrogen as a new carbon-free energy source, relevant costs are still high. Without a further breakthrough, it may take much time to realize a low-cost, stable supply network for hydrogen. In such a situation, many economies have chosen a realistic solution to adopt renewables as a mainstay power source. The massive penetration of stationary batteries that are safe and highly durable, suitable for long charge/discharge cycles and able to be easily enlarged for power grids is seen as indispensable for the coming age of massive renewable energy introduction.

The Japanese government declared a 2050 carbon neutral target in October 2020. A pillar for its sixth Strategic Energy Plan now under formulation is the adoption of renewables including offshore wind as a mainstay power source. As the massive penetration of batteries is indispensable for the further diffusion of renewables, policy support will grow even more important for enhancing Japanese battery manufacturers' international competitiveness, as well as for nurturing and expanding the battery industry including electrolyte solution producers. Regarding RFBs and other batteries, Japan faces the problem of how to secure rare metals that are endowed in a limited range of countries and vulnerable to international price fluctuations. For the purpose of reducing and stabilizing RFB prices, Japan's public and private sectors are required to cooperate in procuring vanadium as a resource that has not necessarily been highlighted.

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