EU-Japan Centre
for Industrial Cooperation
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# The Energy Storage Landscape in Japan

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**Market & Industry Analysis**

# 1. Introduction

## a. Executive Summary

In the 21st century, the future of the energy landscape throughout the industrialized world is a context defined by the rise of renewable energies, as well as the diversification and diffusion of energy generation. However, the emergence of this reality gives rise to the need for highly-specialized supporting infrastructure and technologies.

Renewable energy sources, such as wind and photovoltaic energy generation, generate power intermittently, both increasing their cost and undermining their viability as primary energy generation sources. The intermittent nature of energy generation is further exacerbated by the fact that peak energy generation is likely to occur at off-peak consumer demand scenarios. In order to be reliably integrated into the existing energy grids therefore, energy storage is required to provide ancillary services, thereby smoothing the integration into the energy markets

Another feature of the 21st century is the rise of smart grid infrastructure, allowing both localized and even small-scale energy generation, as well as local-level, small-scale energy trading.

In principle, associated energy storage capacity is needed in all of these contexts. Energy storage technology adds value by maintaining energy system flexibility in a cost-effective manner across the energy supply chain.

While energy storage has traditionally been a key component of energy infrastructure systems in developed energy markets, the technological developments of the coming century give rise to a new set of demands for technological flexibility and sophistication, as well as a new scale at which energy storage technology will be needed.

In Japan, one of the world’s primary energy – and renewable energy– markets, as well as the current world leader in smart-grid and energy storage technology, the specific idiosyncratic situation gives rise to considerably more well-established demand for energy storage technology going forward, considering the country’s long-term energy market needs.

Aside from Japan’s plans for wide-spread implementation of smart-city and smart-grid technology during the coming decades, the country’s market is also defined by a general shift away from nuclear and fossil-fuel energy towards a highly-diffuse renewable energy infrastructure. The emergence of this new reality will have ramifications not only at the grid-level utility-scale, but also at the local-scale and even the residential scale. Additionally, this means not only demand for actual energy storage devices, but also for infrastructure and software with which such systems interact.

For European firms interested in Japan’s market, this shift presents opportunities, especially at the residential-scale level, where the competitive market is the most robust, and the regulatory burden the smallest. Given that residential-scale is also the segment of the market which has the smallest hurdles in terms of entry costs, it is also the optimal insertion point for SMEs. A further point of interest for the European firm interest in this sector of the Japanese economy, is the potential for similar demand to emerge in Europe in the coming decades, by which time, presence and experience on the larger and more well-established Japanese market would be highly advantageous to the establishment of substantial market share in Europe.

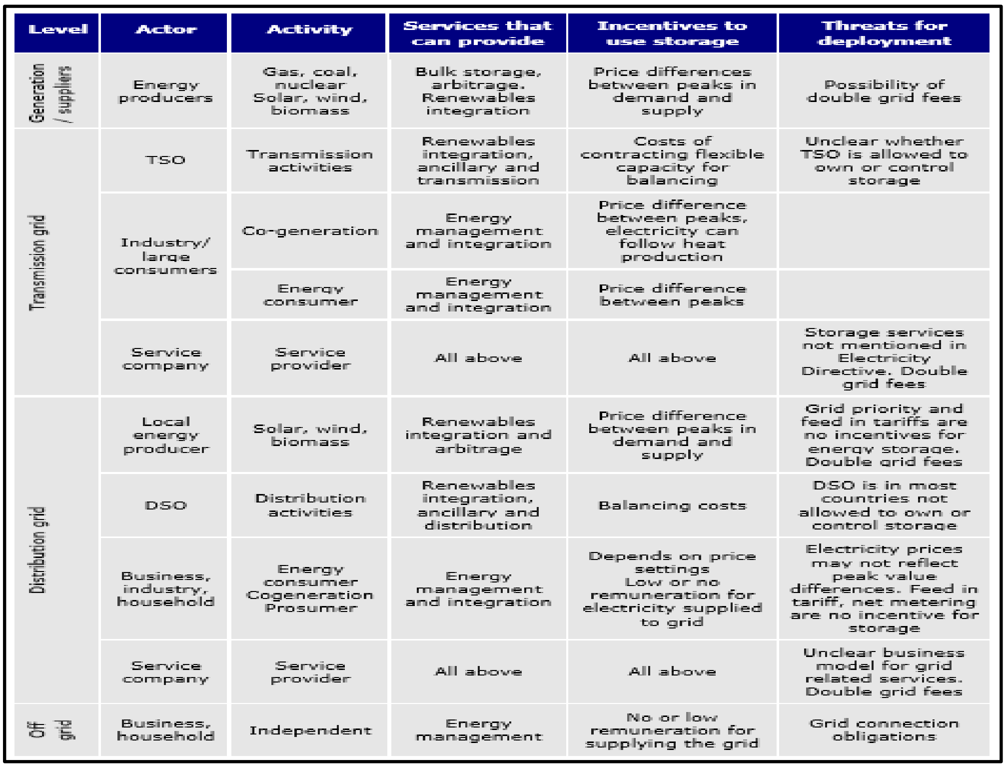
## b. Scope of the Research in to Energy Storage Market

In industrialized markets, energy storage has traditionally been a key component of energy infrastructure systems, adding value by maintaining energy system flexibility in a cost-effective manner across the energy supply chain. While energy storage markets have certainly added value to coal-fired and nuclear based energy supply chains, the evolving nature of energy landscapes in the major industrialized markets at large – and in Japan in particular – has created new challenges and new demands, which have given rise to new technologies and regulatory responses to energy storage.

In a 21st century context, the advance of energy storage technologies and markets is of core relevance for the future economic and logistical development of both smart grid systems and renewable energy generation technologies. With this in mind, a diversification of economically-viable energy storage technologies is currently emerging to meet the new economic realities given rise to by the logistical demands of the emerging 21st century energy landscape.

In principle, the energy storage market has many stakeholders, who maintain various and diversified incentives and priorities. Primarily, incentives to deploy energy storage, relate either to reducing and managing costs within the energy supply chain, or to the opportunity to add value by acting on price differences between peaks in supply and demand. Threats meanwhile, relate primarily to uncertainty regarding efficient markets, accurate prices, regulatory ambiguity, and double grid fees. Figure 1 provides a thumbnail-overview of the overall taxonomy of the primary stakeholders, for whom the development of energy storage markets are relevant, as well as their specific activities and interests at three stages of the energy market’s supply chain (Generation, Transmission, and Distribution).

**Figure 1: Actors and Incentives in the Energy Storage Market**[1]



| Level | Actor | Activity | Services that can provide | Incentives to use storage | Threats for deployment |
|---|---|---|---|---|---|
| Generation / suppliers | Energy producers | Gas, coal, nuclear Solar, wind, biomass | Bulk storage, arbitrage. Renewables integration | Price differences between peaks in demand and supply | Possibility of double grid fees |
| Transmission grid | TSO | Transmission activities | Renewables integration, ancillary and transmission | Costs of contracting flexible capacity for balancing | Unclear whether TSO is allowed to own or control storage |
| | Industry/ large consumers | Co-generation | Energy management and integration | Price difference between peaks, electricity can follow heat production | |
| | | Energy consumer | Energy management and integration | Price difference between peaks | |
| | Service company | Service provider | All above | All above | Storage services not mentioned in Electricity Directive. Double grid fees |
| Distribution grid | Local energy producer | Solar, wind, biomass | Renewables integration and arbitrage | Price difference between peaks in demand and supply | Grid priority and feed in tariffs are no incentives for energy storage. Double grid fees |
| | DSO | Distribution activities | Renewables integration, ancillary and distribution | Balancing costs | DSO is in most countries not allowed to own or control storage |
| | Business, industry, household | Energy consumer<br>Cogeneration<br>Prosumer | Energy management and integration | Depends on price settings<br>Low or no remuneration for electricity supplied to grid | Electricity prices may not reflect peak value differences. Feed in tariff, net metering are no incentive for storage |
| | Service company | Service provider | All above | All above | Unclear business model for grid related services. Double grid fees |
| Off grid | Business, household | Independent | Energy management | No or low remuneration for supplying the grid | Grid connection obligations |

In Japan, the establishment and promotion of both energy storage policy, as well as an overall energy policy focused on emphasizing regional flexibility, energy diversification, and improved regional self-sufficiency, is explicitly enshrined Japan's 2014 Fourth Strategic Energy Policy, which emerged in the aftermath of the 2011 Fukushima disaster.

The plan specifically mentions the importance of solar, wind, and hydropower as strategic energy generation technologies, and makes explicit mention of the Japan revitalization strategy's mention of energy storage markets. Furthermore, the Fourth Strategic Energy Plan sets an explicit target of capturing 50% of the world's projected global storage battery market by 2020, which the plan estimates to be valued at ¥20 Trillion.[2]

Japan's policy towards battery technology for energy storage systems is outlined in both Japan's 2014 Strategic Energy Plan and the 2014 revision of the Japan Revitalization Strategy. In Japan's Revitalization strategy, Japan has the stated goal to capture 50% of the global market for storage batteries by 2020.

## 2. The Energy Storage Sector

### a. Energy Storage Applications

In principle, energy storage technology plays a central role in both the integration of renewable energy sources and the establishment of smart-grid systems, both of which are stated goals of Japan's Post-Fukushima energy policy, as

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[1] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

[2] Ministry of Economy, Trade and Industry (METI), (2014), Fourth Strategic Energy Plan

outlined by Japan’s 2014 Fourth Strategic Energy Policy and as demonstrated by Japan’s METI-supervised smart-cities projects and renewable energy subsidies.

Given the fundamental direction of Japan’s energy landscape, energy storage technology is set to play an integral part in Japan’s energy future due to energy storage technology’s role in both smart grid technology and in renewable energy’s integration into Japan’s energy landscape.

A developed energy-storage market serves to underpin the transition towards an energy-landscape characterized by generalized end-user flexibility and regional self-sufficiency, in which end-users can contribute generation capacity, and regions can rely on wide diversification of energy-generation and energy-sourcing measures.

### i. Energy Time Shift/Time-Arbitrage

Energy time-arbitrage involves energy generation or procurement during low-price energy-glut periods, to be stored and subsequently sold or consumed during period in which energy prices are elevated.

Energy storage technology can also serve in the time-shift function by storing excess production for the purposes of consumption-smoothing or for distribution during high-price periods. In the context of renewable energy production such as from photovoltaic or wind energy production, excess production might otherwise have to be curtailed in the absence of adequate energy storage capability.

With respect to international energy markets, the time-arbitrage concept can be used to modulate energy imports with respect to international energy prices, thereby reducing energy imports when energy prices are high on international markets, and resuming energy imports when prices drop. This can reduce dependence on international energy import markets.

### ii. Seasonal Storage

The ability to store energy for weeks or months can be used to strategically inventory energy output for long-term and medium-term purposes, in order to engage in energy consumption-smoothing. Seasonal variation in both energy consumption and energy generation can be facilitated via energy storage.

### iii. Infrastructure Flexibility and Service life

Energy storage can be used to mitigate and/or defer the need for infrastructural expansions and upgrades to the energy grid system by augmenting the performance of existing transmission and distribution (T&D) infrastructure. This also means that repairs, expansions and upgrades can be undertaken, whilst energy supply continues relatively undisturbed.

Service life of existing T&D infrastructure can also be extended by reducing line congestion, and thereby both peak-loading and overloading of transmission lines.

### iv. Support for Renewables

Due to weather, climate, and sunlight-dependent variations of wind, tidal, and photovoltaic energy production, time-arbitrage is highly relevant for the viability of renewable energy systems. Energy storage is crucial for managing volatility in electricity production associated with renewable-based energy production. Energy storage systems can store excess electricity produced from renewable resources during ideal energy generation conditions, and provide electricity during cloudy and calm weather conditions.

This can help make renewable energy more reliable, while bolstering energy tradability, thereby making energy markets less illiquid. Moreover, if energy production from renewable sources is stabilized, utility companies and investors would be more likely to invest in the transmission infrastructure necessary to trade energy to and from geographically remote regions where renewable energy generation is most optimal.

#### *Economic Maturity of Renewable Energy Generation*

In principle, what energy storage technology's role in supporting the rise and integration of renewable energy generation has come to mean, is that the destinies of renewable energy generation markets and those of energy storage technologies are intertwined.

Concretely, this can be seen both in The European Union and Japan. In Europe, more traditional pumped-heat energy storage systems (which were originally implemented to store excess production from coal and nuclear generation), are gradually seeing their growth eclipsed by molten-salt based energy storage systems (which are more closely associated with solar energy generation, but are also known for their flexibility towards renewable generation sources in general). In Japan, meanwhile, the rise of energy-efficient smart-cities explicitly call for the integration of energy storage systems in order to facilitate both the smart-grid, and the integration of diversified sources of renewable energy generation.

With this in mind, the rising economic maturity of the renewable sector will play a key role in the further growth of demand for energy storage technologies, as well as the growth in diversification and sophistication thereof. In terms of measuring the comparative economic maturity and productivity of energy projects, as well as macro-level industries and regions, published economic literature focuses on levelized cost of energy (LCOE) figures.

LCOE is an economic factor-cost measurement used for comparing power source output. In principle, LCOE compares different methods of electricity generation by estimating the average total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime, thereby providing viable comparison between and among energy installations of various types.

Figure 2, demonstrates the comparative LCOE costs of various energy generation technologies. On the right-hand-side, the more cost-effective end of the scale is populated by the more economically-mature energy generation technologies, such as coal, nuclear, and natural gas. Incidentally, coal and natural gas also account for the largest and second largest shares of the global energy generation market respectively.[3]

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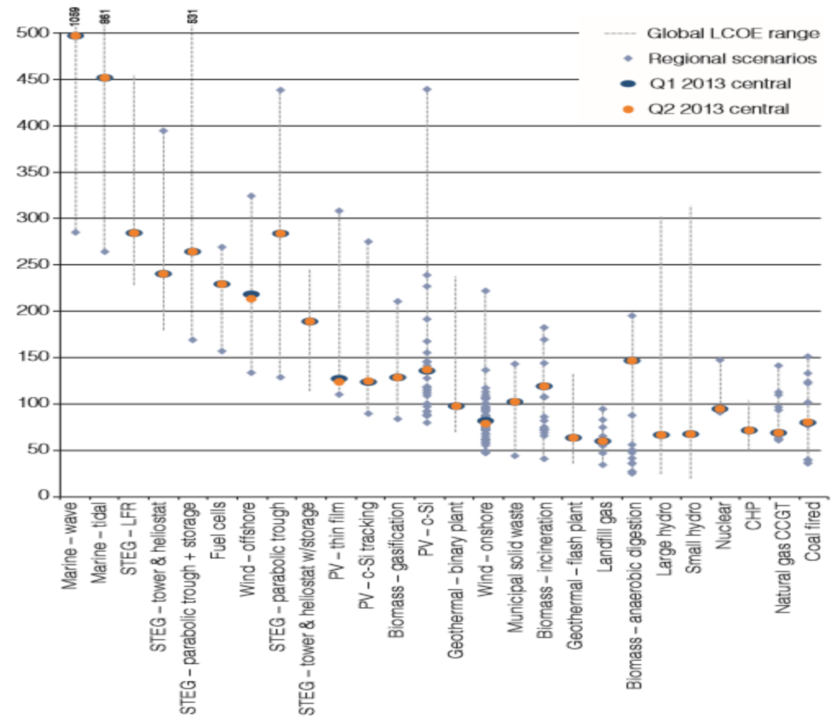
[3] World Energy Council (2013), World Energy Perspective: Cost of Energy Technologies, London, UK

**Figure 2: Global Levelized Cost of Energy in Q2 2013 (USD/MWh)**



Over the past few years however, LCOEs for photovoltaic and wind generation have fallen dramatically, as governments have provided financial support that has encouraged rapid deployment, causing the cost of manufacturing those technologies to come down while the efficiency of producing electricity from them has increased.[4] According to the Bloomberg New Energy Outlook 2016, photovoltaic and wind energy generation technologies are set to become the cheapest ways of producing electricity in many countries during the 2020s and in most of the world in the 2030s. Onshore wind costs fall by 41% and solar PV costs fall by 60% by 2040[5].

Figure 3, provides some visualization of this phenomenon. According to 2015 IEA figures, renewable energy currently generation accounts for roughly one quarter of OECD energy generation. Meanwhile, a sizeable portion of the actual growth in terms of cumulative installed power generation capacity (both actual and projected), is being accounted for by renewable energy generation sources. Stated plainly, Figure 3 indicates that while coal and natural gas energy generation technology has reached economic maturity, and grows at a relatively slower rate, photovoltaic and wind energy generation are currently maturing, which is accompanied by relatively aggressive growth rates.

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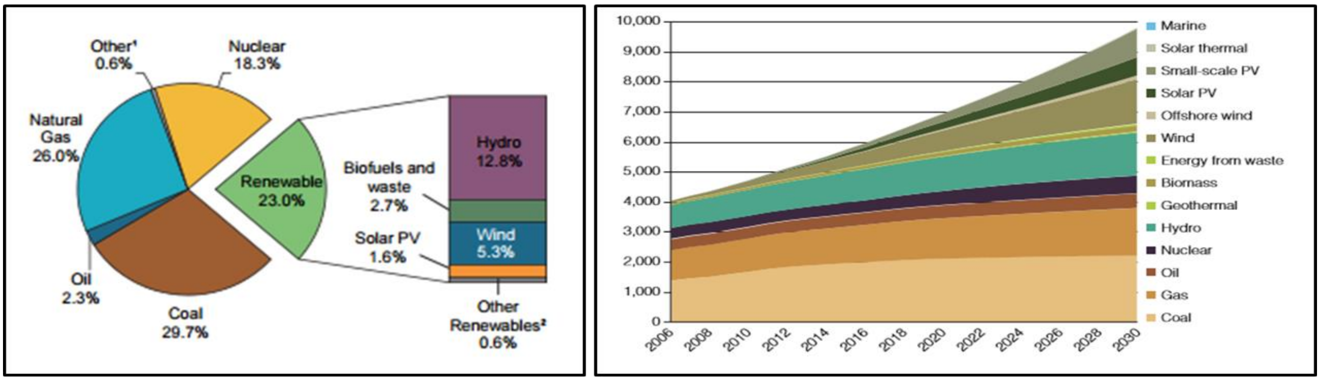
[4] World Energy Council (2013), World Energy Perspective: Cost of Energy Technologies, London, UK

[5] Bloomberg New Energy Outlook 2016 (2016)

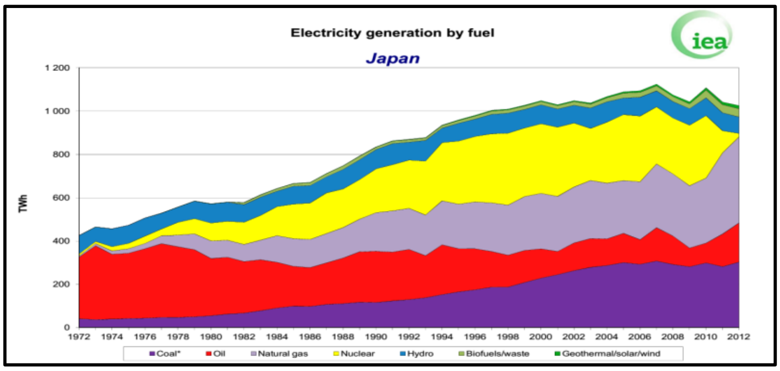
Figure 3: Share of Renewable Energy Generation in OECD Markets (2015 IEA Figures and 2015 Bloomberg Figures)[6] [7]



While the overall worldwide growth of renewables certainly has its implications for the development of the energy storage landscape, the evolution of the energy landscape in Japan, is also indicative.

Figure 4, provides a window into the technological maturity of various energy generation sources on the Japanese market. Overall, coal has reached its growth potential, and has been relatively constant since the early 2000s, while oil and nuclear are being phased out. Renewables on the other hand, while still a small component of Japan's overall energy landscape, have grown as a share of the energy landscape, and seem set to grow further as renewable energy technology matures both economically and technologically. This outlook is expressed both in Japan's official policy stance, and in IEA figures.

Figure 4: Electricity Generation in Japan by Fuel (2013 IEA figures) [8]



Concerning photovoltaic generation capacity for instance, Japan has been the most aggressively-growing market, according to the IEA. In 2014, Japan added 9.7 GW of installed generation capacity, followed by US (3.1 GW) and UK (2.5 GW). The sum of these three countries account for 68.4% of the total 2013 to 2014 increase.[9]

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[6] International Energy Agency, (2016), "Key Renewables Trends Excerpt From: Renewables Information

[7] World Energy Council (2013), World Energy Perspective: Cost of Energy Technologies, London, UK

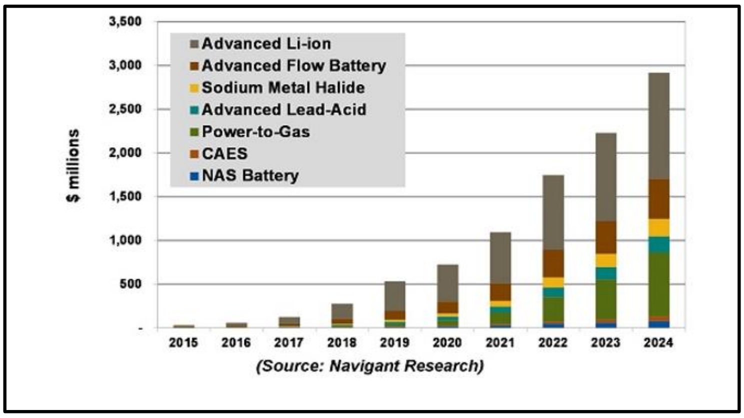
[8] International Energy Agency, (2016), "Key Renewables Trends Excerpt From: Renewables Information", Paris

[9] International Energy Agency, (2016), "Key Renewables Trends Excerpt From: Renewables Information", Paris

In terms of concrete relevance to the energy storage market, the market for energy storage technology aimed at energy-grid integration of photovoltaic and wind energy generation is projected to grow aggressively over the course of the coming decade.

Figure 5 displays figures published by Navigant Research earlier this year regarding the link between photovoltaic and wind energy generation, and the most relevant energy stationary storage technologies for renewable energy grid integration. According to Navigant Research, the world wind-and-solar-linked energy storage market is set to grow more than ten-fold vis-à-vis 2015 figures.

**Figure 5: Energy Storage for Wind and Solar Integration 2015-2024** [10]



(Source: Navigant Research)

At the worldwide level, the growing wind-and-solar-linked energy storage market is dominated by lithium-ion battery technology. Although Navigant Research projects that rival energy storage technologies, such as power-to-gas and lead-acid technologies will begin catching-up to lithium-ion's market share by 2024, lithium-ion will still be the dominant energy storage technology in this specific market niche by 2024.

## b. The Energy Storage Technology Landscape

### i. Scale

Given the development of divergent energy storage technologies, with divergent optimal applications and uses, the energy storage landscape is segmented by size and scale.

*Utility-Scale*

At the utility level, energy storage technology is used to provide necessary ancillary services to support a smoothly-running energy grid system at the macro-level. The integration of renewable energy generation resources implies intermittent energy generation output, which furthermore cannot generally be optimized to suit peak-demand as easily as fossil fuel energy generation can, giving rise to greater needs for frequency regulation. In addition to demand-supply mismatches, intermittent energy generation can cause load-fluctuations, which can increase energy infrastructure maintenance costs, necessitating ramp-control to manage rapid output changes. Utility-level energy

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[10] Navigant Research (2016), "Energy Storage for the Grid and Ancillary Services"

storage systems can also be used to support ancillary services such as black start (restarting the grid in the event of an outage).

Given the scale involved, the utility-scale energy storage market makes of the entire range of commercially-available energy storage technology.

### *Local/Municipal/Grid-Scale*

At the municipal level, energy storage is used in distribution networks in order to manage consistent supply to the grid in the face of short-term fluctuations of both energy supply and energy demand.

In a smart-grid context, characterized by dispersed energy generation, and peak times of local-level energy generation, energy consumption and energy trade, local-level grid systems need medium-to-large-scale energy storage capability in order to help the market clear and facilitate the continued smooth operation of the local energy market. To this end, smart-grid systems need the ability to quickly charge and deploy stored energy.

Furthermore, smart-grids relying on a dispersed residential-scale energy storage network may encounter the limits of small-scale energy storage to manage local peak demand and supply extremes. With this in mind, the local/municipal-scale grid energy storage market is a diversified landscape shaped by the needs of clustered small-scale and municipal-scale energy generation facilities and short-run frequency-regulation in order to manage demand and supply fluctuations.

### *Residential-Scale*

In the residential energy storage market, energy storage technology is used mainly for demand management and optimization of energy use. In principle, energy can be bought from the grid when energy prices are cheaper and supply is more plentiful (during off-peak times), and consumed during peak-hours. Residential-scale energy storage systems can also be used with small-scale energy generation systems, such as home photovoltaic installations. Aside from use in homes, small office spaces and retail stores face similar needs and concerns with respect to energy storage.

The choice of energy storage technologies involved are more limited than other segments of the energy storage landscape due to space and safety concerns.

### *Industrial-Scale*

The industrial scale energy storage market consists of large facilities which have some flexibility in choice of energy storage systems, given the scale and facility conditions involved. Like the residential-scale energy market, the industrial scale energy storage market is mainly focused on demand-management and optimization of energy use.

Additionally, smart-factories, smart hospitals, and smart office buildings or apartment buildings can viably host smart micro-grids, which can integrate residential-scale energy storage systems with limited larger-scale energy storage systems. Because the scale and the nature of the facilities is more varied than at the residential scale however, the breadth of viable energy storage system options is more diverse than at the residential-scale.

## ii. Relevant Technologies

As it currently stands, the marketplace for energy storage technologies consists of four main classifications,

- Mechanical Energy Storage
- Electrical Energy Storage
- Chemical Energy Storage
- Thermal Energy Storage

Overall, mechanical energy storage technologies and chemical energy storage technologies are the two most widespread types of energy storage technology. The most common mechanical storage systems are pumped hydroelectric power plants (pumped hydro storage, PHS), compressed air energy storage (CAES) and flywheel energy storage (FES).[11] Mechanical energy storage technologies have the advantage of already being technologically mature compared to chemical energy storage. The principle exception to this is CAES, whose efficiency can still be improved according to the International Electrotechnical Commission. [12]

In contrast, chemical energy storage – principally battery technology – is a still economically-maturing family of technologies. In principle, this means that investments being made in battery technologies today, will result in more efficient iterations of the technology and its deployment in the future. Moreover, compared mechanical energy storage technologies, much smaller scales are already achievable, making viable a diverse range of applications, ranging from utility-scale energy storage sites, as well as utility-scale deployment directly at the generation site, to residential, vehicular, and individual-appliance-scale applications. It is precisely this scale-flexibility, which reinforces the viability of smart-grids and diffuse, small-scale renewable energy generation in the context of energy grids overall. For these reasons, as well as the geographical flexibility of battery storage, the majority of energy storage sites are chemical energy storage sites.

### *Mechanical Energy Storage*

### *Pumped Hydro*

Pumped Hydro energy storage (PHS) is currently the most commonly-used energy storage technology, due primarily to its efficiency, low costs, and speed of integration.[13] Another key factor in pumped hydro's success is its technological simplicity compared to other energy storage technologies, given that PHS uses elevated water reservoirs for energy storage and gravity to discharge the energy.

Aside from price, technological simplicity, and economic maturity, the technology's primary advantage is that elevated water represents energy source that can be fed into a hydroelectric turbine connected to the power grid, and be put into use on short notice.

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[11] International Electrotechnical Commission (2011), "Electrical Energy Storage", White Paper, Geneva Switzerland

[12] International Electrotechnical Commission (2011), "Electrical Energy Storage", White Paper. Geneva Switzerland

[13] http://energystorage.org/energy-storage/energy-storage-technologies/pumped-hydro-power

In terms of downsides, PHS's main disadvantages are its geographic constraints, given that PHS facilities depend on topographical features, as well as PHS's specific ties to hydroelectric infrastructure. Additionally, the practical growth of pumped hydro energy storage is constrained by the cost, size and construction time of energy storage sites, given that the scale is incompatible with small-scale residential, business, and industrial energy-storage uses.

**Figure 6: Kangaroo Valley Pumping and Power Station (Australia)[14]**

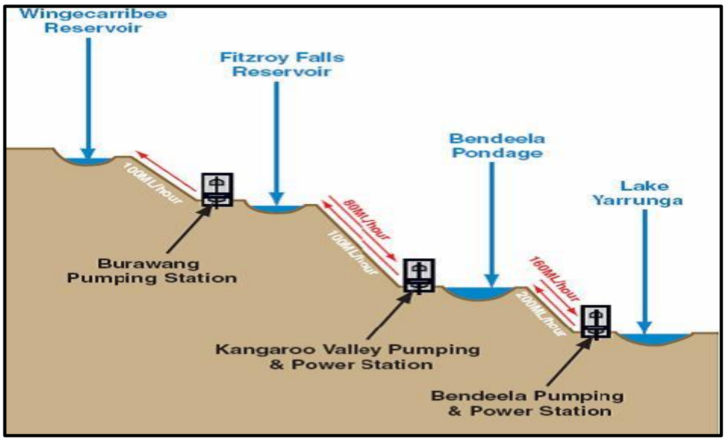
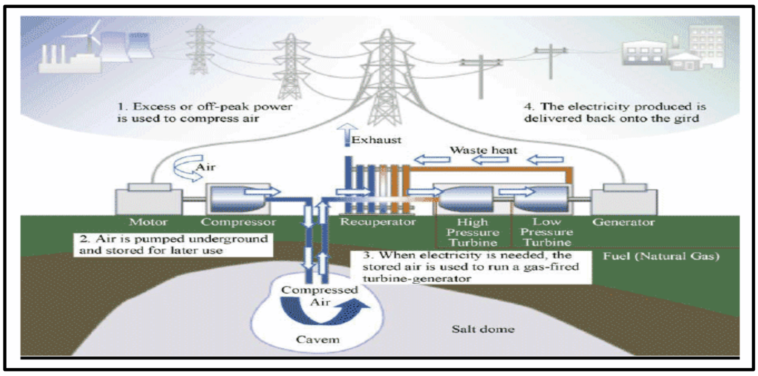


Figure 6 is a diagram of the Kangaroo Valley Pumping and Power Station in Australia, drawn from the DOE Global Energy Storage Database. This facility has two 80-megawatt pump turbines, for a total electricity generating capacity of 160 megawatts.

### *Compressed Air Energy Storage*

As a mechanical energy storage technology, Compressed Air Energy Storage (CAES) energy storage similar to pumped-hydro power plants in terms of applications, output and storage capacity[15].Air heats when compressed from atmospheric pressure to storage pressure. Standard multistage air compressors use inter and after coolers to reduce discharge temperatures and pressures. Figure 7, displays an example of a CAES energy storage system, drawn from the Scottish Government's Energy Storage and Management Study.

**Figure 7: Schematic Diagram of Compressed Air Energy Storage System[16]**



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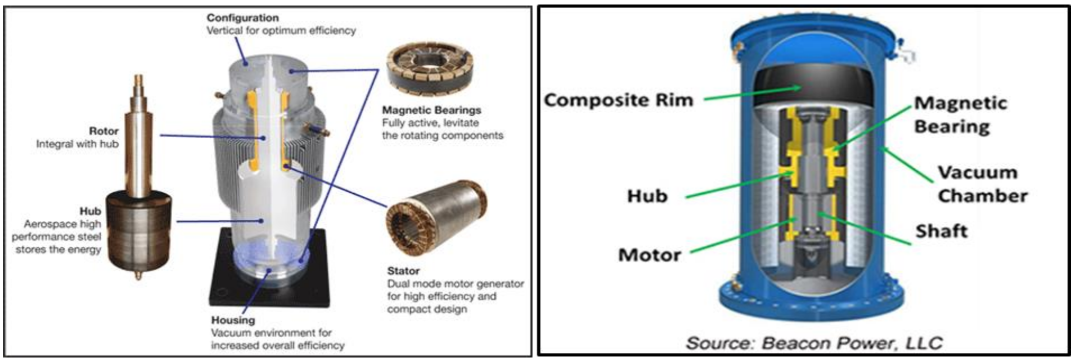
[14] DOE Global Energy Storage Database. http://www.energystorageexchange.org/projects/339
[15] http://energystorage.org/compressed-air-energy-storage-caes
[16] Scottish Government (2010), Energy Storage and Management Study http://www.gov.scot/Publications/2010/10/28091356/4

Like pumped hydro energy storage, CAES's main disadvantage is its geographic constraints, given that CAES depends on the availability and spatial capacity of suitable cavern sites. Unlike PHS however, CAES technology is still projected to economically mature further, according to the International Renewable Energy Agency.

### *Flywheel Storage*

Flywheel energy storage technology makes use of kinetic energy held by means of a spinning mass (a rotor), while in motion. The flywheel is connected to an integrated motor-generator that interacts with the energy grid. Figure 8 displays two examples of flywheel energy storage technology, in which the key flywheel components are outlined. Energy input via the motor-generator accelerates the mass, while drawing down the kinetic energy using the motor-generator discharges the energy into the grid system. Modern flywheel energy storage systems consist of a massive rotating cylinder (a rim attached to a shaft) that is supported on a stator by magnetically levitated bearings.

**Figure 8: Examples of Flywheel Energy Storage Technology**



*Source: Beacon Power, LLC*

The amount of energy that can be stored is determined by the system's inertia its angular velocity. Efficiency, is optimized when the flywheel spins at maximum speed. The modern single flywheel offers a capacity up to 25 kilowatt hours (kWh), which can be absorbed and distributed directly. At present, the world's largest flywheel energy storage plants are the Beacon New York Flywheel Energy Storage Plant, which opened in 2011 and the Beacon Hazle Township Pennsylvania Plant, which opened in 2014. Both of these plants host 100 flywheels and have a 20mW capacity.[17]

### *Pumped Heat Energy Storage*

Pumped-heat electricity storage (PHES), is a heat-pump system is used to store energy as a temperature difference between storage tanks. These are maintained at different temperatures, and is reversible via a heat pump. Often, PHES systems rely on storage tanks filled with solid matter, such as solid matter such as gravel, concrete or pebbles, because these can be heated to high temperatures – as high as 1200 °C – by electrical means, and therefore have a very high energy storage capacity per unit of volume.

The stores are connected by a series of pipes filled with a stable gas. When electricity is in surplus, it is used to power a motor that operates a compressor to compress the gas, thereby heating it. As it is pumped through the first silo it transfers its heat to the gravel. The cooler gas that emerges is then expanded, which lowers its temperature. When it

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[17] Arseneaux, Jim, Beacon Power LLC (2014), 20 MW Flywheel Energy Storage Plant, http://www.sandia.gov/ess/docs/pr_conferences/2014/Thursday/Session7/02_Areseneaux_Jim_20MW_Flywheel_Energy_Storage_Plant_140918.pdf

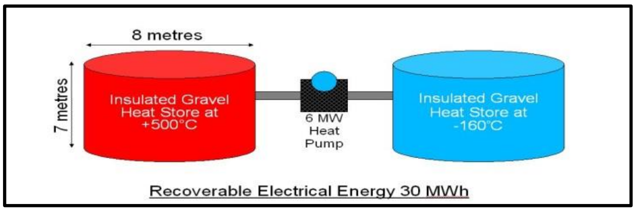
is pumped through the second store it cools the gravel there. Gas heated by the hot storage tank flows to the cold one, driving the cylinders of what had been the pump to turn what had been the motor as a generator[18].

Pumped Heat Energy Storage (PHES) is the most commonly-used energy storage technology in the EU market. Moreover, PHES is an economically mature energy storage technology, and levelized cost of electricity measures indicate that PHES is currently among the more cost-effective in terms of cost per kWh.[19] [20]

According to the EU's 2015 DG Internal Policy report on energy storage market design, PHES can cover the demand for seasonal variations, but are not suitable solutions for the increasing role of fluctuating renewable energies (wind and solar)[21]. Accordingly, the share of energy storage markets held by PHES-based systems is currently decreasing in both the EU and the world market overall[22].

Figure 9 is a rudimentary diagram demonstrating an example of a pumped-heat energy storage system. It uses argon – a stable noble gas – to transfer heat to the gravel in the two tanks. The compressor heats the argon to 500°C. The cooler gas, once expanded, lowers its temperature to -150°C.

**Figure 9: Example of Isentropic Pumped Heat Storage System[23]**



*Battery Technology Landscape:*

At present, there are exists a diversity of commercially-available electrochemical battery types for the purposes of energy storage, the most robust being of Sodium Sulfur (NaS), Lithium-ion (Li-ion), and Lead-Acid (Pb-Acid) -based technology.[24]

However, battery energy storage systems have not yet achieved widespread market use due to challenges in energy density, power performance, lifetime, charging capabilities, safety, and system cost[25]. According to the European Commission, expectations are that battery energy storage technologies will reduce costs by a factor of two during the 2020s, thereby allowing the competitiveness of battery storage technology to catch up to the more economically

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[18] The Economist, Babbage Science and Technology, (Mar. 12, 2014), "Electricity storage: Pumping heat" http://www.economist.com/blogs/babbage/2014/03/electricity-storage

[19] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

[20] Zakeri, B., Syri, S, (2014) "Electrical energy storage systems: A comparative life cycle cost analysis", Renewable and Sustainable Energy Reviews Vol. 42, 2015, pp. 569–596.

[21] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

[22] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

[23] Wesoff, Eric (Feb. 23, 2010), "Breakthrough in Energy Storage: Isentropic Energy", Greentechmedia.com, http://www.greentechmedia.com/articles/read/breakthrough-in-utility-scale-energy-storage-isentropic

[24] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

[25] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

mature energy storage technologies currently available.[26] Currently for this application lead acid batteries are the most common technology due to the technology's low investment costs. Meanwhile, lithium-ion batteries generally yield efficiency but have higher investment cost, and sodium-sulfur batteries many face overheating issues. Looking forward, cost data outlined in the LCOE figures in Table 3, indicate that Vanadium redox battery technology may also grow to become both practical and economically viable, going forward.

### *Solid State Batteries*

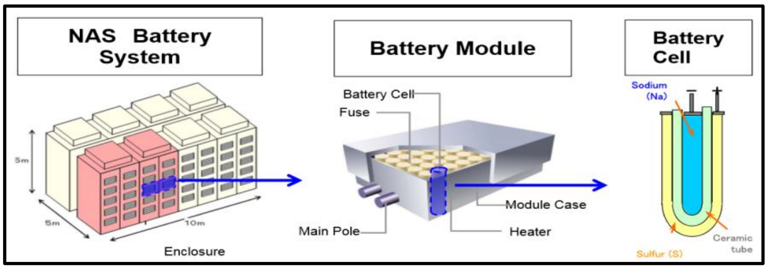
In principle, a solid-state battery technology consists of one or more electrochemical cells, which serve to convert stored chemical energy into electricity. The cell contains negative and positive terminals. Advances in technology and materials have greatly increased the reliability and capacity of contemporary battery technology systems. Moreover, economies of scale have served to dramatically reduce the associated costs. Aside from energy costs (measured as levelized costs of energy (LCOE)), other key metrics are longevity, energy density (energy-to-volume ratio), and power density (rate at which energy charges).

### Sodium Sulfur (NaS)

Sodium–sulfur (NaS), also known as Molten Salt Storage, has high energy density, high efficiency of charge and discharge, and a long cycle life. NaS batteries are built from relatively inexpensive materials, making them a relatively cost-effective form of energy storage. Once in operation, the heat produced by charging and discharging cycles is sufficient to maintain operating temperatures and usually no external source is required.

Figure 10, demonstrates and example of a Sodium-Sulfur battery storage system. Each battery system contains multiple battery modules consisting of multiple high-temperature battery cells, heaters, and fuses, in addition to charged polar connection for the battery module as a whole. Each cell is enclosed by a corrosion-protected steel casing. The outside container, which holds molten sulfur, serves as the positive electrode, while the inside container, carrying liquid sodium, serves as the negative electrode[27].

**Figure 10: Sodium-Sulfur (NaS) Battery System**



NaS batteries are a useful energy storage technology to support renewable energy generation, specifically wind farms and solar generation plants. NAS battery technology is largely used in utility-scale load-leveling and peak shaving applications.[28] Originally developed for use with electric vehicles, NaS was later selected as one of four battery types

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[26] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

[27] http://nickelbackchina.blogspot.be/2009/04/sodium-sulfur-battery.html

[28] http://nickelbackchina.blogspot.be/2009/04/sodium-sulfur-battery.html

intensively researched by MITI as part of the Moonlight Project, in an effort to develop economically viable utility-scale energy storage systems.

Today, the NaS market is dominated by Japan’s NGK, an energy firm which entered the research arena in conjunction with TEPCO in 1983, commercialized the technology in 2002. Worldwide, Japan’s NGK continues to dominate the market for NaS batteries. [29]

NaS technology’s advantages are cost-efficiency and density. In terms of cost-efficiency, LCOE figures for NaS are projected to shrink over the course of the next decade, as the technology matures economically. Furthermore, NaS has high energy density compared to many other battery types. The drawbacks of NaS technology relate to the system’s high operating temperature. Aside from the direct temperature-related risks posed by the molten salt, containment risks are also present. In future, low temperature NaS batteries might be developed but they are still in R&D phase[30].

### Lithium-ion (Li-ion)

Lithium-ion battery technology is diverse, highly-scalable, and has become ubiquitous throughout the energy landscape and the consumer market. They are deployed in a wide range of energy storage applications, ranging from small-scale batteries of a few kilowatt-hours in residential systems with rooftop photovoltaic arrays to multi-megawatt containerized batteries for the provision of grid ancillary services. In 2014, the technology accounted for 75% of electric vehicle battery demand, and 92% of announced grid-connected stationary energy storage projects.[31]

Lithium-ion batteries have a high energy density, as well as power density compared to other battery technologies. This allows them to take up minimal space, while providing high energy and power output and discharge speed. This makes Li-ion technology ideal for frequency regulation and other applications requiring relatively short discharge and high power performance**.**

Aside from scalability, the key advantage of Li-ion battery technology is the high potential for technology improvement and cost reduction going forward. The primary drawbacks of lithium-ion battery systems, are the high cost of production and scalability for battery systems, which is also reflected in high levelized cost of energy for Li-ion storage systems. In addition, Li-ion technology is more sensitive to temperature and pressure variations than other energy storage technologies. As with NaS technology, Li-ion battery technology has the additional disadvantage of safety concerns.

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[29] DG Internal Policy (2015), “Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?”, European Commission, Brussels, Belgium

[30] DG Internal Policy (2015), “Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?”, European Commission, Brussels, Belgium

[31] Innovation for Cool Earth Forum (2015) “Distributed Solar and Storage ICEF Roadmap 1.0”, Innovation for Cool Earth Forum, Bloomberg New Energy Finance

### Lead-Acid (Pb-Acid)

Lead-acid battery technology is [32]the oldest rechargeable battery technology currently in use, dating to the mid-19th century. As an older technology, it can be considered a more economically mature technology. Lead-acid technology's costs are low, and the implementation and market implications of the technology are already widely understood. IN terms of cost, lead prices account for approximately 49% of the overall cost of the lead acid batteries produced. While its primary uses are in industrial and vehicular uses, [33] business and residential application of Pb-Acid technology are also used. According to Future Market Insight Global & Consulting Pvt Ltd, the fastest-growing segments of the Pb-Acid market are stationary industrial-scale uses, and utility-scales uses.[34] Eurobat's 2013 figures estimate that approximately 80% of the total installed capacity among industrial batteries is based on Pb-Acid technology.

In Japan, Lead-Acid battery technology was one of four battery types selected as candidates for intensive research by MITI as part of the Moonlight Project, in an effort to develop economically viable utility-scale energy storage systems.

Pb-Acid's drawback is very low energy density (roughly one third that of Li-ion battery technology). On the other hand, Lead-Acid battery technology's ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio.

### Nickel-Based Batteries

Nickel-Cadmium (NiCD) and Nickel-Metal Hydride (NiMH) are the two most established nickel-based battery technologies on the world's energy storage market. According to Eurobat, nickel-based batteries are the second most commonly-deployed battery after lead-based batteries.

Although deployment on the Japanese market is focused on the vehicular market, it ranges in scale from utility and industrial scale to home-appliance scale. As such, nickel-based batteries are a rival energy technology to Li-ion in terms of scale-flexibility. Compared to other battery technologies, nickel-based batteries have higher energy density than Pb-Acid, but less than Li-ion, while capital costs are smaller than all battery types, except Pb-Acid, and maintenance requirements are low.[35] The disadvantage of nickel-based batteries is their use of potentially-expensive rare-earth ceramics.

### *Flow Batteries*

A flow battery is a type of rechargeable battery where rechargeability is provided by two chemical components dissolved in liquids contained within the system and typically separated by a membrane. Flow batteries were originally

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[32] Future Market Insight Global & Consulting Pvt Ltd. (2015) "Lead Acid Battery Market: Asia Pacific, Latin America, Japan, Middle East & Africa Industry Analysis & Opportunity Assessment 2014-2020"

[33] Shimzu, K. (1988) "The Lead/acid Battery Industry in Japan", Journal of Power Sources, Volume 23, Issues 1–3, May–June 1988, Pages 33-46

[34] Future Market Insight Global & Consulting Pvt Ltd. (2015) "Lead Acid Battery Market: Asia Pacific, Latin America, Japan, Middle East & Africa Industry Analysis & Opportunity Assessment 2014-2020"

[35] Chen, Haisheng, et al. (2009), "Progress in electrical energy storage system: A critical review", Progress in Natural Science, Volume 19, Issue 3, 10 March 2009, Pages 291–312

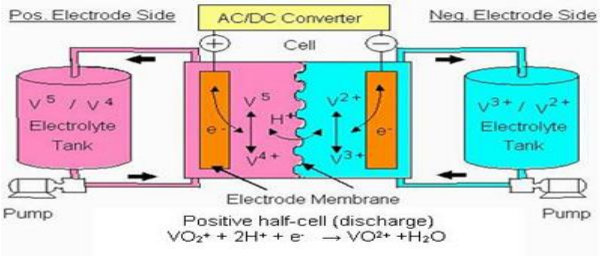
invented by US energy utilities to provide macro-scale energy storage capacity beyond the geographic constraints of hydroelectric facilities[36].

### Vanadium Redox Flow Batteries (VRFB)

Vanadium Redox Flow Battery (VRFB), is a type of rechargeable flow battery that employs vanadium ions in different oxidation states to store chemical potential energy. The VRFB stores energy by employing vanadium redox couples. Redox flow batteries have the advantage of unlimited longevity due to their refueling concept, although the long-term stability is still an issue for research. [37] One key factor making redox flow battery systems attractive is the high potential for technology improvement and cost reduction going forward. The Vanadium Redox Flow Battery was one of four battery types selected as candidates for intensive research by MITI as part of the Moonlight Project, in an effort to develop economically viable utility-scale energy storage systems.

Figure 11 is a diagram demonstrating VRFB technology, as it is used by Sumitomo Electric Industries. In contrast with solid-state batteries, the VRF battery features separate liquid tanks for the positive and negative side of the apparatus, with pumps to ensure controlled flow to and from the electrode membrane.

**Figure 11: Diagram of Vanadium Redox Flow Battery[38]**



*Source: Sumitomo Electric Industries, Ltd. (SEI) - Copyright 2001*

## iii. Trends in the Energy Storage Market

At present, pumped hydro occupies the lion's share of energy storage capacity currently used by the world's electricity grids. Figure 12, outlines the worldwide distribution of the energy storage landscape. Installed PHS is shown to currently shown to outpace all other energy storage capacity, combined, by a large margin.

Nevertheless, pumped hydro's limitations imply that while remote mountainous regions located near population centers and energy demand generating regions can serve to host large-scale pumped energy storage capacity, the growth of pumped hydro energy storage capacity is constrained in other topographical regions, vis-à-vis storage battery technology. Furthermore, the incompatibility of pumped-hydro technology with small-scale energy storage markets also acts as a growth constraint vis-à-vis battery-based storage technologies.

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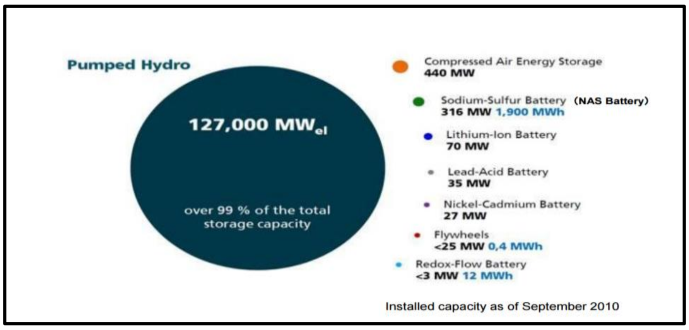
[36] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.
[37] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium
[38] Sumitomo Electric Industries Ltd.

**Figure 12: 2010 Installed Electrical Energy Capacity**[39]



While pumped hydro does hold the vast majority of the energy storage landscape prior to the 2011 Fukushima disaster, this reality is set to change going forward, taking recent developments on the Japanese and EU markets into consideration. This is principally because size, cost and geographic constraints render pumped-hydro technology incompatible with small-scale energy storage markets such as residential and business-space energy storage markets, where much of the research and development is focused, and where most of the growth is set to occur over the coming decades.

Moreover, although the majority of energy-storage capacity in the world is pumped hydro, batteries are the most common form of energy stoare, and range in size from the small-scale wristwatch-batteries to megawatt load leveling applications. They are efficient storage devices, with output energy typically exceeding 90% of input energy, except at the highest power densities.[40]

## iv. Economic and Technological Maturity of Energy Storage

As the rest of this chapter elaborates, there is notable diversity in both types of energy storage technologies, as well as in energy storage costs and levels of economic efficiency. Nevertheless, not all energy storage options that are technology mature are not yet economically mature.[41] [42]

In principle, this has implications for investor confidence. Given that energy storage systems are major infrastructural projects with extended productive life cycles and sizeable price tags, investment in them carries considerable financial risks.

Economically pre-mature technological standards for any given technology may cause investors may be uncertain as to whether costs will be cost-competitive vis-à-vis competing options (such as waiting for the technology to mature before investing), or whether investment yields will be manifest themselves at economically justifiable levels.

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[39] International Electrotechnical Commission (2011), “Electrical Energy Storage”, White Paper. Geneva Switzerland

[40] Whittingham, Stanley, (2012), “History, Evolution, and Future Status of Energy Storage”, Proceedings of the IEEE | Vol. 100, May 13th, 2012

[41] DG Internal Policy (2015), “Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?”, European Commission, Brussels, Belgium

[42] US Department of Energy (2013), “Grid Energy Storage”, Working Paper, Washington DC.

**Figure 13: Maturity of Energy Storage Technologies**[43]

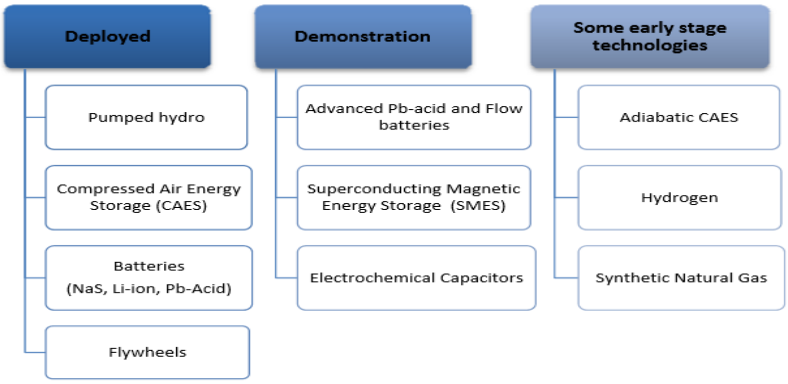

Figure 13, drawn from the US Department of Energy's 2013 report on grid energy storage, outlines which technologies are mature on the US market. According to the DOE, mechanical energy storage technologies are generally mature and sell-established technologies, while chemical energy storage technologies range from deployed, to demonstration-phase, to early-stage development. The more mainstream established energy storage technologies, flywheel, pumped hydro, and compressed air are the more economically mature energy storage technologies. As for battery-based energy storage technologies, NaS, Li-ion, and Pb Acid battery technologies are already deployed, while flow batteries and advanced Pb-Acid batteries are still in the demonstration phase. This indicates that battery energy storage technology overall, in still maturing economically, and in some cases is still in the pre-deployment phase.

### *LCOE Costs, Advantages, Disadvantages*

Table 1, drawn from a 2013 US department of energy working paper on grid energy storage, and from a 2015 European Commission study on energy storage and energy storage markets. The European Commission study published comparative LCOE-cost figures, finding that while pumped heat energy storage (PHES) is currently the most cost-effective energy storage technology, battery-based energy storage systems are not far behind. While sodium-sulfur (NaS) energy storage is as cost-effective as PHES, Vanadium Redox Flow technology is not far behind. Lead-Acid and Lithium-Ion battery technology however, have not yet managed to bring LCOE costs down to a comparatively low level. Nevertheless, these LCOE cost figures are of particular interest because energy-storage costs associated with battery-based energy storage are predicted to fall during the next two decades as the technology matures economically.

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[43] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

**Table 1: Costs, Benefits, and Drawbacks[44] [45]**

| Technology | Cost Range (EUR/kWh) | Advantages | Challenges & Drawbacks |
|---|---|---|---|
| Pumped Hydro | n.a. | * Technologically mature<br>* Cost-effective<br>* Large scale<br>* Ramp rates | * Geographic limitations<br>* Environmental impact<br>* Overall project costs are high |
| Pumped Heat Storage (PHES) | 0.05 to 0.15 | * Cost Effective | |
| Flywheel Energy Storage | n.a. | * Life cycle<br>* Scalability<br>* Rapid response<br>* Low overheating concerns | * Limited energy storage time<br>* Frictional energy losses<br>* Max. capacity limitation |
| Lithium-Ion (Li-Ion) Battery | 0.30 to 0.45 | * High energy density<br>* Life cycle<br>* High charge/discharge efficiency | * High production and scaling costs<br>* Temperature and pressure sensitive<br>* Intolerant of deep discharges |
| Sodium-Sulfur (NaS) | 0.05 to 0.15 | * Life cycle<br>* Energy density<br>* Response speed<br>* Scalability | * Hazardously high operating temperatures<br>* Containment risks |
| Compressed Air Storage (CAES) | 0.10 to 0.20 | * Technologically mature<br>* Ramp rates | * Geographic limitations<br>* Lower Efficiency Due to Round Trip Conversions<br>* Slower response time |
| Lead-Acid | 0.25 to 0.35 | * Technologically mature<br>* Cost-effective<br>* Long battery life | * Low energy density<br>* Limited depth of discharge<br>* Corrosion limits useful life |
| Vanadium Redox Flow Battery (VRFB) | 0.15 to 0.25 | * Long life span<br>* Ability to perform high number of discharge cycles. | * Low energy density<br>* Complex designs<br>* Technology not yet mature |

## *Efficiency and Useful Service Life*

In addition to direct costs of energy storage, efficiency, maintenance and service life are all major factors in the selection, implementation, and optimization of energy storage. According to the International Renewable Energy Agency's 2015 Market Status and Technology Outlook, focusing on cost alone is insufficient to accurately assess battery storage options, in light of contextualized maintenance, reliability, space, capital cost and performance concerns.

In order to keep energy storage costs in check, capital costs, operating and maintenance costs, and self-discharge metrics would be the most relevant factors to be considered in choosing the optimal energy storage technology portfolio.

In contrast, energy density, the amount of energy that can be stored within specific weight and/or volume constraints, is a key metric in the selection of energy storage technology. This particularly the case at smaller-scale, distributed energy storage contexts, such as residential, small-commercial, and vehicular energy storage markets. Meanwhile, useful life, discharge time, and self-discharge metrics are useful in contexts characterized by limited, fractionalized, or constrained energy grids (such as on islands or remote jurisdictions), given that flexibility and reliability will be of heightened significance.

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[44] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

[45] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

**Table 2: Efficiency, Flexibility, and Maintenance Costs [46] [47]**

| **Technology** | Capital Cost (USD/kW) | Flexibility: Discharge time | Efficiency: Self-Discharge per day | Efficiency: Energy Density (Wh/kg) | Efficiency: Energy Density (Wh/Liter) | Useful Life (years) | Useful Life (cycles) | Operating and Maintenance costs |
|---|---|---|---|---|---|---|---|---|
| Pumped Hydro | 600 to 2000 | 6 to 10 hours | Negligible | 0.5 to 1.5 | - | 40 to 60 years | - | $3/kW/year |
| Flywheel Energy Storage | 250 to 300 | Seconds to minutes | 100% | 10 to 30 | 20 to 80 | 15 years | 20,000 | $.004/kW/year |
| Lithium-Ion (Li-Ion) Battery | 1200 to 4000 | Minutes to hours | 0.1 to 0.3% | 75 to 200 | 200 to 500 | 5 to 15 | 1,000 | - |
| Sodium-Sulfur (NaS) | 1000 to 3000 | Seconds to hours | 0.1% to 20% | 150 to 240 | 150 to 250 | 10 to 15 | 2,500 | $80/kW/year |
| Compressed Air Storage (CAES) | 400 to 800 | 30 to 40 minutes | Negligible | 30 to 60 | 3 to 6 | 20 to 40 | - | $19/kW/year |
| Lead-Acid (Pb-Acid) | 300 to 600 | Seconds to hours | 0.1 to 0.3% | 30 to 50 | 50 to 80 | 5 to 15 | 500 to 1000 | $50/kW/year |
| Vanadium Redox Flow Battery (VRFB) | 600 to 1500 | Seconds to hours | Negligible | 10 to 30 | 16 to 33 | 5 to 10 years | 12,000 | $70/kW/year |

Table 2 outlines the comparative efficiency, flexibility, life cycle, and maintenance costs of the most widely-implemented energy storage technologies. Aside from the question of the ongoing development of economic maturity among the main energy storage technologies, Mechanical energy storage technologies have the advantage of having lower capital costs and a longer useful life, while battery-based storage technologies generally have the advantage of much higher energy densities, allowing their more widespread and diversified deployment. Furthermore, as battery-based energy storage technology matures economically, capital costs and operating costs would decrease, while useful life and efficiency metrics would generally increase.

### *Projections Going Forward*

Figure 14, elaborating on the view outlined by Figure 13, grants a more detailed look into the comparative economic maturity profiles of mechanical and battery-based energy storage technologies going forward. Because pumped hydro is the more economically-mature technology, its associated costs are projected to remain flat going forward. Nevertheless, it is noteworthy that pumped hydro costs occupy a rather wide price range. Meanwhile, the four primary battery-based energy storage technologies are projected to see a reduction in costs going forward. Li-ion batteries are projected to see a gradual tapering-off of cost-reductions going forward, as this technology approaches economic maturity.

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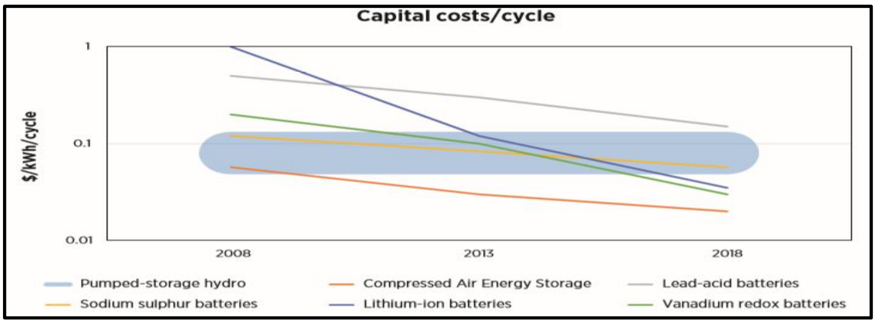
[46] Chen, Haisheng, et al. (2009), “Progress in electrical energy storage system: A critical review”, Progress in Natural Science, Volume 19, Issue 3, 10 March 2009, Pages 291–312

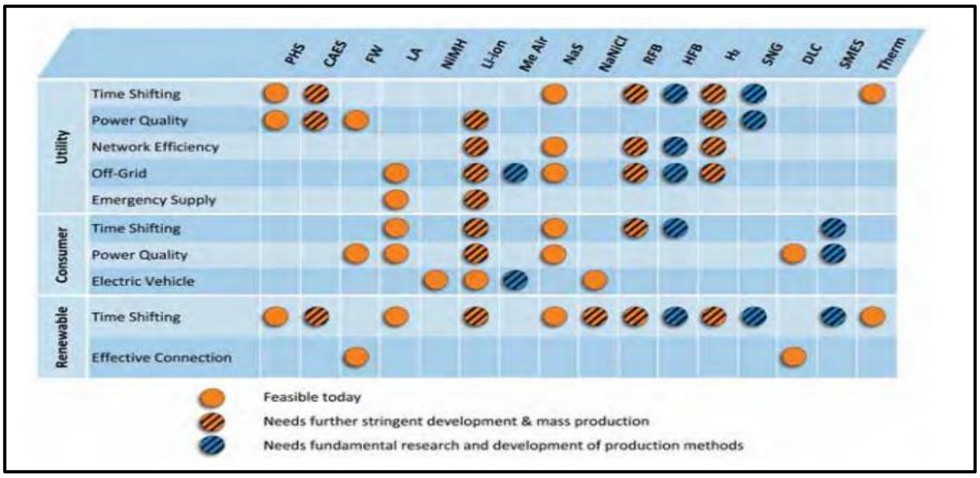
[47] Luo, X., Wang, J. Dooner, M. Clarke, J. (2014) “Overview of Current Development in Electrical Energy Storage Technologies and the Application Potential in Power System Operation” Applied Energy 511-536

**Figure 14: Cost Projections for Energy Storage Technologies 2008-2018**[48]



At present, there is insufficient experience with energy storage technologies in the market. This uncertainty acts to hinder investment into the further development and widespread adoption of energy storage technology in several major markets. Figure 14, taken from the International Electrotechnical Commission 2011 white paper on Electrical Energy Storage, outlines which energy storage technologies are technologically and economically mature, and where further gains in research and development are likely to be realized going forward. According to the IEC, the further development in terms of pumped hydro and compressed air energy storage is constrained in many markets, given that the limits of scalability have already been reached. Moreover, the lack of further suitable locations for both of these provides as further constraint. Further development is possible for CAES however, which going forward might help improve its cost-effectiveness.

**Figure 15: Feasibility and Maturity of Principle Energy Storage Technologies** [49]



| | | PHS | CAES | FW | LA | NiMH | Li-Ion | Me Air | NaS | NaNiCl | RFB | HFB | $H_2$ | SNG | DLC | SMES | Therm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Utility | Time Shifting | ● | ▨ | | | | | | ● | | ▨ | ▧ | ▨ | ▧ | | | ● |
| | Power Quality | ● | ▨ | ● | | | ▨ | | | | | | ▨ | ▧ | | | |
| | Network Efficiency | | | | | | ▨ | | ● | | ▨ | ▧ | ▨ | | | | |
| | Off-Grid | | | | ● | | ▨ | ▧ | ● | | ▨ | ▧ | ▨ | | | | |
| | Emergency Supply | | | | ● | | ▨ | | | | | | | | | | |
| Consumer | Time Shifting | | | | ● | | ▨ | | ● | | ▨ | ▧ | | | | ▧ | |
| | Power Quality | | | ● | ● | | ▨ | | ● | | | | | | ● | ▧ | |
| | Electric Vehicle | | | | | ● | ● | ▧ | | ● | | | | | | | |
| Renewable | Time Shifting | ● | ▨ | | ● | | ▨ | | ● | ▨ | ▨ | ▧ | ▨ | ▧ | | ▧ | ● |
| | Effective Connection | | | ● | | | | | | | | | | | ● | | |

● Feasible today
▨ Needs further stringent development & mass production
▧ Needs fundamental research and development of production methods

In contrast, battery technology has notable possibilities for technological and scale improvements to upgrade efficiency, cost-effectiveness and ease of integration going forward, according to the IEC. In addition, the extensive introduction of electrochemical energy-storage systems, such as NaS, Li-ion and RFB is expected, specifically aimed at discharge times of hours to days.[50]

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[48] International Renewable Energy Agency (2015), "Renewables and Electricity Storage: A Technology roadmap and Remap 2030"

[49] International Electrotechnical Commission (2011), "Electrical Energy Storage", White Paper. Geneva Switzerland

[50] International Electrotechnical Commission (2011), "Electrical Energy Storage", White Paper. Geneva Switzerland

# 3. Research and Development

## a. Recent Advancements and Coming Challenges in R&D

According to the International Energy Agency's 2014 Energy Technology Roadmap, the primary aims of current R&D efforts are focused on achieving technology cost reductions, as well as improving the performance and capabilities of both existing and emerging storage technologies.

### i. 2013 Technology Roadmap for Stationary Battery Technology

The New Energy and Industrial Technology Development Organization's Stationary Battery Roadmap projects that energy storage technology will develop and mature at both the small-scale level and the macro-level. By 2030, infrastructural and technological life spans will increase two to four times, while middle-scale grid technologies used in factories and apartment buildings will mature from the demonstration phase to market entry by 2020, becoming widespread on the Japanese market by 2030.

At the macro-level, both long-time fluctuating control and short time fluctuating control (50,000-100,000 and 200,000 kW range respectively), are projected to become commercialized by 2030, while the technology's life-span may increase 50 to 100%. At the residential level, where battery storage capacities are projected at 100,000 to 250,000 kW, life-span is also projected to increase 50 to 100%. Other small-scale uses, such as data center backup energy storage are projected by NEDO to become commercially widespread in Japan before 2020.

Overall, large and centralized storage technologies have been mature for a longer period of time. In Japan and in the EU, research and development efforts are heavily focusing on batteries. Furthermore, the trend in research and development is a focus on distribution and the end-user level energy storage. For the coming years, demonstration and pilot projects on distribution/local level are expected, in particular on electrochemical, chemical and thermal storage.[51] Research and development in the energy storage sector will concern the development and eventual commercializing of energy storage technology which is as of yet, in its nascent and/or developing stages. With energy storage technologies which have already begun to establish a presence in the market, research and development is set to focus on developing the technology's economic maturity.

### ii. Battery Technologies

*Li-ion*

Considering that lithium-ion battery technology's primary current drawback is its cost. Li-ion battery technology's primary challenge is to achieve cost reduction in the future.

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[51] European Commission (2007), "Inquiry Pursuant to Article 17 of Regulation (EC) No 1/2003 into the European Gas and Electricity Sectors (Final Report)", Brussels, Belgium

Furthermore, as the small-scale energy storage has effectively become a niche-market dominated by Li-ion technology, improving safety and optimizing its role within the small-scale market will be chief priorities for the lithium-ion segment of the market, going forward. [52]

### *NiMH*

At present, Nickel-based batteries are a potential contender to lithium-ion batteries in the small-scale energy storage segment of the market. They are already used in electric vehicles and in electro-domestic appliances. In order to compete on a more equal footing in the market however, they will need to not only reduce costs, but also improve charge and discharge efficiency.[53]

### *Pb-Acid*

Pb-Acid's main shortcomings are low energy density, charge efficiency, and concerns over corrosion as the battery ages.  Although Lead-Acid Battery technology is already a mature technology, the research and development frontier in Pb-Acid technology concerns advanced lead-acid hybrid battery technology, which uses ultracapacitor technology to improve the battery-technology's useful life and charge efficiency. In the long run, Pb-Acid technology will need to not only improve its performance characteristics but also the diversity of its viable implementations.

### *NaS*

Sodium-Sulfur battery technology's primary shortcomings concerns are safety.  These are linked to NaS technology's operational temperature, which also increases its maintenance costs and limits the technology's viable uses. In addition, cost reductions will be necessary if NaS is going to remain a viable battery technology in the future.

### *VRFB*

Overall, VRFB is still an emerging technology, and can be improved and matured in several aspects. According to Japan's Institute of Energy Economics, VRFB technology's development challenges going forward concern environmental acceptability, energy density, durability, and cost reduction.

## b. Nascent and Emerging Energy Storage Technologies

According to the US department of Energy's 2013 Grid Energy Storage working paper, hydrogen-based energy storage and adiabatic CAES technologies are still in early stages of development, while Superconducting Magnetic Energy Storage (SMES) is just entering the demonstration stage. This view is broadly corroborated by the International Energy Agency's 2014 Energy Technology Roadmap, which identifies the three technologies as early-stage.

Economically speaking, the primary challenges involved with such early-stage emergent technology are financial risk and high capital requirements.

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[52] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

[53] Eurobat (2013), "Battery Energy Storage for Smart Grid Applications", working paper, Brussels, Belgium
European Commission (2007), "Inquiry Pursuant to Article 17 of Regulation (EC) No 1/2003 into the European Gas and Electricity Sectors (Final Report)", Brussels, Belgium

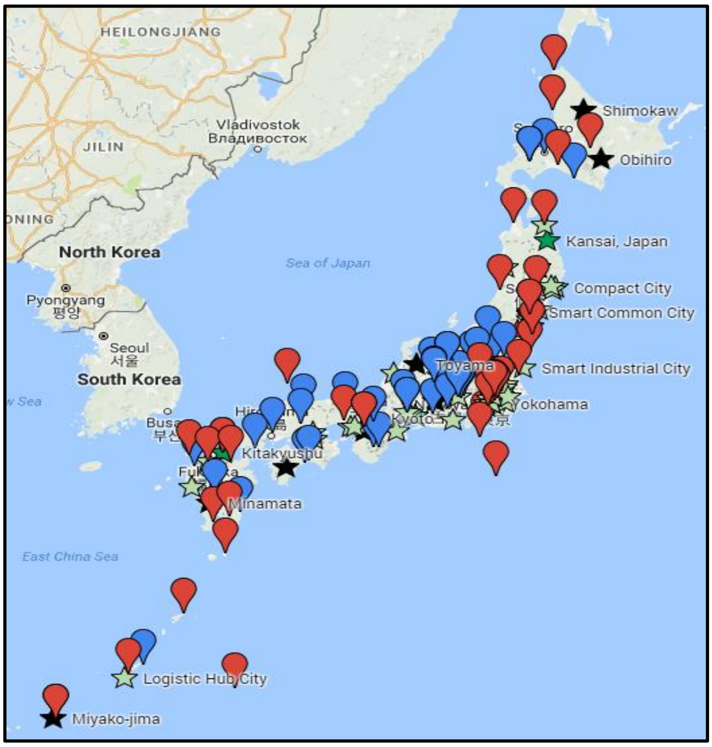
# 4. Market & Industry Analysis

Japan’s energy storage landscape is widely distributed across the whole of Japan, geographically-speaking. Furthermore, Japan’s energy-storage landscape is characterized by its connection with Japan’s smart-grid and smart city landscape.

## a. Interactive Map of Japan’s Energy Storage Landscape

Figure 16, is a snapshot of the interactive map of Japan’s large-scale energy storage geography, as well as its smart-grid and smart-city landscape. Overall, the map demonstrates that Japan has a visible overlap between its smart-grid infrastructure and the country’s energy storage sites.

**Figure 16: Map of Japan's Energy Storage and Smart Grid Sites** [54] [55]



Interactive Map Link: https://www.google.com/maps/d/edit?hl=en&authuser=0&mid=1Mw2FxURLwa7noKWGbdof_KYJRRA

The interactive map, whose energy-storage data is drawn from the US Department of Energy’s Global Energy Storage Database, maps Japan’s primary energy-storage sites, as well as Japan’s smart-grid infrastructure. The interactive map includes GPS coordinates for Japan’s primary energy storage sites, as well as capacity, launch year, primary operator/owner, and a brief description of the site.

One immediately apparent trend demonstrated by the interactive map is the distribution of Japan’s energy storage sites. Japan’s smart-grind and smart-city infrastructure (highlighted by the star-shaped markers) are geographically

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[54] US Department of Energy Global Energy Storage Database

[55] Berre, Max (2015), “Cluster mapping and industry landscape of the clean-tech sector in Japan” EU-Japan Centre for Industrial Cooperation.

intertwined with the country's energy storage infrastructure (highlighted by the teardrop-shaped markers). Moreover, the country's more mountainous and topographically-diverse central regions host a denser concentration of pumped hydro sites (highlighted by the blue markers), while battery-based energy storage sites (highlighted by the red markers), are more concentrated in the country's densely-populated low-lying east-coast regions.

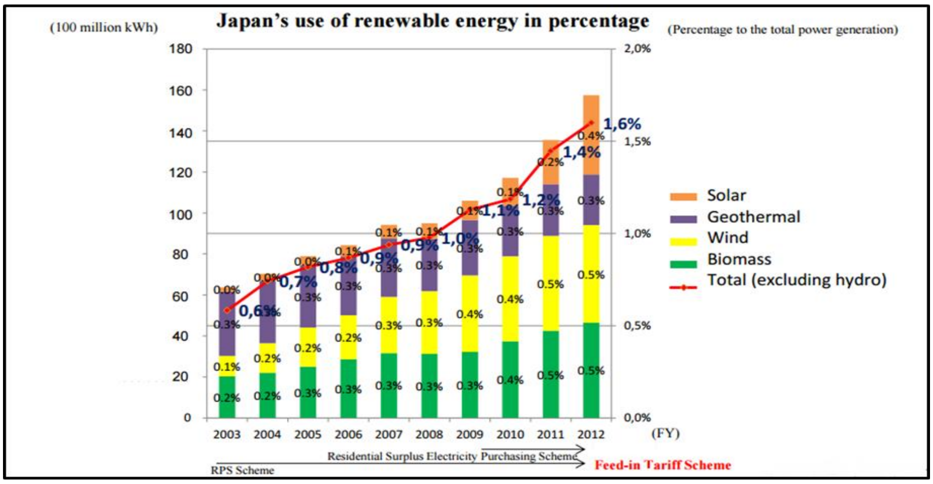
Although the interactive map only displays the large-scale energy storage sites, such as utility-scale, industrial scale, and municipal-scale energy storage sites (all sites included in the map feature storage capacity of 300 kW or more), thereby overlooking the small-scale energy storage market (such as residential and business-scale energy storage), small-scale energy storage is typically contextualized within a smart-grid environment.

## b. Specific Issues and Features of the Energy Landscape in Japan

### i. Japan's Renewable Landscape and the Role of Smart-Grids

Although Japan's current use of renewable energy generation represents just a small fraction of Japan's total power generation, as demonstrated here in Figure 17, (as well as in Figure 3, which compares OECD averages for renewable energy generation to fossil fuel, in the previous chapter), the scale of proportional growth of Japan's renewable sector indicates not only growing integration of renewable energy generation in the Japanese market, but also of the growing economic maturity of renewable energy generation.

**Figure 17: Japan's Use of Renewable Energy in Percentage [56]**



This is particularly the case concerning wind and photovoltaic energy generation technologies, which have both seen dramatic increases to scale since 2003.

Compared to other major energy markets, Japan will be a serious contender in terms of its photovoltaic energy generation capacity going forward, according to 2014 projections from Bloomberg New Energy Finance. Figure 18 demonstrates the specific energy diversification breakdown of the major energy markets going forward. Flexible capacity in this figure includes power storage, demand response, grid-scale, consumer and electric vehicle battery storage, cross-border interconnection, renewable control systems, and flexible distributed capacity. Although Japan is projected to develop both its photovoltaic and its flexible capacity resources substantially, this lags behind Germany,

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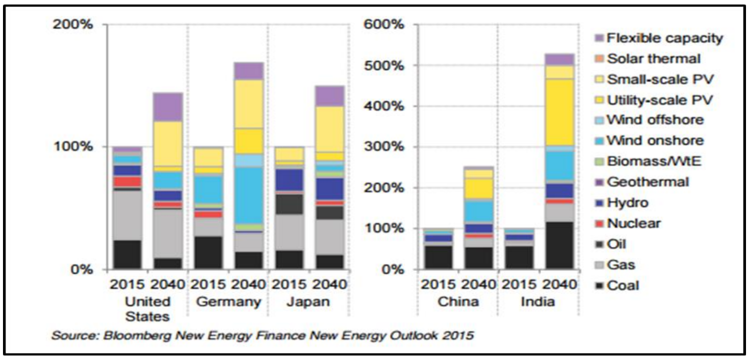
[56] Agency for Natural Resources and Energy (2014), English provisional translation of Japan's new Strategic Energy Plan

which is projected to substantially develop not only photovoltaic and flexible capacity resources, but also wind energy generation resources by 2040.

**Figure 18: Energy Breakdown in Top Energy Markets**[57]



*Source: Bloomberg New Energy Finance New Energy Outlook 2015*

## *Energy Costs and Economic Maturity Issues*

Economic maturity however, is still a work in progress. According to the World Energy Council's 2013 report on energy technology costs, Japan is faced with unusually high energy generation costs compared to Japan's peers in the OECD, and with China. This is also the case comparing individual types of energy generation in Japan with those of Japan's peers.[58]

While wind energy prices in the US and Australia are competitive with both coal and Combined Cycle Gas Turbine (CCGT) energy prices, Japan's wind energy prices are a full 48% higher than gas energy prices. Photovoltaic energy prices in Japan, meanwhile, nearly *triple* those of CCGT prices, whereas US and Australian markets have PV prices closer to double that of CCGT prices.

Table 3 draws on 2013 WEC figures to provide a brief illustration of price energy differences between Japan, Chine, the US, UK, and Australia. According to the WEC, Japan has higher energy generation costs for every energy generation source for which it has data.

**Table 3: Levelized Cost of Electricity by Generation Source and Market**[59]

| **Energy Source** | **LCOE China (2013 USD/mWh)** | **LCOE UK (2013 USD/mWh)** | **LCOE Australia (2013 USD/mWh)** | **LCOE USA (2013 USD/mWh)** | **LCOE Japan (2013 USD/mWh)** |
|---|---|---|---|---|---|
| Onshore Wind | 49 to 93 | n.a. | 71 to 99 | 61 to 136 | 220 |
| Combined Cycle Gas Turbine (CCGT) | n.a. | 114 to 141 | 92 to 108 | 61 to 69 | 148 |
| Coal | 35 to 39 | 119 to 172 | 93 to 126 | 77 to 78 | n.a. |
| Photovoltaic | 79 to 145 | n.a. | 127 to 191 | 117 to 239 | 439 |

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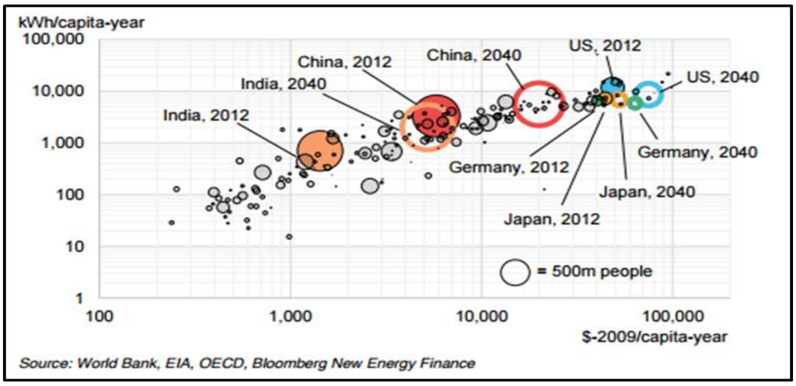
[57] Bloomberg New Energy Finance, (2015) New Energy Outlook 2015
[58] World Energy Council (2013), World Energy Perspective: Cost of Energy Technologies, London, UK
[59] World Energy Council (2013), World Energy Perspective: Cost of Energy Technologies, London, UK

These higher energy costs are due to higher labor costs, as well as to Japan's generous Feed-In-Tariff Scheme[60], which was, in principle designed to incentivize the diversified generation of renewable energy, as well as the installation of related energy-generation capacity. As can be seen in Table 3, solar energy prices demonstrate the largest gap between Japan and her peers. Accordingly, since Japan's FIT program started in July 2012, solar energy has benefited more than other renewables by far.[61] Such prices have lead however, to Japanese utility companies limiting the amount of renewable energy they purchase.[62] Moreover, Japan's energy prices are not without its macroeconomic consequences. Figure 19, outlines official estimates of per capita energy use and per capita GDP for 2012 and 2040. While rival markets such as China, Germany, and the US are projected to increase per capita output by 2040, while per capita energy use stays stable (or even decreases in the case of the US), Japan's market is projected to be in roughly the same place in 2040 as it was in 2012, concerning per capita energy use and economic output. Considering the effect of energy prices on the development of the value chain and on economic output overall, the relationship is somewhat intuitive.

**Figure 19: Major Energy Markets Energy Per Capita 2012 and 2040**



Source: World Bank, EIA, OECD, Bloomberg New Energy Finance

### *Japan's Smart-Cities*

A major theme in Japan's energy landscape both today, and looking forward into the future, is the Post-Fukushima rise of smart-cities, a concept which sits at the intersection of localized grid infrastructure, distributed residential and business-scale energy generation, storage, and demand management, and the municipal diversification of energy generation.

According to the US Department of Energy's 2013 report on Grid Energy Storage, Japan's energy landscape is characterized by the large-scale adoption of renewable power generation resources, of intermittent energy generation[63].

Given that the Fukushima disaster involved the loss of highly-concentrated, utility-scale energy generation infrastructure, widespread adoption of renewable power generation resources of intermittent energy generation in

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[60] World Energy Council (2013), World Energy Perspective: Cost of Energy Technologies, London, UK

[61] Dechert, Sandy (2015), "Japan's METI Subsidizes Battery Storage, Energy Efficiency, Changes FIT" Cleantechnica.com.

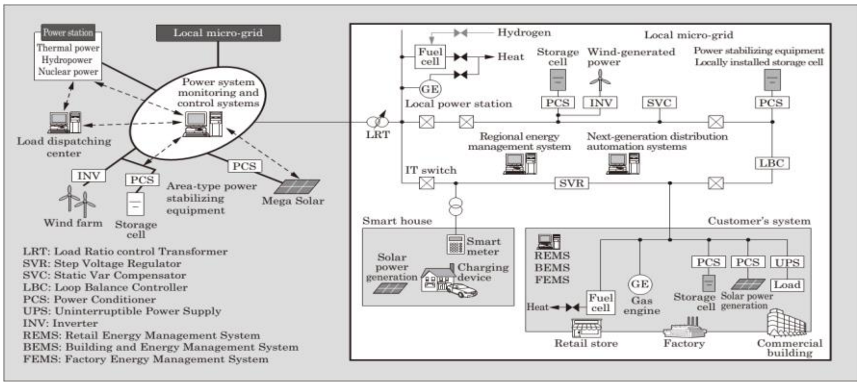
[62] Dechert, Sandy (2015), "Japan's METI Subsidizes Battery Storage, Energy Efficiency, Changes FIT" Cleantechnica.com.

[63] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

Japan's post-Fukushima energy market landscape can be contextualized in relation to the rise of Japan's Smart City plans.

While Japan's Smart-cities concept can be traced to the 2008 Eco-cities project, which earmarked six cities with a variety of population, geographical and industry backgrounds for development, METI earmarked seven municipalities in Tohoku for support concerning smart community projects including initiatives such as smart grids to facilitate the integration of renewable energy, the adoption of renewable-energy vehicles and encouragement for development and implementation of local renewable energy resources in 2012, in the aftermath of the Fukushima disaster. Thereafter, the smart city concept was explicitly endorsed by Japan's 2014 Fourth Strategic Energy Plan because of the role that smart cities play in terms of both energy demand management and in improving Japan's geographic flexibility in terms of domestic energy generation.

**Figure 20: Example: Fuji's Smart Network System Grid** [64]



Both Figure 20 and Figure 21 display models of the smart-grid infrastructure underlying Japan's smart-cities. In principle, the relevant infrastructure consists of:

- Renewable energy generation capacity, which is diversified in nature (photovoltaic, wind, tidal, geothermal), and in scale (residential scale, industrial scale, utility scale)
- Energy saving technology systems (BEMS, FEMS, REMS)
- Energy storage infrastructure (however, the type of energy storage system is not specifically mentioned, given that in principle, different types of energy-storage systems are a viable fit for the smart-city concept)

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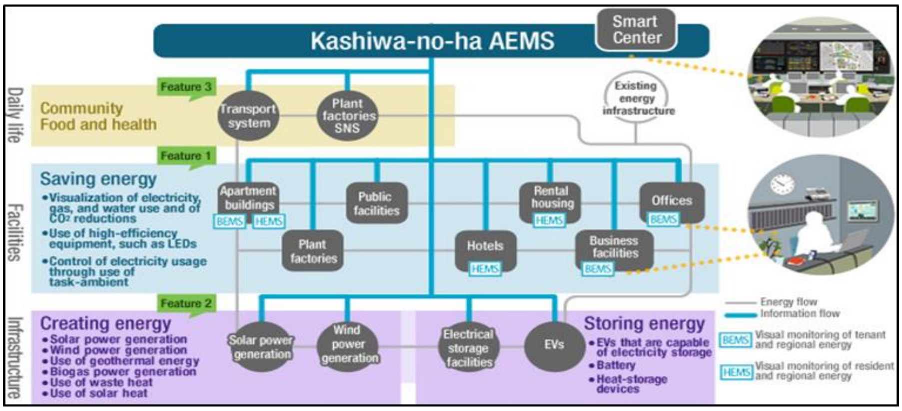
[64] Fueki and Kuwayama (2014)

Figure 21: Kashiwanoha Integrated Smart City Concept [65]

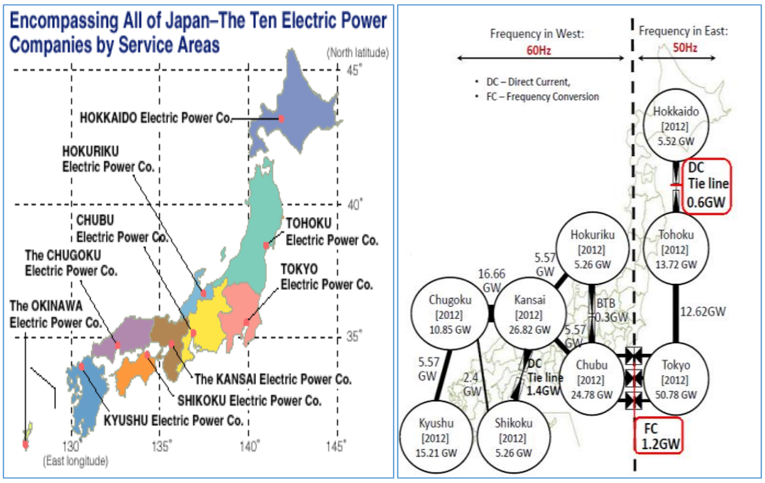


In terms of implications for Japan's energy storage markets, it bears mention that the Technology Roadmap for Stationary Battery, explicitly includes various scale-levels including integration of utility/grid-level energy storage, middle-scale CEMS and FEMS systems, and small-scale BEMS and HEMS.[66]

### *Japan's East-West Grid Division*

Japan is furthermore, confronted with isolated energy grids, with insufficient transmission infrastructure between them. Compounding Japan's internal domestic energy transmission challenges, is the fact that Japan's national energy infrastructure is partitioned into two national-level energy grids with limited transmission capability between them. Figure 22 is an energy infrastructure map which demonstrates both the national-level partition of Japan among Japan's 10 utility companies, and also the country's dual power grid system.

Figure 22: Japan's National Energy Grid [67]



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[65] Retrieved, September, 2015, http://www.hitachi.com/products/smartcity/case/kashiwanoha/index.html

[66] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

[67] Retrieved October 2015, from the Global Energy Network Institute's website: http://www.geni.org/globalenergy/library/national_energy_grid/japan/graphics/chap02-1.gif

While Japan's Eastern Grid runs on a 50Hz AC frequency, Japan's Western Grid runs on a 60 Hz AC frequency. This division dates back to the late 19th century, when the East coast grid was organized along North American lines, while the West coast grid was organized using German AC standards. The two grids are geographically divided at the 140th meridian and the standard voltage at Japan's power outlets is 100V in both zones.

This phenomenon complicates Japan's energy landscape somewhat, given Japan's two grids have only limited capability to directly exchange AC power. Currently, Japan has three *shūhasū henkan sōchi* (frequency converter stations), two in Shizuoka Prefecture and one in Nagano Prefecture, all located near the border between the grids. Those plants can convert 50 Hz power into 60 Hz power and vice versa, but their combined capacity is about 1.2 GW.[68]

In practice, the East-West divide has had the effect of isolating Japan's different regions, and making national-level energy trade and transfer more difficult, giving rise to more localized energy generation needs. This idiosyncratic feature of the Japanese energy landscape gives rise a clear and straightforward incentive towards the development of decentralized energy infrastructure, which can be seen manifested in Japan's current smart-city plans.

### ii. The Nuclear Landscape in Japan: Reduction on Nuclear Dependence

Japan's Fourth Strategic Energy Plan identifies nuclear energy as a key base-load power source with several strategic advantages. Specifically, the Strategic Energy Plan mentions:[69]

- Nuclear power's ability to continue generating power while using only Japan's domestic fuel stockpile.
- Stability of Energy Supply
- Low, stable operational costs for nuclear energy generation
- Nuclear energy generation is free from greenhouse gas emission during its operation.

Prior to Fukushima, Japan's dependence on nuclear power for energy self-sufficiency was among the most pronounced in the entire industrialized world. This saw a dramatic reduction as a result of Fukushima. Whereas nuclear power supplied 28.6% of Japan's energy market in FY 2010, it supplied just 1.7% of Japan's power source consumption in FY 2012.[70]

Figure 23 displays the evolution of primary energy self-sufficiency rates in Japan. While the dramatic reduction of the use of nuclear energy can be seen in this figure, it is also notable that in general, Japan's primary energy self-sufficiency rate *depended* on Japan's nuclear energy production prior to Fukushima.

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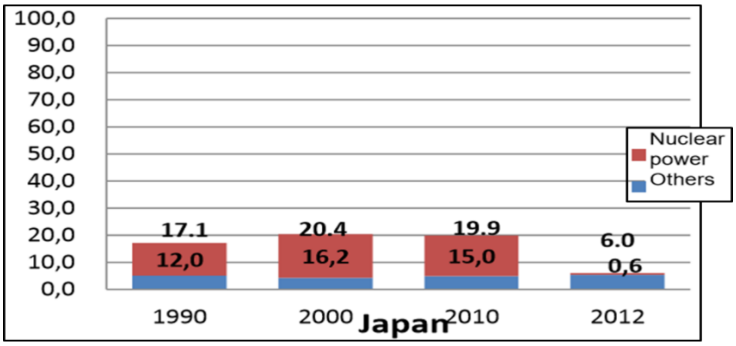
[68] Japan Times, (2011), "Japan's incompatible power grids", http://www.japantimes.co.jp/news/2011/07/19/reference/japans-incompatible-power-grids/#.V7HlYph96hc

[69] Ministry of Economy, Trade and Industry (METI), (2014), Fourth Strategic Energy Plan

[70] Agency for Natural Resources and Energy (2014), "Energy Situation in Japan and Summary of the 4th Strategic Energy Plan"

**Figure 23: Primary Energy Self Sufficiency Rate in Japan**



In terms of long-term strategic policy, Fukushima has not only spelled out the current reduction of nuclear energy use, but also nuclear energy's long-term phase-out. Whereas Japan's 2010 Basic Energy Plan called for an increase in nuclear power use in Japan from supplying one third of Japan's power needs at the time, to around half of the country's power needs by 2030[71], Japan's 2014 Energy Plan, while nuclear energy facilities meeting post-2011 Nuclear Regulation Authority (NRA) safety standards were to be restarted, nuclear dependency is to be reduced as much as possible[72].

### iii. Japan's Legal and Policy Landscape as it relates to the Energy Storage and Renewable Sectors

*1970-1990s*

Japan's public support for energy storage technology traces back to the aftermath of the 1970's oil crisis[73]. The Moonlight Project, a 1978 government-sponsored 10-year METI R&D program to support research in heat pump technology, energy storage, and gas turbine technology, with a budget of ¥140 Billion[74], launched alongside METI's 1974 ¥440 Billion Sunshine Project[75], which focused on renewable energies (photovoltaic, geothermal, hydrogen), as well on coal gasification and liquefaction.

Due to the long construction periods large scale, and large budgets associated with pumped hydro energy storage facilities, it became evident that new types of energy storage technology were needed.[76] In response, the New Energy and Industrial Technology Development Organization (NEDO) was established in 1980 (prior to 1988, NEDO was named the New Energy and Development Organization), and thereafter launched new battery technology development throughout the 1980s,[77] alongside renewable and smart-grid technology development.

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[71] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

[72] METI (2014), Fourth Strategic Energy Plan

[73] Behling, Noriko Hikosaka (2012) "Fuel Cells: Current Technology Challenges and Future Research Needs"

[74] Hamakawa, Yoshihiro, (2004), "Thin-Film Solar Cells: Next Generation Photovoltaics and Its Applications"

[75] Hamakawa, Yoshihiro, (2004), "Thin-Film Solar Cells: Next Generation Photovoltaics and Its Applications"

[76] Large Scale Energy Storage Systems, Issue 34

[77] Large Scale Energy Storage Systems, Issue 34

While the Sunshine Project was originally intended to address the problems caused by energy shortages, Moonlight Project was intended to support the development of high-efficiency energy-conversion in order to reduce Japan's dependence on oil imports.[78] The project featured research into utility-scale and industrial-scale fuel cell and battery storage technology.

In terms of battery technology, the Moonlight Project developed Sodium-Sulfur (NaS), Improved Lead-Acid (Pb-Acid), Vanadium Redox Flow (VRFB), and Zinc Bromide technologies, seeking to develop a durable utility power storage technology which:

- Was in the 1000 kW class
- Featured eighth-hour charging and discharging at rated load
- Has efficiency of 70% or better
- Has a lifetime of 1500 cycles or longer.[79]

Thereafter, ¥15 Billion R&D program focusing on global environment technologies was established in 1989.[80] This was followed in 1993 by the New Sunshine Program, which integrated the three previous projects and continued funding relevant R&D, aiming for sustainable growth and the resolution of energy and environmental problems.

Japan's energy landscape in the 1990s was also characterized by deregulation, which gave rise to the commercialization of increasingly diverse energy storage and energy generation options.

### *21st Century*

In 2006, NEDO launched a technology development project, with the aim of developing cheaper, longer-lived, and more efficient, battery technology, in order to manage fluctuations in renewable energy output. [81]

Japan's 2010 Basic Energy Plan called for an increase in nuclear power use in Japan from supplying one third of Japan's power needs at the time, to around half of the country's power needs by 2030[82]. In the aftermath of the March 2011 Fukushima disaster, the 2014 Strategic Energy Plan called for an improved focus on reliability and diversification of electricity generation sources to meet Japan's energy needs going forward.

In January 2012, METI established a Storage Battery Strategy Project Team, integrating the Agency for natural Resources and Energy, the Commerce and Information Policy Bureau, and the Manufacturing Industries Bureau, in order to formulate and implement plans and policies for storage batteries, storage battery markets, related competitive enhancement, and international standardization of relevant technologies[83].

2014 saw the launch of Japan's Fourth Strategic Energy Plan. As outlined in the plan, the primary objective is the establishment and promotion of a multilayered energy supply system, which should be sufficiently resilient to ensure

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[78] Behling, Noriko Hikosaka (2012) "Fuel Cells: Current Technology Challenges and Future Research Needs"

[79] http://nickelbackchina.blogspot.fr/2009/04/sodium-sulfur-battery.html

[80] Hamakawa, Yoshihiro, (2004), "Thin-Film Solar Cells: Next Generation Photovoltaics and Its Applications"

[81] Large Scale Energy Storage Systems, Issue 34

[82] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

[83] Ministry of Economy, Trade and Industry (METI), (2012), Establishment of Storage Battery Strategy Project Team, Press release

stable energy supply. In principle, this has given birth to the "3E+S" policy viewpoint. The underlying policy objectives are: [84]

- Energy Security
- Economic Efficiency
- Environmental Sustainability
- Safety

Under the 2014 plan, while nuclear energy facilities meeting post-2011 safety standards were to be restarted, nuclear dependency is to be reduced as much as possible. Furthermore, the introduction of renewable energy is to be maximized under the 2014 energy plan, while incorporation of wind and geothermal energy are to be promoted via enhancement and growth of grid technology and infrastructure. The plan also calls for the widespread promotion of energy efficient management systems (EMS) in Japan.

At the national level, and in a long-term strategic sense, this context has given rise to the structural demand for energy storage infrastructure on Japan's energy market. Also highly-relevant in shaping structural demand for energy storage Japan's post-Fukushima energy market landscape, has been the rise of Japan's Smart City plans. In principle, the smart city concept also needs energy storage in order to help regulate energy demand management systems.

### *Japan's Current Legal and Regulatory Infrastructure*

Table 4 outlines the relevant legal and regulatory architecture upholding Japan's energy storage market. Legally, there is a regulatory distinction between small-scale and large scale energy storage usage established by the Electricity Business Act and the Fire Prevention Ordinance. Furthermore, regulatory guidelines and technical standards outline the norms for grid-connection.

**Table 4: Relevant Regulator Structure of Japan's Energy Storage Market** [85]

| Legal and Regulatory Structure | | | Governing Organization |
|---|---|---|---|
| Relevant Legislation | Electricity Business Act (1964) | Required approval for large electricity storage system more than 80,000kWh | Ministry of Economy, Trade and Industry (METI) |
| | Fire Service Act (1948) | Dangerous material for more than 1,000 organic electrolyte solution | Fire and Disaster Management Agency, Ministry of Internal Affairs and Communications |
| | Fire Prevention Ordinance | Required approval for large battery (4,800Ah/cell) | |
| | Building Standards Act (1950) | Construction application for building regarding to fire prevention property | Ministry of Land, Infrastructure, Transport and Tourism |
| Technical Norms and Guidelines | Technical requirements guideline of grid interconnection to secure electricity quality (2004, revised in 2013) | | Ministry of Economy, Trade and Industry (METI) |
| | Grid Interconnection Code (JEAC 9701 - 2006) (Superseded by JEAC 9701 - 2012) | | Japan Electric Association (JEA) |

Law and regulation is more involved concerning larger-capacity energy storage systems. This is because larger systems have more diverse safety risks, systemic energy supply risks and incentive concerns for grid integration.

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[84] Ministry of Economy, Trade and Industry (METI), (2014), Fourth Strategic Energy Plan

[85] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

In principle, this regulatory structure appears to favor small-scale energy storage usage, in the sense that the regulatory burden is more extensive on large-scale energy storage sites and facilities. In contrast, private home-scale energy storage does not have the goal of entering the electricity market as a supplier. Typically, the small-scale energy-storage system user also does not have a large battery, meaning that the Fire Prevention Ordinance does not regulate her energy storage use. Nor does the small-scale energy-storage user necessarily need to connect her energy storage system to the local energy grid in order for her to benefit from energy storage technology.

#### *Current Energy Storage Market Target*

In July 2012, METI announced Japan's strategy on energy storage batteries, alongside the storage target of acquiring 50% of the world's storage battery market share by 2020[86]. Furthermore, METI also aims to capture 35% of the world's large-scale battery market and 25% of residential/industrial use battery storage market by 2020.[87]

## c. Market Characteristics of the Energy Storage Market in Japan

In terms of energy storage technology, Japan is supported primarily by pumped hydro and by NaS and Li-ion battery storage capability, according to the US Department of Energy.[88] While Japan is the world leader in Nas battery energy storage technology, it is also the world's second manufacturer of Pb-Acid energy storage systems.

Future trends in Japan's energy storage market are focused on the growth, diversification, and diffusion of the battery-based energy storage market.

### i. Market Size

Overall, much of the available energy storage markets data excludes pumped hydro storage technology. Aside from the fact that PHS is already an economically mature technology, its constraints render it incompatible with small-scale energy storage markets such as residential and business-space energy storage markets, where much of the research and development is focused, and where most of the growth is set to occur over the coming decades.

**Table 5: Evolution of Japan's Total Energy Storage Market Size 2012 to 2020 (Excluding PHS)** [89]

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2020 |
|---|---|---|---|---|---|---|---|
| Energy Storage Systems Market Size (kWh) | 109,346 | 189,189 | 299,643 | 581,491 | 634,252 | 1,195,708 | 3,306,600 |
| Year-on-year growth | - | 173.02% | 158.38% | 194.06% | 109.07% | 188.52% | - |
| Annual growth | - | 73.02% | 58.38% | 94.06% | 9.07% | 88.52% | - |
| Growth since 2012 | - | - | 174.03% | 431.79% | 480.04% | 993.51% | 2923.98% |

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[86] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

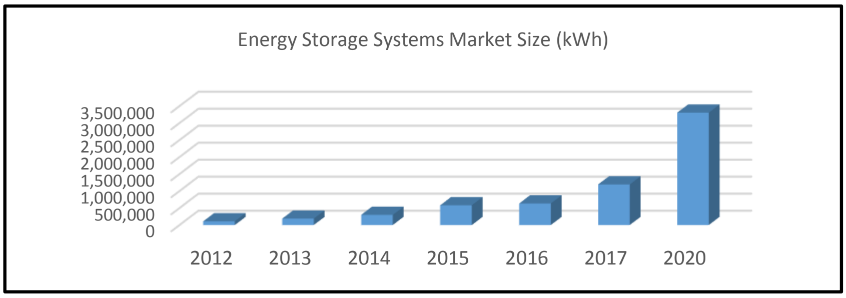
[87] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

[88] US Department of Energy (2013)

[89] Yano Research Institute Ltd. (2015), "Stationary ESS (Energy Storage System) Market in Japan: Key Research Findings 2015", Tokyo, Japan

According to National Policy Unit estimates, Japan's total storage battery market size is ¥930 Billion (according to 2011 figures).[90] In terms of energy storage usage, Japan's battery-based energy storage market is growing aggressively. As demonstrated both by Table 5 and by Figure 24, Japan's energy storage systems market size is projected to increase its aggregate storage capacity aggressively over the next few years, in line with Japan's official policy goals.

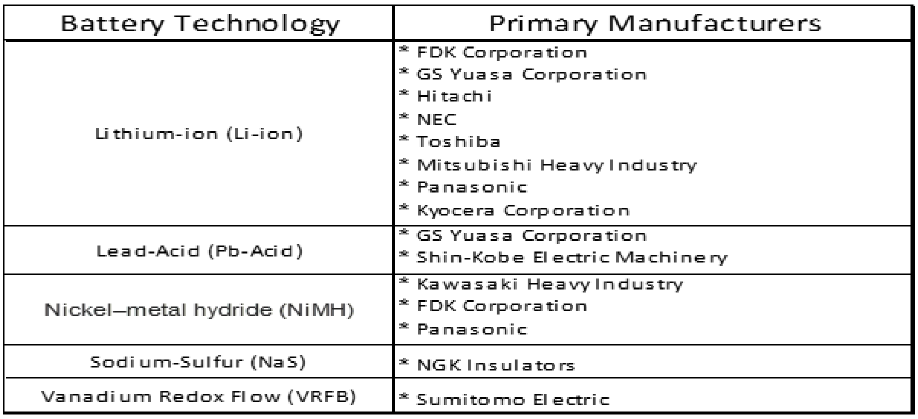
**Figure 24: Japan's Total Energy Storage Market Size 2012 to 2020 (Excluding PHS)** [91]



## ii. Primary Firms of Japan's Energy Storage Landscape

In addition to the diversity of energy storage technologies available, the Japanese battery-based energy storage market has a diversity of relevant firms.

**Figure 25: Primary Firms in Japan's Energy Storage Market** [92]



| Battery Technology | Primary Manufacturers |
|---|---|
| Lithium-ion (Li-ion) | * FDK Corporation<br>* GS Yuasa Corporation<br>* Hitachi<br>* NEC<br>* Toshiba<br>* Mitsubishi Heavy Industry<br>* Panasonic<br>* Kyocera Corporation |
| Lead-Acid (Pb-Acid) | * GS Yuasa Corporation<br>* Shin-Kobe Electric Machinery |
| Nickel–metal hydride (NiMH) | * Kawasaki Heavy Industry<br>* FDK Corporation<br>* Panasonic |
| Sodium-Sulfur (NaS) | * NGK Insulators |
| Vanadium Redox Flow (VRFB) | * Sumitomo Electric |

As demonstrated by Figure 25, the lithium-ion battery market has a wider diversity of firms than other segments of the energy storage systems landscape. This reflects both the wider variety of uses and scale-applications of lithium-ion battery technology, as well as the large consumer market and robust competitive environment of the small-scale residential and business energy storage market.

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[90] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

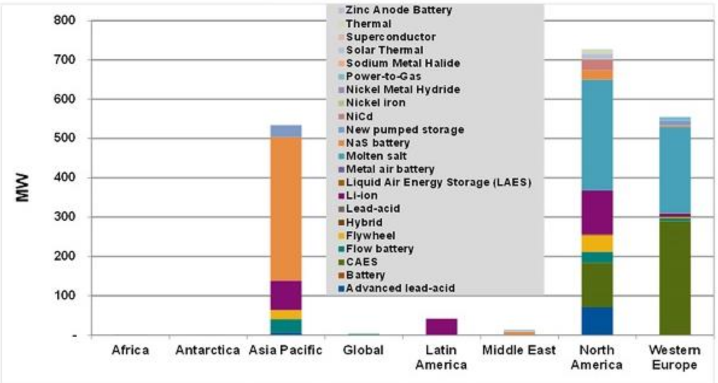
[91] Yano Research Institute Ltd. (2015), "Stationary ESS (Energy Storage System) Market in Japan: Key Research Findings 2015", Tokyo, Japan

[92] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

### iii. Distribution of the Energy Storage Market

As outlined in the previous section, much of the available data on energy storage markets does not include pumped hydro storage, which is already an economically mature technology, and its constraints render it incompatible with small-scale energy storage markets, where most of the future growth is set to occur.

**Figure 26: 2014 World Deployed Energy Storage (Excluding PHS)[93]**



*(Source: Navigant Research)*

Once pumped hydro has been excluded, Japan's energy storage market is currently dominated NaS battery technology. Figure 26 demonstrates that the Asia-Pacific energy storage market (which although large, is dominated mostly by Japan and South Korea), consists largely of NaS and Li-ion battery technology. This is in marked contrast to European and North American markets, which are dominated by mechanical and thermal energy storage technologies.

Going forward however, trends in the small-scale energy storage market seem set to overthrow the dominance of NaS battery technology in the long-run. According to figures by Yano Research Institute Ltd. (which also exclude pumped hydro figures), the majority of the Japanese market for energy storage systems is concentrated in small-scale residential energy storage. According to Yano's 2020 projections, the trend towards small-scale energy-storage is set to continue.

Figure 27 displays the consumer distribution of Japan's market for energy storage systems. Whereas 2015's energy storage systems market is 52% residential and 28% utility-based, the projections for Japan's market in 2020 market will be 66% residential and only 17% utility-based. Given that NaS is mostly a large-scale and utility-scale and industrial-scale battery technology, and that Japan's residential energy storage market features more Li-ion and Pb-Acid battery systems, it seems likely in the future Li-ion battery technology will eventually dominate the Japanese energy storage market.

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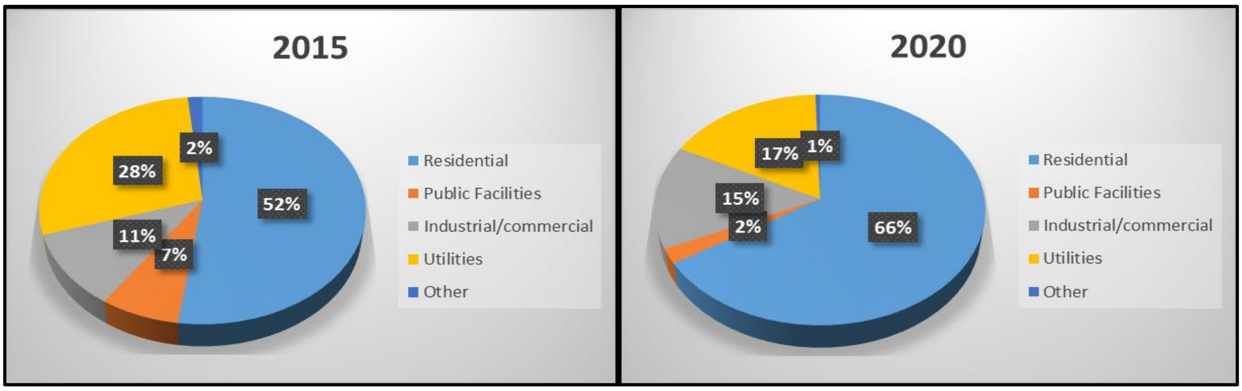
[93] Dehamna, A. (2015), "Energy Storage for Renewables Integration: A Burgeoning Market", Navigant Research

Figure 27: 2015 and (Projected) 2020 Energy Storage Systems Market Distribution (Excluding PHS) [94]



### *Installations: Pumped Hydro*

In principle, Japan is an ideal market for the rise of pumped hydro energy storage. Japan's geography provides for both extensive topographical differences and large densely-populated energy consumption markets. In combination, these two factors can support a large number of very large-scale pumped-hydro energy storage sites.

Table 6 displays Japan's primary pumped-storage hydroelectric power stations of note. For the most part, these pumped hydro energy storage sites have installed capacity in excess of 1,000,000 kW (1,000 mW). [95] In addition, one of the sites, the Kannagawa Hydropower Plant, is still under construction, with completion slated for 2020.

The smallest of the sites, is the Okinawa Yanbaru Seawater Pumped Storage Power Station. Although small, Yanbaru is noteworthy because it is the world's first pumped-storage to use seawater for storing energy. Japan currently has the world's largest pumped hydro storage capacity, with over 25GW of pumped hydro energy storage available, even according to pre-Fukushima figures.[96]

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[94] Yano Research Institute Ltd. (2015), "Stationary ESS (Energy Storage System) Market in Japan: Key Research Findings 2015", Tokyo, Japan

[95] Pumped-Storage Hydroelectric Plants in Japan, http://www.industcards.com/ps-japan.htm

[96] Yang, Chi-Jen. (2010) "Pumped Hydroelectric Storage", Duke University

Table 6: Japan's Primary Pumped Hydro Energy Storage Sites[97] [98]

| Site | Location | Operator | Installed Capacity (kW) |
|---|---|---|---|
| Honkawa (Motokawa) Pumped Storage Power Plant | Kochi | Shikoku Electric | 600,000 |
| Imaichi Pumped Storage Plant | Nikko | Tokyo Electric | 1,050,000 |
| Kannagawa Hydropower Plant | Gunma | Tokyo Electric | 2,820,000 (under construction) |
| Kazunogawa Dam | Yamanishi | Tokyo Electric | 1,200,000 |
| Mazegawa Daiichi | Gifu | Chubu Electric | 288,000 |
| Matanoagawa Dam | Tottori | Chugoku Electric | 1,200,000 |
| Midono | Nagano | Tokyo Electric | 260,000 |
| Niikappu | Hokkaido | Hokkaido Electric | 200,000 |
| Okawachi Pumped Storage Power Station | Hyogo | Kansai Electric | 1,280,000 |
| Okinawa Yanbaru Seawater Pumped Storage Power Station | Okinawa | Electric Power Development Company | 30,000 |
| Okukiyotsu Pumped Storage Power Station | Niigata | Electric Power Development Company | 1,000,000 |
| Okutataragi Pumped Storage Power Station | Hyogo | Kansai Electric | 1,932,000 |
| Okuyahagi Pumped Storage Power Station | Aichi | Chubu Electric | 1,125,000 |
| Okuyoshino Pumped Storage Power Station | Totsukawa | - | 1,206,000 |
| Omarugawa Pumped Storage Power Station | Saga | Kyushu Electric | 1,200,000 |
| Shimogo Pumped Storage Power Station | Fukushima | - | 1,000,000 |
| Shin Takasegawa Pumped Storage Station | Nagano | Tokyo Electric | 1,280,000 |
| Shin Toyone Dam | Aichi | J-Power | 1,125,000 |
| Takami | Hokkaido | Hokkaido Electric | 200,000 |
| Tamahara Pumped Storage Power Station | Gunma | - | 1,199,000 |
| Tenzan | Saga | Kyushu Electric | 600,000 |

### *Installations: Batteries*

Japan is a major producer and exporter of battery-based energy storage technology. According to the International Renewable Energy Agency’s 2015 Market Status and Technology Outlook, Japan in the world’s primary exporter of utility-scale NaS battery technology, while Li-ion battery production (at various scales) is also heavily concentrated in Japan and Korea. Compared to Japan’s peers in the G20 and the OECD, Japan’s market characteristics and energy landscape provide exceptionally ideal conditions not only for the energy storage sector as a whole, but also for the rise and implementation of battery-based energy storage in particular.

### Smart Cities and Smart Grids

A smart-grid context is characterized by dispersed energy generation, trade between sites which engage in both energy generation and consumption, and a diversity of energy storage technologies and needs, ranging from municipal and building-level grids and micro-grids to small-scale residential energy storage systems, all of which are niche-markets

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[97] Pumped-Storage Hydroelectric Plants in Japan, http://www.industcards.com/ps-japan.htm
[98] US DOE Global Energy Storage Database

for battery technology. As trade activity on smart grid systems intensifies going forward, further energy storage capabilities will be demanded in order to help the market clear and to facilitate the continued smooth operation of the local energy market.

### Localized Energy Grids

According to the International Renewable Energy Agency's 2015 report on battery storage for renewable energy application, islands represent one of the most attractive opportunities for the deployment of renewable energy support battery-based energy storage technology. Additionally, Japan's dual national energy grid system gives rise to further need for implementation of energy storage technology.

In principle, fractionalized energy networks have more restrained flexibility in responding to fluctuations in energy demand and energy generation. Japan's energy landscape is punctuated with small island-based local-level grids and micro-grids in some areas, rendering local energy costs more expensive, given that island micro-grids depend on diesel-fuel electricity generation – a technology which yields considerably higher levelized costs than most mainstream energy generation technologies – . Moreover, in the absence of larger grids from which to buy energy, small-scale island-based energy generation networks overproduce energy in order to meet peak-demand. [99] Furthermore, Japan's mainland energy grid is characterized by an East-West Energy grid divide, constraining utility-level energy redistribution in support of ancillary services. According to the International Renewable Energy Agency, fractionalized energy networks represent significant growth opportunities for energy storage technologies, both because expansion of ancillary services can mitigate needs to overproduce energy, as well as mitigating diesel-fuel dependency, and because the deployment of energy storage systems in a micro-grid contexts increase the economic viability of renewable energy generation.  Scale concerns however, heavily favor battery-storage systems in a localized or fractionalized small-scale grid context.

### Economic Conditions

At the Macroeconomic level, the scale of Japan's energy consumer market is among the world's largest. Aside from a residential consumer-market consisting of over 127 million residents, per capita energy use is among the world's highest. As displayed in Figure 19, World Bank figures estimate per capita energy consumption of nearly 10,000 kWh per year. This reflects not only Japan's residential consumer market, but also Japan's heavily industrialized manufacturing sector, which exports largely high-value-added (and high-energy consuming) goods and services.

A compounding economic factor in addition to the scale of Japan's energy demand is the country's high energy prices. Due to the country's relative energy-isolation, and its generous subsidy of still-maturing renewable energy technologies, Japan's LCOE figures are among the highest in the industrialized world.

Overall, macroeconomic contexts such as that of Japan, characterized by large energy markets and high energy prices also represent a substantial opportunity for implementation and expansion of energy storage technology, in as far as widespread deployment of energy-storage systems can serve to manage demand, and to mitigate demand-supply mismatches throughout the economy at large. Overall, the long-run economic incentives to energy storage suppliers are clear.

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[99] International Renewable Energy Agency (2015), "Battery Storage for Renewables: Market Status and Technology Outlook"

Compounding these incentives in the immediate term, is Japan's extensive public funding and support for energy storage research, as well as extensive subsidies for energy storage at both residential and utility scale.

## The Large-Scale Battery Storage Landscape

Japan's total battery storage capacity is considerably smaller than its overall pumped hydro energy storage capacity. This can be attributed to the question of technological comparative maturity between pumped hydro energy storage technology and the various battery storage technologies.

Table 7, enumerates the major battery-based energy storage facilities in Japan, as listed on the US Department of Energy's Global Energy Storage Database. For the most part, these battery energy storage sites have installed capacity larger than 300 kW (although *technology-demonstrator sites* such as the Maeda Area Smart Grid Demonstration are excluded from this list).

Various battery technology types are represented in Japan's energy storage landscape. These range in diversity, from large-scale NaS sites with output capacity of up to 50 mW, to wind-farm-based VRFB facilities, to a 600 kW facility built of aggregated Li-ion electric vehicle batteries.

**Table 7: Japan's Primary Battery-Based Energy Storage Sites** [100]

| Site | Technology | City | Operator | Installed Capacity (kW) |
|---|---|---|---|---|
| Shiura Wind Park | Valve Regulated Lead-acid Battery | Shiura | Kuroshio Power | 4,500 |
| Yuza Wind Farm Battery | Valve Regulated Lead-acid Battery | Yuza | Shonai Wind Power Generation Co. | 4,500 |
| Okinawa Battery System | Lead-acid Battery | Okinawa | Okinawa Electric Power Company | 2,000 |
| Minami Hayakita Substation Vanadium Redox Flow Battery | Vanadium Redox Flow Battery | Abira | Hokkaido Electric Power Company | 15,000 |
| Hokkaido Electric Power- Sumitomo | Vanadium Redox Flow Battery | Abira-Chou | Hokkaido Electric Power Company | 15,000 |
| Tomamae Wind Farm | Vanadium Redox Flow Battery | Tomamae | Hokkaido Electric Power Company | 4,000 |
| Sumitomo Densetsu Office | Vanadium Redox Flow Battery | Osaka | Sumitomo Densetsu Co., Ltd. | 3,000 |
| Yokohama Works | Vanadium Redox Flow Battery | Yokohama | Sumitomo Electric Industries, Ltd. | 1,000 |
| Minami Daito Island Frequency Regulation | Nickel Metal Hydride Battery | Minami Daito | Okinawa Electric Power Company | 300 |

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[100] DOE Global Energy Storage Database

### Table 7 (cont.): Japan's Primary Battery-Based Energy Storage Sites

| Site | Technology Type | City | Operator | Installed Capacity (kW) |
|---|---|---|---|---|
| Nishi-Sendai Substation - Tohoku Electric / Toshiba | Lithium-ion Battery | Sendai | Tohoku Electric Power Company | 40 000 |
| Minami-Soma Substation - Tohoku Electric / Toshiba | Lithium-ion Battery | Minamisoma | Tohoku Electric Power Company | 40,000 |
| Tanegashima Island Toshiba Li-Ion | Lithium Ion Titanate Battery | Nakatane | Kyushu Electric Power Company | 3,000 |
| Mifuneholdings Kagoshima Solar Plant with 1 MWh Samsung SDI | Lithium-ion Battery | Tokunoshima Island | Kyushu Electric Power Company | 2,000 |
| Amamioshima Island Toshiba Li-Ion | Lithium Ion Titanate Battery | Tatsugo | Kyushu Electric Power Company | 2,000 |
| Tobu Railway Regenerative GS Yuasa Power Storage System | Lithium-ion Battery | Fujimino | Tobu Railway Co. Ltd. | 1,800 |
| Kasai Green Energy Park - Panasonic | Lithium-ion Battery | Kasai | SANYO Electric Co. | 1,500 |
| Kyushu Electric Power, Ashibe Substation, GS Yuasa ESS Demo | Lithium-ion Battery | Ashibe, Iki | Kyushu Electric Power Company | 1,279 |
| Toshiba Unga Station TESS | Lithium Ion Titanate Battery | Nagareyama | Tobu Railway Co., Ltd | 1 000 |
| IHI Corporation Long Duration A123 System | Lithium-ion Battery | Tohoku | - | 1,000 |
| Niijima Island Microgrid | Lithium-ion Battery | Niijima, Izu Island | Tokyo Electric Power Company | 1,000 |
| Sumitomo EV Battery | Lithium-ion Battery | Yume-shima Island | Sumitomo Corporation | 600 |
| Yokohama Smart City Project, SCADA Virtual Battery | Lithium-ion Battery | Yokohama | Tokyo Electric Power Corporation | 600 |
| Kashiwa Smart City Hitachi Li-ion AEMS | Lithium-ion Battery | Kashiwa City | - | 500 |
| NEC Kyushu BESS | Lithium-ion Battery | Fukuoka | Kyushu Electric | 500 |
| Kyushu Electric - Buzen Substation - Mitsubishi Electric / NGK Insulators | Sodium-sulfur Battery | Buzen | Kyushu Electric Power Co. | 50,000 |
| Rokkasho Village Wind Farm - Futamata Wind Development | Sodium-sulfur Battery | Rokkasho | Tohoku Electric Power Company | 34,000 |
| Hitachi Automotive Plant | Sodium-sulfur Battery | Hitachinaka | Hitachi Ltd., Automotive Systems Group | 9,600 |
| NGK NaS: Morigasaki Water Reclamation Center | Sodium-sulfur Battery | Ota-ku | Tokyo Electric Power Company (TEPCO) | 8,000 |
| NGK-Chugoku Electric | Sodium-sulfur Battery | Nishinoshima Town | Chugoku Electric Power Nishinoshima Substation | 4,200 |
| Miyako Island Mega-Solar Demo: NaS | Sodium-sulfur Battery | Miyakojima | Okinawa Electric Power Company | 4,000 |
| Kasai Water Reclamation Center | Sodium-sulfur Battery | Edogawa-ku | Tokyo Electric Power Company (TEPCO) | 2,400 |
| Japan Confidential Industrial Customer 1 Durathon Battery Project | Sodium-nickel-chloride Battery | Confidential | Confidential | 2,000 |
| Japan Confidential Industrial Customer 2 Durathon Battery Project | Sodium-nickel-chloride Battery | Confidential | Confidential | 2,000 |
| Sunamachi Water Reclamation Center | Sodium-sulfur Battery | Koto-ku | Tokyo Electric Power Company (TEPCO) | 2,000 |

**Table 7 (cont.): Japan's Primary Battery-Based Energy Storage Sites**

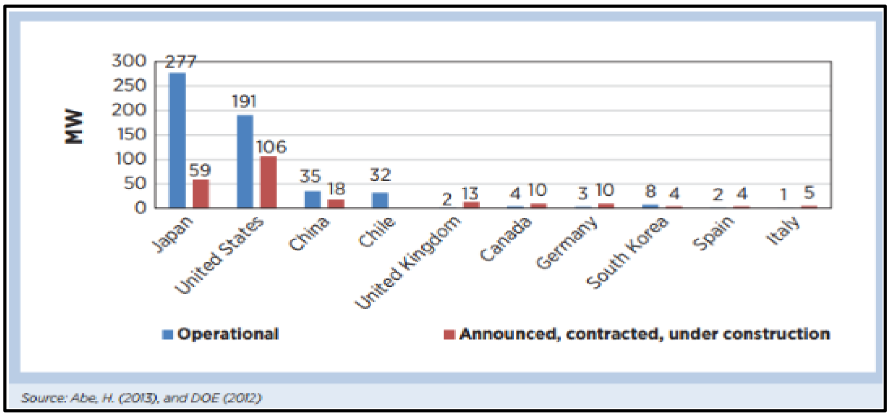
| Site | Technology Type | City | Operator | Installed Capacity (kW) |
|---|---|---|---|---|
| Miyagi Water Reclamation Center | Sodium-sulfur Battery | Adachi-ku | Tokyo Electric Power Company (TEPCO) | 2,000 |
| Wakkanai Megasolar Project | Sodium-sulfur Battery | Wakkanai | Hokkaido Electric Power Company | 1,500 |
| Kita-Tama Ichigo Water Reclamation Center | Sodium-sulfur Battery | Fuchu City | Tokyo Electric Power Company (TEPCO) | 1,000 |
| Hachijo Island NaS Battery | Sodium-sulfur Battery | Hachijo | Tokyo Electric Power Company (TEPCO) | 400 |

While Table 7 outlines Japan's large-scale and utility-level battery-based energy storage sites, this table does not capture Japan's entire battery market. What is missing from this table, is Japan's small-scale energy storage market, which is dominated by residential energy storage, and whose share of Japan's energy storage landscape is set to grow in the future, as demonstrated by Figure 27.

### iv. Japan's Battery Storage Market on the World Stage

Compared to her peers, Japan's battery storage sector holds a commanding lead in comparison with the world stage overall. In line with decades of R&D into battery energy storage technology and systems, Japan currently occupies a world-leading position in terms of battery storage capacity. Figure 28, compares the size of Japan's battery storage market to that of Japan's largest G20 peers. It is noteworthy that in terms of total energy storage capacity, Japan outpaces all comparable energy storage markets, including not only the US, but also China, Canada, and the European Union member nations. Although the US currently has the largest additional battery storage capacity under construction, Japan is still the projected world leader in battery storage capacity. Furthermore, Japan's revitalization strategy aims to capture 50% of the world's battery storage market by 2020.

**Figure 28: Estimate of Operational and Planned Battery Storage**



Source: Abe, H. (2013), and DOE (2012)

In principle, given the energy situation and context of the Japanese market, as well as the sheer size of the overall Japanese market, the global position of Japan's emery storage market vis-à-vis that of Japan's peers should not be particularly surprising, given Japan's status as a major energy-importer, and Japan's prioritizing of energy storage in support of Japan's energy self-sufficiency since the 1970s. Since the late 1990s, NAS battery-based installations in

Japan have grown exponentially from 10 MW in 1998 to 300 MW/2000 MWh in April 2009, and to over 350 MW by the year 2010. Worldwide, Japan's NGK currently dominates the market for NaS batteries[101]. As of 2012, NGK had over 450 MW of sodium sulfur storage systems installed.[102]Meanwhile, Japan is also the world's second-largest Pb-Acid battery manufacturer after the United States.[103]

**Figure 26: World Utility-Scale Battery-Based Energy Storage Market (2014) [104]**

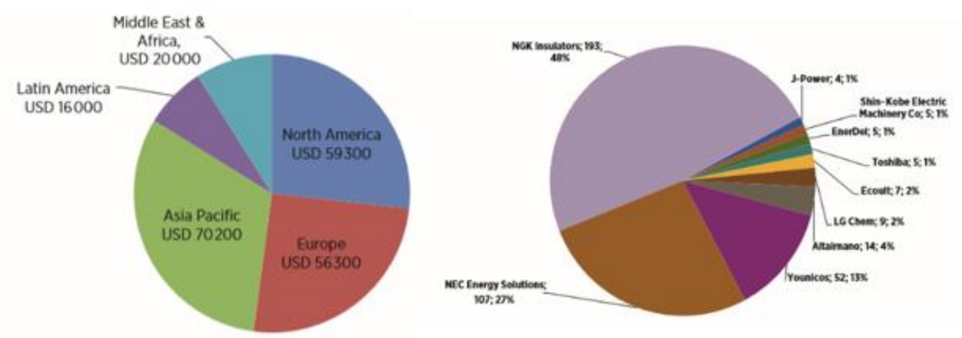


Figure 29 summarizes the worldwide utility-scale battery-based energy storage market. According to the International Renewable Energy Agency's 2014 figures, the Asia-Pacific region's utility-scale market is larger in US-dollar-terms than either Europe or North America. Furthermore, most of the world markets top firms are Japanese, with the largest two firms being NGK insulators and NEC Energy Solutions Respectively.

### Major Subsidy Programs Relevant to Battery Energy Storage Technology

According to Japan's International Institute of Energy Economics, as of FY 2012-2013, Japan's ministry of Environment oversaw two major energy storage subsidy programs. Both the Renewable-energy in Local Area plan and the Storage Battery for Renewable Energy Generation program offered subsidize up to one half of costs associated with targeted energy storage projects.

Meanwhile, METI oversaw several major energy storage technology subsidy plans, which were focused on integration of battery-based energy storage technology. The Stationary Lithium-ion battery program was allocated a budget ¥21 Billion and offered to subsidize one-third of costs for approved parties. The Battery-integrated stand-alone renewable energy generation program offered to subsidize one-half of energy storage costs, but was endowed with a smaller budget of ¥30 Million. [105]

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[101] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

[102] Wen, Z., Hu, Y., Wu, X., Han, J., Gu, Z., 'Main Challenges for High Performance NAS Battery: Materials and Interfaces', Advanced Functional Materials, Vol. 23, № 8, 2012.

[103] Shimzu, K. (1988) "The Lead/acid Battery Industry in Japan", Journal of Power Sources, Volume 23, Issues 1–3, May–June 1988, Pages 33-46

[104] International Renewable Energy Agency (2015), "Renewables and Electricity Storage: A Technology roadmap and Remap 2030"

[105] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

Three of METI's programs, the Smart Energy System program, the Smart Community program, and the Battery-Integrated Renewable Energy Generation program, focused on area affected by the 2011 Fukushima Earthquake. Moreover, the Smart Energy System program offered especially generous subsidy towards SMEs. [106]

In 2014, METI launched a large stationary lithium-ion battery support scheme, offering to two-thirds of costs for approved parties willing to install 1 kW or larger stationary lithium-ion batteries, subject to technical assessment and approval.[107]

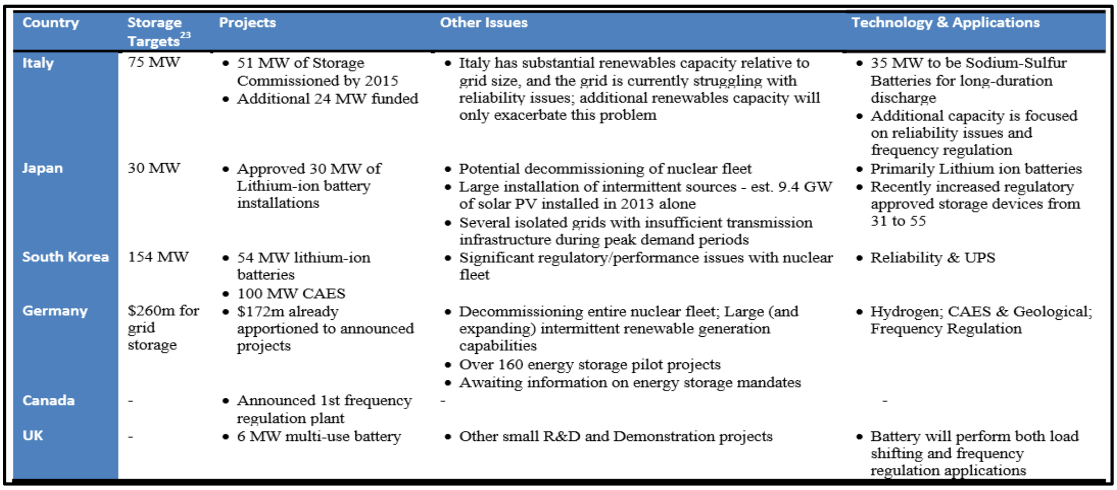
At the start of 2015, METI unveiled plans to allocate approximately, ¥93 Billion to subsidize distributed battery storage and energy-efficient technologies[108]. In addition, METI also set ¥81 Billion aside in response to grid issues the country is facing in order to accommodate more renewable energy.[109]

## d. Energy Storage Markets Abroad

On a global scale, energy storage technologies have emerged in several of the world's key industrial markets.

Figure 30 provides a brief thumbnail-overview of the international grid energy storage landscape, as it was in 2013, examining only the largest markets for energy storage technologies. Overall, Figure 29 demonstrates that no international consensus has yet emerged in terms of optimal size nor in terms of preferred technologies on the energy storage market. One common theme which can be seen here for Japan and Germany (and is also the case in other OECD markets), is the potential retirement of nuclear energy generation in the long run.

**Figure 30: International Landscape of Grid Energy Storage[110]**



| Country | Storage Targets[23] | Projects | Other Issues | Technology & Applications |
|---|---|---|---|---|
| **Italy** | 75 MW | • 51 MW of Storage Commissioned by 2015<br>• Additional 24 MW funded | • Italy has substantial renewables capacity relative to grid size, and the grid is currently struggling with reliability issues; additional renewables capacity will only exacerbate this problem | • 35 MW to be Sodium-Sulfur Batteries for long-duration discharge<br>• Additional capacity is focused on reliability issues and frequency regulation |
| **Japan** | 30 MW | • Approved 30 MW of Lithium-ion battery installations | • Potential decommissioning of nuclear fleet<br>• Large installation of intermittent sources - est. 9.4 GW of solar PV installed in 2013 alone<br>• Several isolated grids with insufficient transmission infrastructure during peak demand periods | • Primarily Lithium ion batteries<br>• Recently increased regulatory approved storage devices from 31 to 55 |
| **South Korea** | 154 MW | • 54 MW lithium-ion batteries<br>• 100 MW CAES | • Significant regulatory/performance issues with nuclear fleet | • Reliability & UPS |
| **Germany** | $260m for grid storage | • $172m already apportioned to announced projects | • Decommissioning entire nuclear fleet; Large (and expanding) intermittent renewable generation capabilities<br>• Over 160 energy storage pilot projects<br>• Awaiting information on energy storage mandates | • Hydrogen; CAES & Geological; Frequency Regulation |
| **Canada** | - | • Announced 1st frequency regulation plant | - | - |
| **UK** | - | • 6 MW multi-use battery | • Other small R&D and Demonstration projects | • Battery will perform both load shifting and frequency regulation applications |

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[106] Tomita, Tetsuji (2014), "Policies and Regulations for Electricity Storage in Japan", The Institute of Energy Economics, Japan (IEEJ), New and Renewable Energy and International Cooperation Unit

[107] Tsagas, I (March, 19, 2014) "Japan proposes new FITs, unveils lithium-ion battery subsidies", PV magazine

[108] Dechert, Sandy (2015), "Japan's METI Subsidizes Battery Storage, Energy Efficiency, Changes FIT" Cleantechnica.com.

[109] Watanabe, Chisaki (Jan, 9, 2015), "Japan to Support Energy Saving, Storage-Battery Installations", Bloomberg.com

[110] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

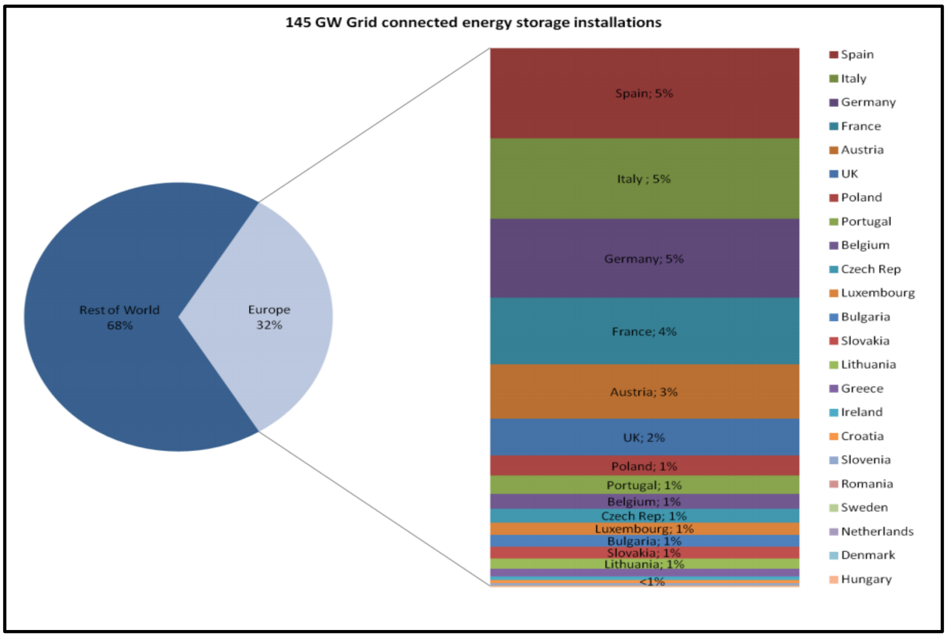
### i. European Union

The EU market currently occupies roughly one-third of the world's energy storage market[111]. According to the US Department of Energy, the EU total capacity of the EU's energy storage market is 145 GW of installed capacity.

Overall, the EU market has a diversity of energy storage technologies. Nevertheless, most existing energy storage systems in the EU, were originally established in order to store base-load overcapacity from coal-fired and nuclear energy generation.

As can be seen in Figure 31, the largest energy storage markets within the EU are Spain, Italy, and Germany, each of whom, hold roughly 1/20th of the world's total installed energy storage capacity. This is followed closely by France, Austria, and the UK, who together hold a further 9% of the world's installed energy storage capacity.

Figure 31: Overview of the EU Energy Storage Market's Cumulative Capacity [112]



In the European Union, the European Commission launched the Energy Union Package in 2015. The core objective of the EU's Energy Union, is the creation and establishment of a unified energy market within the EU.

The Energy Union aims to establish a single energy market to ensure affordable, secure, competitive, and sustainable energy for the EU market at large[113]. In support of these, the EU has established five dimensions

1) Energy Security, Solidarity, and Trust
2) Fully Integrated European Energy Market

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[111] US Department of Energy (2015), Global Energy Storage Database, http://www.energystorageexchange.org/, Sandia National Laboratories, 2015.

[112] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

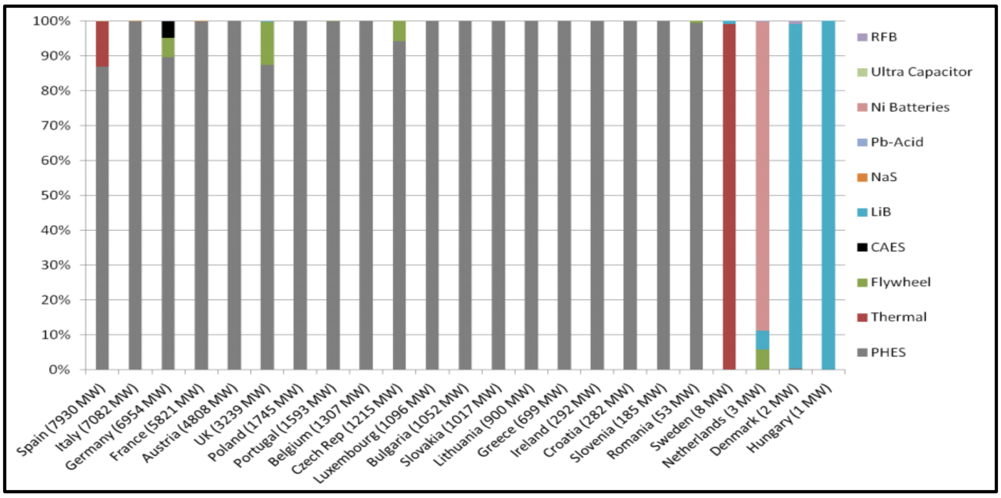
[113] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium

3) Energy Efficiency Contributing to Moderation of Demand
4) De-Carbonization of the Economy
5) Research Innovation and Competitiveness

The development and adoption of energy storage offers valuable services to all five dimensions of the EU Energy Union. This is especially the case, given that energy-efficiency and reliability lie at the core of the EU's vision.

As demonstrated in Figure 32, the most widely employed energy storage technology in the European Union is Pumped Heat Electrical Storage (PHES), which holds markets shares above 85% in 24 of the 28 EU markets. This includes Spain, Italy, Germany, France, and Austria, the largest five EU markets, in terms of capacity.

**Figure 32: Grid-Connected Energy Storage Diversification Within EU Markets** [114]



Nevertheless, PHES energy storage in the EU is growing more slowly other energy storage technologies in the EU market. Considering that PHES is not suitable solutions for the increasing role of fluctuating renewable energies, it is likely the case that other energy storage technologies are seeing higher growth rates in connection with the growth of renewable energy markets in Europe. The share of non-PHES energy storage systems has grown from below 1% in 2005 to more than 1.5% in 2010 and 2.5% in 2015, according to the EU. Sodium-based energy storage, is widely used in Sweden, and is increasing its presence in Spain, largely due to its association with solar energy production.

### ii. United States

Overall, the US energy storage market is smaller than that of Japan. According to a 2013 DOE report, the US market's cumulative operational energy storage capacity in August 2013, was 24.6 GW[115] (roughly equivalent to one fifth of the EU market, as well as to Japan's current pumped hydro storage capacity). The US energy storage market is dominated by pumped hydro energy storage systems. Figure 32 demonstrates the distribution of the US market's energy storage

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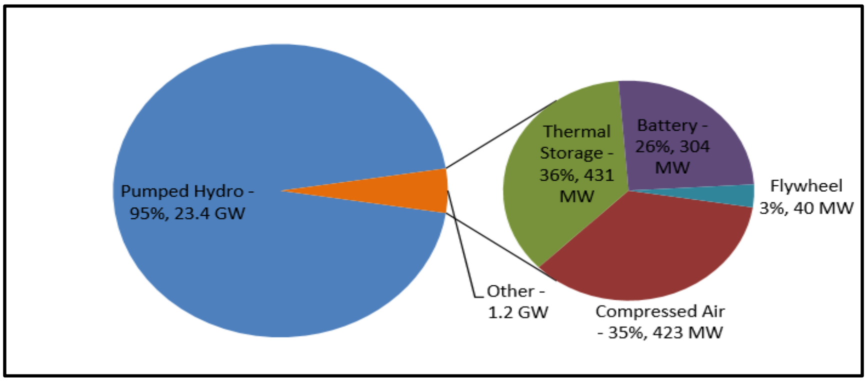
[114] DG Internal Policy (2015), "Energy Storage: Which Market Designs and Regulatory Incentives Are Needed?", European Commission, Brussels, Belgium
[115] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.

capacity. According to the US Department of Energy, pumped hydro accounts for 95% of the US energy storage market, while the remaining 5% is dominated by thermal storage (PHES) and CAES systems.

Figure 27: Overview of US Grid Energy Storage Market's Capacity[116]



At the regulatory level, the US energy and energy storage landscape is defined by extensive multilevel oversight and market-regulatory infrastructure, which governs[117]:

- Grid-connected storage services
- Market opportunities
- Incentives
- Cost-effectiveness criteria
- Cost-recovery methods

At the federal level, the Federal Energy Regulatory Commission (FERC) regulates interstate energy transactions, while state-level Public Utility Commissions (PUCs) regulate the rate structures, capacity management, and utility management operations at the state level[118].

According to the Cooperative Research Network's case study on regulatory and policy drivers in the energy storage market, key FERC rulings include[119]:

- FERC order no. 719: An October 2008 ruling, which establishes standards for non-generator energy resources proving ancillary services[120].

- FERC order no. 755: An October 2015 ruling, which mandates that fast-responding technologies, which can provide grid stabilization and/or frequency regulation be compensated for performance, requiring Independent System Operators/Regional Transmission Operators (ISO/RTOs) to use market-based

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[116] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.
[117] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.
[118] US Department of Energy (2013), "Grid Energy Storage", Working Paper, Washington DC.
[119] Gahlot, J. and Kirk, T.J. (2015), "The Energy Storage Market: Regulatory and Policy Drivers & the California Mandate, a Case Study", Cooperative Research Network: TechSurveillance
[120] Gahlot, J. and Kirk, T.J. (2015), "The Energy Storage Market: Regulatory and Policy Drivers & the California Mandate, a Case Study", Cooperative Research Network: TechSurveillance

mechanisms to compensate both capacity and performance[121]. This provides a framework for energy storage for energy storage providers to sustainably enter energy markets.

- FERC order no. 784: A July 2013 ruling, which stimulates competition and transparency in the ancillary service markets. It creates new opportunities for energy storage technology use, and allows for third-party ancillary service procurement for transmission public utilities that reward accuracy and speed. This order also addresses accounting and financial reporting of new energy storage technologies, and requires utilities to speed and accuracy when deciding among providers for procurement. [122]

- FERC order no. 792: A November 2013 ruling, which revised the Small Generator Interconnectedness Procedures, as well as the Small Generator Interconnectedness Agreement (SGIP an SGIA, respectively), to specifically include language relating to energy storage.[123]

- FERC order no. 888: An April 1996 Ruling which defined ancillary services, and established the Open Access Transmission Tariff (OATT) for them.[124]

- FERC order no. 1000: A July 2001 ruling which reforms the commission region transmission planning, allowing grid operators to collaborate on regional planning and allows independent developers to establish new transmission lines in order to compete with existing utilities. For energy storage markets, as well as renewable energy integration, this ruling provides key underlying regulatory framework, by establishing guidelines for planning, building, and funding the transmission infrastructure needed to integrate renewables and energy storage solutions into the grid, thereby bringing them to market[125].

At the state level, California, Hawaii, New York, Texas, and Washington have all proposed polices regarding energy storage.[126] For example, in 2013, the California PUC (CPUC) adopted a 1.325 GW procurement target for energy storage, for each of the state's three investor-owned utilities by 2020. CPUC furthermore, has policies and mandates in place specifically encourage fast-discharging energy storage sources, such as capacitors and flywheels.[127]

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[121] Gahlot, J. and Kirk, T.J. (2015), "The Energy Storage Market: Regulatory and Policy Drivers & the California Mandate, a Case Study", Cooperative Research Network: TechSurveillance

[122] Gahlot, J. and Kirk, T.J. (2015), "The Energy Storage Market: Regulatory and Policy Drivers & the California Mandate, a Case Study", Cooperative Research Network: TechSurveillance

[123] Gahlot, J. and Kirk, T.J. (2015), "The Energy Storage Market: Regulatory and Policy Drivers & the California Mandate, a Case Study", Cooperative Research Network: TechSurveillance

[124] Gahlot, J. and Kirk, T.J. (2015), "The Energy Storage Market: Regulatory and Policy Drivers & the California Mandate, a Case Study", Cooperative Research Network: TechSurveillance

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## e. Key Success Factors

Overall, the success factors for industry acceptance of renewable energy technologies going forward, are fairly straight forward. In principle, in order for demand for energy storage technologies to grow, and for their markets to develop, several forces will have to align.

- Macroeconomic Factors
- Growth of the Renewable Energy Markets and Smart Grids
- Maturity of energy storage technology
- Regulatory Environment

### i. Macroeconomic factors

In order for energy markets at large – the markets which energy storage systems ultimately serve – to grow, the scale of economic output, which generates both demand for energy and differences between supply and demand peaks in the first place, will also need to grow.

In principle, this means that Japan’s energy storage technology manufacturers will be presented with potentially lucrative trade and export opportunity in Japan’s near-abroad, as the 21st century develops. This can help mitigate the investment risks in the research and development of commercially-viable energy storage systems.

### ii. Growth of Renewable Energy Markets and Smart Grids

Because renewable energy and energy storage technology clearly have their fates intertwined, the rate of growth, implementation, technological sophistication and development of economic viability of renewable energy generation systems will profoundly impact not only demand levels in the energy storage technology market, but also play a deterministic role in the make-up, diversification, and distribution of energy storage technology markets going forward, given that some energy storage technologies are more closely associated with fossil fuel and nuclear power, while other storage technologies such as pumped hydro are geographically limited in scope, as closely associated with hydroelectric facilities.

### iii. Maturity of Energy Storage Technology

The economic and technological maturity of energy systems will also be of key importance going forward. As a straightforward matter of supply and demand, lower LCOE costs are set to play a deterministic role in the emergence of demand for energy storage.

In addition, wide scale adoption of energy storage technology systems will lead to cost reductions in LCOE terms, simply due to economies of scale.

Lastly, comes the question of investor confidence. Given that energy storage systems are major infrastructural projects with extended productive life cycles and sizeable price tags, investors may be uncertain as to whether costs will be cost-competitive vis-à-vis competing options, or whether investment yields will be justifiable in the long run.

### iv. Regulatory Environment

In principle, energy-sector market architecture is determined largely by regulation. A consistent policy stance vis-à-vis energy storage is still in its infancy among major markets. Without established and consistent norms for revenue generation among utilities and storage operators, the case for investment in the relevant technology and infrastructure might remain understated in the near future.

## f. Challenges and Opportunities in the Energy Storage Market

According to the 2013 US Department of Energy report on grid energy storage, there are four primary obstacles to the widespread development and assimilation of energy storage technology.

- Economic Viability
- Performance and Safety
- Regulatory Environment
- Industry Acceptance

### i. Economic Viability

In the long-run, the overall cost of energy storage technology, infrastructure, as well as the supporting installation, maintenance, and grid integration costs needs to be cost-competitive vis-à-vis competing options available to electric utilities.

Furthermore, the same economic viability obstacle applies to the widespread implementation of renewable energy generation systems overall. While there is a strong focus on improving efficiency and reducing costs of storage components such as actual costs of storage batteries and flywheel technologies, the actual storage component constitutes only around one third of the total system cost[128].

### ii. Performance and Safety

Although regulatory guidelines exist governing the use of energy storage technologies, unified means for consistent evaluation and reporting of performance of existing energy storage systems has yet to be established, according to the US Department of Energy.

Furthermore, operational safety of energy storage systems is a concern and will be a barrier in their deployment in urban areas, –both at the residential scale and the utility scale –  as well as in proximity to other grid resources such as substations. Design practices that incorporate safety standards and safety testing procedures for the different storage technologies need to be developed, standardized, and written into regulation.

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[128] US Department of Energy (2013), “Grid Energy Storage”, Working Paper, Washington DC.

### iii. Regulatory Environment

The regulatory environment is mentioned here a second time, because it can be both a key success factor, and a potential challenge to overcome. In order to see regulatory success, a consistent policy stance on energy storage will eventually need to emerge across major energy markets.

Without established and consistent norms for revenue generation among utilities and storage operators, investor confidence in energy storage infrastructure and markets might be undermined, or might remain understated going forward.

In Japan, a number of steps have been taken in the direction of establishing both clear, consistent norms, and in the direction of establishing clear economic incentives for the adoption of both renewable energy and supporting energy storage technologies. Economic incentives for energy storage on the Japanese market are established by Japan's Feed-in-tariff scheme.[129] Furthermore, 2012-2013 saw the launch of numerous, high-budget energy storage subsidies on the Japanese market, as outlined in previous chapters of this research.

### iv. Industry Acceptance

There is still significant uncertainty regarding how well energy storage technology will perform in practice over the coming years. In principle, industry adoption requires that they have confidence storage will deploy as expected, perform and deliver as predicted and promised.

At present, utility companies and energy grid operators in the world market have yet to develop far-reaching and detailed experience, which would otherwise serve to anchor expectations and the energy, as well as financial and economic performance of investments in the increasingly diversified energy-storage-technology marketplace.

## 5. Summary and Recommendations

Trends in the energy storage market and technological landscape, indicate that energy storage will develop an increasingly prominent role in tandem with the rise, integration, and growing economic maturity economic maturity of the renewable energy generation.

While much ado has been made, and is being made about the energy storage market, source and market data examined here present a highly segmented view of the energy storage market both in Japan and in the world at large. In terms of applicable technologies, the majority of the energy storage market is currently made up of pumped hydro storage capacity, an economically mature, but inflexible, geographically-constrained and scale constrained technology. In contrast, battery-based energy storage technologies, while not yet economically and technologically mature, are diversified and flexible in scale, viable uses, and output.

Another way the energy storage market is segmented is by scale. Whereas residential -scale energy storage technology consists mainly of small-scale lithium-ion batteries used residential energy demand management, utility-scale energy storage can viable deploy a diverse range of energy storage technologies, and is used primarily for ancillary services in

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[129] Dechert, Sandy (2015), "Japan's METI Subsidizes Battery Storage, Energy Efficiency, Changes FIT" Cleantechnica.com.

order to ensure steady and reliable energy supply, as intermittent renewable energy resources grow to occupy an increasing share of the energy generation landscape. Between the two lies the municipal and local-scale energy storage market, which is characterized by the rise of smart grids, diffuse energy generation, and a diversity of energy storage systems to suit various scales.

At the worldwide level, Japan has emerged from the energy-price shocks of the 1970s and from the Fukushima Earthquake in 2011, as a world leader in the energy storage industry, as well as in the renewable energy industry. Furthermore, its future energy landscape will be defined by the rise of smart cities and smart grids.

A common view shared among many of the industry-level and policy-level sources cited in this research, is that the technological development, in and of itself, may be insufficient to wholly and efficiently capture the gains that energy storage technology may ultimately come to represent.

Key to this matter, are the overcoming of implementation challenges, both of energy storage technology itself, and of the renewable energy technologies, which have given rise to the needs for a larger capacity and more sophisticated energy storage technology marketplace in the first place.

From the regulatory point of view, the policy objectives should support the development of energy storage technology's maturity, as well as its diversification and its integration both with the emerging renewable energy and smart-grid landscape, but also with the grid system overall. To this end, policy-level support for highly-diversified R&D within the energy storage sector is key to developing economic maturity and facilitating industry acceptance. Market design policies meanwhile, need to support the establishment of consistent and predictable market incentives for all relevant market players.

Policies on the technology specific to Japan's context are also highly relevant. Given that Japan's energy landscape is punctuated by island-based and local level micro grids, as well as by the emergence of smart-cities, policies such as subsidy schemes and standard guidelines aimed at the adoption of niche-specific energy storage systems are appropriate in light of the Japan's policy ambition to become the world's largest battery energy market.

For European firms, the current trends in Japan's energy storage landscape indicate a clear and straightforward segment of the market on which to focus. While Japan's entire battery energy storage market is growing aggressively, the fastest-growing segment of the marketplace is the residential-scale market. The regulatory landscape appears to favor this development, given that the regulatory burden is lighter on smaller-scale energy storage and battery technologies.

It is also already the case that the marketplace for battery technologies which have more scale-flexibility is populated by a larger number of firms. This trend is most pronounced in the lithium-ion segment of the market. This, more diversified marketplace is also indicative of lower entry costs, which, in principle, favors SMEs.

The trend towards smaller-scale energy storage systems also creates opportunities beyond the sale and deployment of the battery technology itself. According to the US Department of Energy, the direct cost of the storage component still constitutes only 30% to 40% of total energy storage system cost. Supporting costs such as smart-meters, as well as HEMS and BEMS software represent both a further insertion opportunity and a substantial cost-reduction R&D opportunity set to develop as the residential and small-scale market grows.

Lastly, the potential future development of the European residential and business-scale energy storage market presents a third opportunity for European firms to take advantage of the trend in Japan’s energy storage market, in the sense that energy storage technology developed for the present Japanese market can easily become a viable technology as Europe’s markets develop in the future, as renewable energy generation grows in Europe. Familiarity and experience with the residential and business-scale energy storage market, as well as its supporting value chain, presents a substantial future business opportunity.

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## c. Interactive Map Link

- Interactive Map of Japan’s Energy Storage sites and Smart-city projects, Smart Grid systems, and energy-reductions targets: https://www.google.com/maps/d/edit?hl=en&authuser=0&mid=1Mw2FxURLwa7noKWGbdof_KYJRRA

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