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INNOVATION AND TECHNOLOGY NOTES

KOREA'S ENERGY STORAGE SYSTEM DEVELOPMENT: THE SYNERGY OF PUBLIC PULL AND PRIVATE PUSH

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Korea's battery storage industry has experienced remarkable growth for the past years, with two Korean companies accounting for more than 80% of the total lithium-ion battery (hereinafter, LiB) Energy Storage System (ESS) market. Korea's LiB ESS market size reached about 50% of the global market in 2018. The expansion of the LiB ESS industry in Korea has benefited from government's support. The government accelerated the industrialization and commercialization of ESS through a series of long-term development plans together with a list of R&D and investment projects. Notably, the government shifted government policy towards so-called Green Growth in 2009, which was a turning point in government policy toward sustainable development prompting the surge in green R&D expenditure. The ESS-specific national strategy called K-ESS in 2011 set LiB ESS at the center of the strategy to maximize Korean battery producers' competitive edge. Based on the strategy, strong incentives and regulations such as a higher Renewable Energy Certificate (REC) weight of 5.0 to PV and wind-connected ESS system, ESS-specific power rate, and the mandatory ESS installation in public buildings were implemented and contributed to the impressive growth of Korean ESS market. Korea Electric Power Corporation (KEPCO) has helped the growth with its utility-scale frequency regulation (FR) ESS demonstration projects. Also, private companies set ESS as a target for the next generation export product, building on the experience and know-how in Lithium-ion batteries accumulated over more than a decade. They have proactively engaged in R&D projects as well as domestic and overseas demonstration projects aiming at the early commercialization.

Along the way, various challenges have emerged, such as ESS facility fires and the absence of international standards and interoperability for major components. Nevertheless, prospects for Korea's ESS market seem relatively bright, thanks to the accumulated know-how on operating utility-scale ESS, lessons learned from dealing with ESS facility fires, and continuous growth of global ESS market. Korea's LiB ESS development is a good example of the impact of both public pull and private push factors. ESS deployment in developing countries is expected to increase with the rapid LiB ESS cost decline, exceeding the pace of PV. The World Bank also support this expansion of ESS systems, through its global Battery Storage Investment Program.

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Introduction

Since the first oil crisis in the 1970s, countries have recognized the need for energy conservation and alternative energy development. Renewables have emerged as alternatives to fossil fuels to play a vital role in expanding energy supply in a sustainable manner. Globally, electricity consumption has grown substantially. While electricity generation from renewables is taking a growing share in the energy supply mix, their inherent intermittency poses economic and technical challenges. Energy Storage System (ESS) has emerged as the most viable technology option to deal with this intermittency problem. ESS is a device used to store energy produced, to use later.

There are various types of ESS, including pumped hydro storage, flywheel, compressed air system, battery storage (mostly Lithium-ion battery). Among them, Lithium-ion battery (LiB) is most widely adopted ESS in the world. It is used as a backup power and for load leveling and frequency and voltage regulation, to stabilize power supply and to help integrate renewable energy. Korea is one of the global leaders in developing and distributing LiB ESS and three Korean companies, Samsung SDI, LG Chem, and SK Innovation, are among the leading global suppliers of LiB. Korea's LiB ESS market has grown to occupy nearly half of the global LiB ESS market in 2018.[1]

This report aims to identify and examine the key success factors of Korea's energy storage industry, including government policies, roles of private companies, and global market factors. It aims to share lessons learned from the country's rapid development of LiB ESS. Throughout the report, ESS, LiB ESS, and battery storage are used interchangeably, according to the reference sources. Globally, the most commonly adopted battery storage system is currently LiB ESS.

In recognition of the importance of ESS for the development of the energy sector in developing countries, the World Bank launched a global Battery Storage Investment Program in 2018. In May 2019, Energy Storage Partnership (ESP) comprising WB Group and 29 organizations was announced, to support the development of energy storage solutions in developing countries. Two Korean entities, KIAT (Korea Institute for Advancement of Technology) and K-BIA (Korea Battery Industry Association), have joined ESP.

Understanding LiB ESS TECHNOLOGY

ESS originated from a simple concept in which the generated power is stored and used when needed. In short, ESS is a device that can help overcome the time difference in its production and consumption, either chemically or physically.

[1] Ryu J., et al. (2019) estimated that Korean domestic market will share almost 47% of the global ESS market.

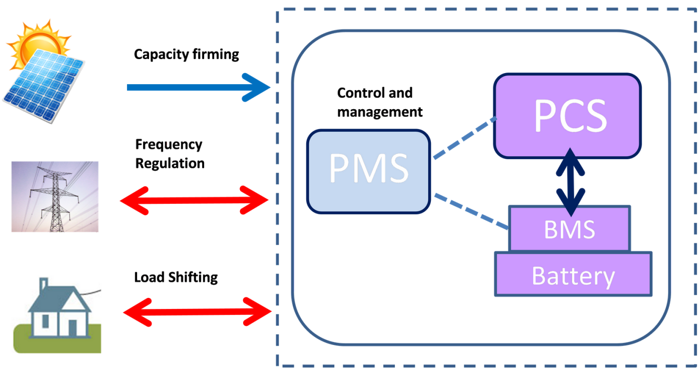
There is a wide range of energy storage technologies available today. ESS technologies include electrochemical storages such as a LiB, a lead-acid battery, and hydrogen, and physical storages such as flywheel and pumped hydropower station. For example, most smartphones use a small LiB ESS, while a pumped hydro is ESS for large-scale power.

ESS offers three main functions: load shifting or demand response (DR), stabilization of output from renewable power sources (renewable energy integration), and frequency regulation (FR) for stabilization of the power supply system. With regards to load shifting or DR, batteries are charged when electricity demand (and tariff) is low and discharged when it is high. By enabling consumers to change the load pattern, an ESS system could help lower the maximum load. ESS helps stabilize power output from renewable energy sources such as solar and wind power as their outputs are difficult to predict due to their intermittency. ESS may well serve to mitigate the output fluctuation and intermittency of power generation from changes in weather conditions. ESS is also used to adjust the power frequency by way of charging and discharging ESS to maintain power quality. When the power demand and supply balance are unmatched, the electric frequency could fluctuate significantly such that the power quality could deteriorate quite seriously. Thus, power system operators must keep the frequency within a specific range to provide and ensure high-quality power to consumers.

In Korea, to prepare for the unanticipated mismatch in demand and supply balance, the power system operators often call on thermal power generators to perform cutback operations with 5% capacity reserved. ESS could replace such reserve capacity as LiB ESS is superior to a thermal power plant in ramp rate, which enables quick dispatch. Also, ESS could function as an emergency power source for safeguarding uninterruptible power supply in case of natural disasters and unexpected power failures. Korea Electric Power Corporation (KEPCO), a monopolistic transmission and distribution operator in Korea, carried out initially a frequency regulation ESS demonstration project for 376MW between 2014 and 2017 and has begun to apply ESS systems for capacity firming for renewable power generators and peak shaving in recent years.

The most common LiB ESS consists of 3 main parts: a storage device, usually a battery with a battery management system (BMS), a power conditioning system (PCS), energy management system (EMS). A battery is a device that stores, and charges electric energy received from a power system, or a PCS and discharges stored electrical energy to a network depending on demand and supply. BMS enables users to monitor voltage and temperature in real-time, calculate the state of charge (SOC), and to predict battery capacity and life span, and communicate information with PCS or EMS. Also, a PCS converts electric energy stored in a battery to power ensuring a standard voltage and frequency, or conversely, converts power with

Figure 1. Components and Functions of LiB ESS



equivalent voltage and frequency into direct current. The PMS or the EMS is a device that monitors and regulates energy consumption in the energy storage device and has a power management function. The primary purpose of the system is to follow the energy storage device and controlling the system based on the information received from PCS and other peripherals.

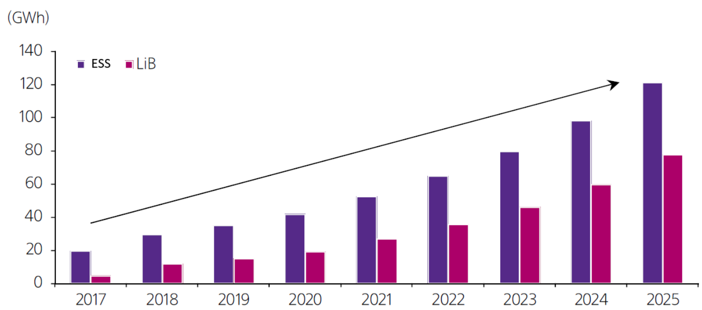
MARKET

The leading countries in the global LiB ESS market have different focuses on their policies and demonstration projects. The United States and Germany focus on the power system ESS, while Japan and China on households ESS, ESS for electric vehicle (EV). Since the WB's announcement of the 1 billion-dollar Battery Storage Investment Program, there has been increased interest from developing countries in ESS applications in their power system. South Africa made an important commitment to distributed energy storage at the end of 2018, with up to 1.44 GWh of battery storage planned in two phases starting in mid-2019.

The global LiB ESS market is forecast to grow at an annual rate of 43% until 2025 whereas global ESS market grows at an annual rate of 26%, according to the report by Ryu, et., al (2019). The growing demand would increase the global LiB ESS capacity to 17.3 GWh by 2020 (see Figure 2). Korea's LiB ESS market has grown in tandem with the global demand. Korea's LiB ESS market expanded from 265MWh in 2016, to 1.2GWh in 2017, and to nearly 4.8GWh in total in 2018 (see Figure 3). Korea's market accounted for almost 50% of the global market in 2018.

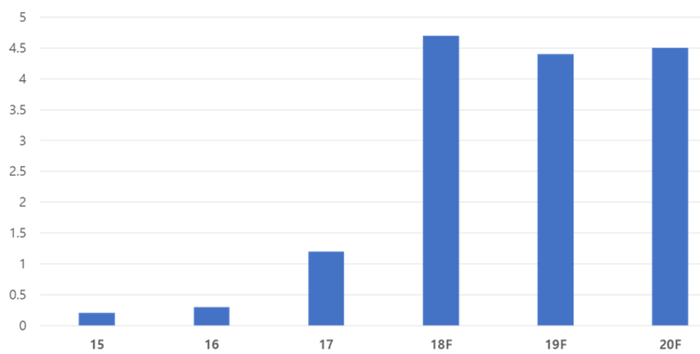
According to a Hana Financial Group 2018 report, two Korean battery producers, Samsung SDI and LG Chem accounted for 43% and 37% of the global LiB ESS market, respectively, in 2018, sharing a staggering 80% of the global market. In 2014, the two companies' combined share was 59% (Samsung SDI 30%, LG Chem 29%).

Figure 2. Global LiB-ESS Demand (Capacity in GWh)



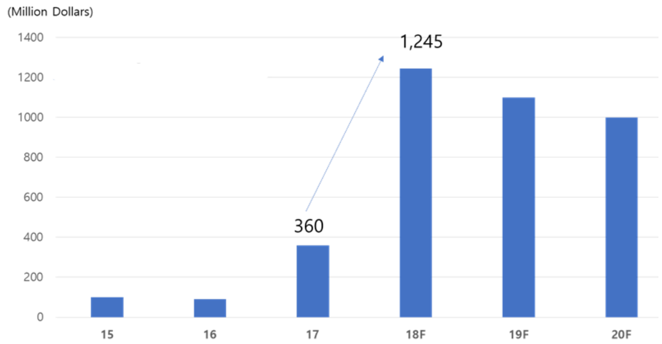
Source: SNE Research (2019), Samsung Securities (2019)

Figure 3. Korea's ESS Market Outlook (Capacity in GWh)



Source: SNE Research (2019), Ryu J., et al. (2018)

Figure 4. Korea's ESS Market Outlook (value)



Source: SNE Research (2019), Ryu J., et al. (2018)

Figure 5. Global ESS Annual Capacity

Source: Wood Mackenzie Power & Renewable (2019), www.greentechmedia.com

The Korean ESS market has grown tremendously.[2] The domestic ESS market grew from KRW 82.7 billion (roughly USD 68.9 million) in 2013, to KRW 400 billion (roughly USD 333 million) in 2017. And it exceeded KRW 1.8 trillion (roughly USD 1.5 billion) in 2018. The total number of the deployed ESS units was 206 in 2016, and now it has risen to 1,490 as of April 2019. The government put the ESS at the center of the 'Renewable Energy 3020 Plan' (the plan to increase the share of renewable energy the national power generation mix to 20% by 2030).

To date, the ESS market in Korea has had marked growth, but it is projected to slow down in 2019 and 2020, mainly because of the recent fire incidents (see Figure 3-4). Although these fire incidents have led to a momentary impasse, they provided valuable lessons on safety standards, preventive measures, and the technology development process. Despite the temporary setback in the growth path, the accumulated know-how on operating utility-scale ESS and improved system safety will put the Korean LiB ESS industry back on the growth track and help make it a more competitive one.

According to Wood Mackenzie[3], global ESS deployments grew 147% to reach 3.3 GW or 6 GWh in 2018 (see Figure 5). And that's almost double the average 74% compound annual growth rate for the industry from 2013 to 2018. The cumulative deployment is expected to expand to 158 GWh by 2024, which is consistent with Oh (2019)'s projection.

LiB ESS development in Korea

KEY FACTORS OF KOREAN LIB ESS GROWTH

Korean's LiB ESS development is a good example of the impact of both public pull and private push factors. The government had strategically

[2] Donga Ilbo, "(Inside & Insight) ESS Stalled by Fire Accidents", May 14, 2019
[3] Wood Mackenzie Power & Renewable (2019), Global Energy Storage Outlook 2019: 2018 year in Review and Outlook to 2024, www.woodmac.com

promoted high value-added industries such as semiconductors, computers, and mobile devices since the late 1980s. Conglomerates like Samsung and LG, actively pursued the development and mass production of Li-ion batteries. The expansion of the domestic market provided valuable opportunities for ESS companies to test technical specifications and inter-operability and to accumulate marketing and sales experiences. Several factors accounted for the notable growth of the Korean ESS industry.

First, the private sector actively pursued the development and mass production of Li-ion batteries, as one of the critical components of their smartphones and other electric appliances, to achieve the cost competitiveness of these products. Korea companies such as Samsung and LG have grown to be the first and second-largest smartphone makers in the world since the 1990s. They pursued the localization and self-sufficiency of the battery aggressively, as a part of their overall cost reduction efforts. As shown in Table 1 below, LG Chem, Samsung SDI, Hyundai Motor Company, SB LiMotive[4], and LG Electronics secured considerable proprietary technologies in the automobile battery area in the late 2000s. This experience with battery development provided them with the core capabilities to help them develop LiB-based ESS technologies. Samsung and LG pushed technology development by mobilizing their subsidiary companies such as Samsung SDI and LG Chem.

Second, from the beginning of the ESS development, many Korean SMEs accumulated technical capacity to produce PCS, EMS, and BMS in a highly competitive manner. For example, KOKAM, a Korean SME, has world-class technology in the development and production of ESS-related batteries and peripherals. It was ranked fourth in Li-ion grid storage deployed capacity (MW) market share in 4Q 2018 by the Navigant Research.

Table 1. Patent Application for EV Battery System

Ranking	Manufacturer	No. of Patents	Share
1	LG Chem	757	17.1%
2	Samsung SDI	528	11.9%
3	Hitachi	349	7.9%
4	Hyundai Motor Company	244	5.5%
5	Toyota Motor Corporation	242	5.5%
6	Panasonic	233	5.3%
7	SB LiMotive	223	5.0%
8	Nissan Motor Co.	146	3.3%
9	Mitsubishi Motors	101	2.3%
10	Lithium Energy Japan	97	2.2%
11	Primearth EV	88	2.0%
12	Tesla	65	1.5%
13	LG Electronics	63	1.4%
	Others	1,291	29.2%
	Total	4,427	100.0%

Source: SNE Research, Jan 2015

Third, government's support policies contributed significantly to the creation of domestic demand for ESS. In particular, ESS installation began to spread at a rapid pace with the introduction of higher Renewable Energy Certificate (REC) weight of 5.0 to PV-connected ESS system in September 2016, the ESS-specific power rate system and the mandatory ESS installation requirement in public buildings in January 2017 that were also accompanied by various financial incentives.

[4] SB LiMotive is a 50:50 joint company of Bosch and Samsung SDI founded in 2008 and its head office is in Giheung Korea.

Box 1. Renewable Energy Certificate (REC)

RECs are proof under Renewable Portfolio Standards (RPS) scheme that energy has been generated from renewable sources such as solar or wind power. Each REC represents 1MWh of renewable energy generation. RPS mandates large-scale power producers with installed capacity of over 500MW to produce a minimum share (7% in 2019, reaching 10% by 2022) of their power using renewable energy sources. The mandated power producers are 6 KEPCO subsidiary generation companies, Korea District Heating Corporation, K-water (public water utility), and 3 private generation companies. The mandated entities are required to meet the target either by generating renewable energy on their own or buying RECs in the market. They are penalized if failed to meet the RPS target. Usually small independent renewable energy generators are the sellers in REC market. The government-determined standard unit price of REC (compensation paid by KPECO to mandated entities) was KRW 87,833 (roughly USD 73) per MWh in 2018. The government sets different weight to each renewable energy source (0.7-1.5 to solar PV, 1.5-2.0 to wind), considering generation cost, technology development level and other factors. REC weight of 5.0 means that 1MWh of discharged power by ESS is treated as 5MWh of renewable energy generation, about five times higher revenue than normal renewable energy. Detailed information on RPS can be found at Korea Energy Agency (KEA) New and Renewable Energy Center website. https://www.energy.or.kr/renew_eng/new/standards.aspx

GOVERNMENT POLICIES AND MEASURES TO SUPPORT LIB ESS DEVELOPMENT

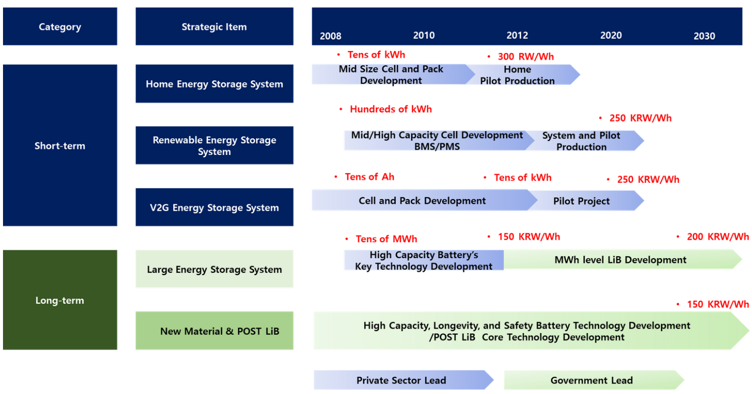
The government's policy shift in ESS-related technology development benefited from the Green Growth Strategy introduced in August 2008, which prioritized low-carbon sustainable growth. In this strategy, green growth is defined specifically as “developing future promising products and new technologies in energy and environment-related technologies and industries and acquiring new growth engines and jobs while fusing them with existing industries.” Green growth was further elaborated in the Energy New Business initiative introduced in 2014. The roadmap for green technology development under the Green Growth Strategy specifically included ESS development, with specific quantitative targets (see Figure 6). So far, these targets have been met.

In 2011, the Ministry of Commerce, Industry, and Energy (MOCIE) chose ESS-related technology development as a priority program and incorporated a detailed ESS development plan, called the Korea Energy Storage Technology Development and Industrialization Strategy 2020 (K-ESS 2020), as an integral part of the Third

National Energy Development Plan. The government set LiB development at the center of the plan. Under this strategy, the government set the target of deploying 1.7 GW of ESS in Korea and reaching a 30% share of the global market by the year 2020. It also targeted reducing the battery cell price to USD 180/kWh, increasing the cell life to 20 years and increasing the pilot size to hundreds MW by 2020.

To promote the development of ESS technology, the government planned and executed various ESS pilot projects in collaboration with interested companies. First, transmission-linked pilots were implemented at KEPCO's substations, starting from an 8MWh testbed at 154kV substation and expanding to tens of MWh pilots at 345kV or bigger substations. Second, power generation-linked pilots were implemented at renewable energy sites such as wind farms. Third, consumer-linked pilots were implemented at houses and buildings in connection with renewable energy subsidy programs such as 1 million Green Home, starting with 10kWh LiB system installation at 100 houses in the southern city of Daegu.

Figure 6. Korea's Green Technology Roadmap for ESS, 2008



Source: Green Energy Technology Roadmap (2008), MOTIE

ESS Technology has entered the government's energy technology R&D pool as an independent accounting entity[5] in 2017. The budget allocated for the project was KRW 43,702 million (roughly USD 36.4 million) in 2017, 45,879 (roughly USD 38.2 million) in 2018, and 36,585 (roughly USD 30.5 million) in 2019. Of late, about KRW 120 billion (roughly USD 100 million) in total was invested in the development of medium-to large-scale, high-density secondary batteries. These R&D investments promoted technology innovation and supported the expansion of the market.

The government also offered a comprehensive policy package to expand the domestic demand for ESS (see Table 2). First, household consumers have had strong incentives such as installation subsidy to install ESS together with renewable energy equipment at their homes and thus contribute to reducing peak load and stabilizing the power grid. Second, the package includes a special power tariff for industrial and commercial ESS users, a 50% discount for ESS charging tariff during light load hours between 23:00 and 09:00. Moreover, these customers have received a base tariff cut for ESS starting in 2016 for electricity sent back to the grid for peak shaving. The reduced tariff amounted to three times of the shaved peak load since 2017. With this special tariff scheme, consumers can shorten the payback period from 10 years to 4.6 years. Third, public entities who have power contracts of larger than 1,000 kW have been required to install the ESS system in their buildings since 2017. Fourth, ESS systems connected to solar photovoltaic (PV) or wind power systems are entitled to get a special Renewable Energy Certificate (REC) weight. Currently, the weight of 5.0 goes to ESS connected with PV and 4.5 to ESS with wind power. These

[5] Independent accounting entity has a government-guaranteed budget allocation during the proposed project period.

weights are significant incentives to ESS investors, considering that normal REC weight is 1.0. Fifth, the ESS system has become one of the legitimate emergency power systems under the 2016 revised guidelines on the application of the emergency ESS.

Table 2. ESS specific Government Support

ESS-supportive policies and measures

Electricity		Sales of electricity stored in ESS is allowed
Incentives		Higher REC weight for solar+ESS (5.0) and wind+ESS (4.5)
		Discount on capacity charges and tariffs
Market Creation	Public Sector	Mandatory ESS installation in public buildings
	Emergency Power	ESS is allowed to replace emergency power generators

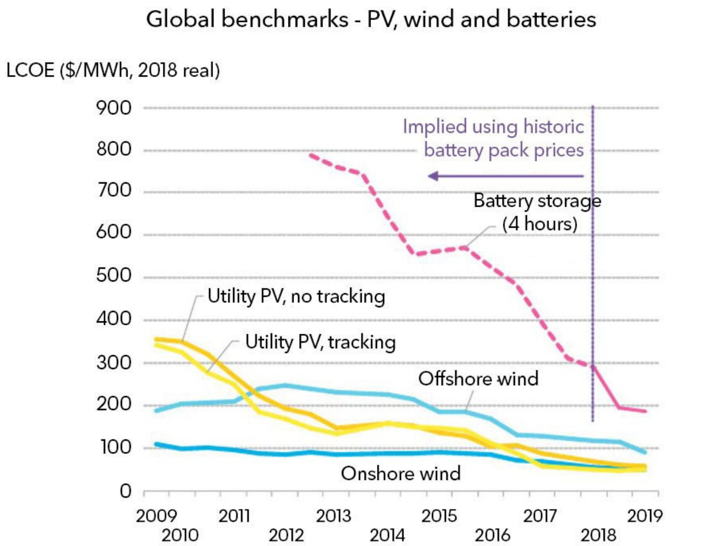
Source: SNE Research, Jan 2015

FINANCIAL VIABILITY OF ESS IN KOREA

The financial viability of ESS system in the globalmarket has been continuously improving with sharp decline of LiB price due toaccelerated deployment of EV and ESS system in several leading countries such as Korea, China and the US.

According to the 2019 Bloomberg New Energy Finance report[6], the benchmark Levelized Cost of Electricity (LCOE) for LiB configured to supply 4 hours of grid power has fallen by 74 % since 2012, as shown in Figure 7 below. In comparison, the LCOE per MWh for onshore wind, solar PV and offshore wind has fallen by 49 %, 84 % and 56 %, respectively, since 2010 (see Figure 7). The report noted that the LCOE for multi-hour LiBs is falling fast. It highlighted that “batteries co-located with solar or wind projects are starting to compete, in many markets and without subsidy, with coal-and gas-fired generation for the provision of ‘dispatchable power’.

Figure 6. Korea's Green Technology Roadmap for ESS, 2008



Source: BloombergNEF. Note: The global benchmark is a country weighed-average using the latest annual capacity additions. The storage LCOE is reflective of a utility-scale Li-ion battery storage system running at a daily cycle and includes charging costs assumed to be 60% of whole sale base power price in each country.

[6] BNEF report (March 26, 2019) “Levelized Cost of Energy for Lithium-Ion Batteries Is Plummeting” https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/

The financial feasibility of an ESS system depends on primarily two factors: the initial investment cost and the revenue from the operation. S.I Lee et al. [7] (2015) concluded that financial support for the initial investment and change in power tariffs are essential in making ESS projects economically viable in the Korean market based on a simulation study. For example, if the initial investment cost of an ESS system fell from KRW 1.3 million to 1 million/kWh (roughly from USD 1,080 to 830/kWh) and the tariff gap between the designated light load hours and peak load hours widened sufficiently to generate a sound revenue stream guaranteeing the reasonable return on investment, the ESS system could become economically viable even for large-scale application. Technology advancement has been rapid, and the investment cost has already gone down to USD 380 per kWh in the case of a 4-hour LiB system, a standard long duration ESS in the U.S. as of 2018, according to the National Renewable Energy Laboratory (NREL) report[8] (see Figure 8). Normally ESS is charged during light load hours and discharged during peak load. Therefore, extending the duration of light load and peak load hours would also improve the economics of ESS system.

The Hana Industry Info 2019 report estimated the internal rate of return (IRR) of 9.2%, with System Marginal Price (SMP)[9] of KRW 86.2/kWh and REC of KRW 76/kWh, assuming PV cost of KRW 2 million/kWh (roughly USD 1,667/kWh) and ESS cost of KRW 0.54 million (roughly USD 450/kWh) for PV (500kW) plus ESS (1.37 MWh) system.

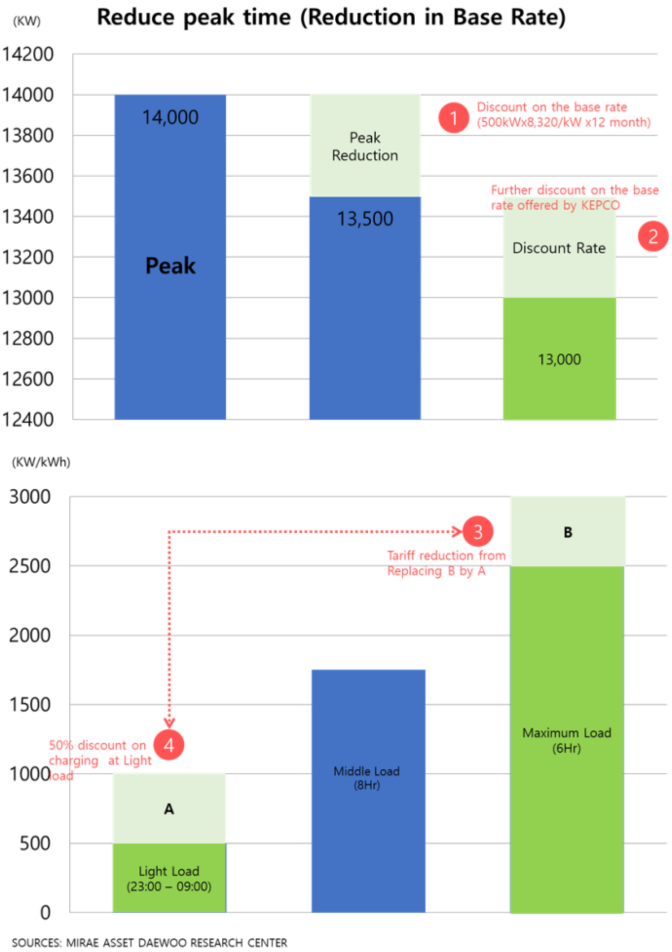
The sensitivity analysis showed that IRR is highly dependent on the price of REC. The IRR fluctuates from 1.4% to 20% if the price of REC changes from KRW 60/kWh to KRW 100/kWh when SMP is fixed at KRW 85/kWh.

As shown in sensitivity analysis by Hana simulation, revenue factor is critical to financial viability of ESS in Korea. Korean power retail tariff comprises two parts: the base tariff and the progressive volume charge. Korean government introduced special tariff plan for ESS system in March 2016. Grid-connected ESS installations can collect tariff benefits in two ways. They pay low base tariff by reducing the peak consumption and obtain additional revenue from the sale of the stored electricity. The primary function of ESS is to shift the use of electricity from expensive hours of peak (maximum) demand to inexpensive hours of low demand (Figure 9). Thus, ESS could lower the base tariff by reducing peak consumption. Those non-household users with a metering device are eligible for such lower tariff plans as industrial use and educational use. Under the current tariff structure, ESS installations are more attractive to those consumers with contract power of 300kW or more compared to low capacity consumers. The tariff difference is significant between light load time and peak load time. For example, tariff for peak load during summer time for industrial use (high voltage A) is KRW 119.8/kWh, which is almost double the tariff for light load, KRW 60.5/kWh. Moreover, the 50% tariff discount is available to ESS charging by these users during light load hours (23:00-09:00). The government also

[7] According to their study, industrial consumers will have economic feasibility when the installation expenses of ESS drop to KRW 1,000,000/kWh (roughly USD 830/kWh) based on the current rate system. In other words, the break-even price of ESS (supposing that its lifespan is 12 years) is KRW 1,000,000/kWh based on the current rate system. Moreover if the installation expenses drop to KRW 500,000/kWh (roughly USD 420/kWh), B/C will be 2.04 to 2.04, payback period will be 4.2 to 4.3 years, and internal rate of return will be 33.0 to 33.4%.
[8] NREL report (November 2018) "2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark", https://nrel.gov/docs/fy19osti/71714.pdf
[9] SMP refers to the cost of the most expensive generating unit included in the Price Setting Schedule.

introduced a special REC weight for Wind + ESS system in October 2015 and PV + ESS system in September 2016, which has provided significant additional revenues to ESS system investors and has contributed to ESS installation boom in 2017-2018.

Figure 9. Korea's Tariff Structure for ESS Users



Source: Mirae Asset Daewoo Research Center

The government's incentive programs (lower tariff and higher REC weight) have pulled up the revenue and LiB producers' technological advance has pushed down the investment cost, leading to improved financial viability of ESS system. Without government support programs, ESS projects are not quite commercially feasible in Korea as of now.

However, according to a Bloomberg New Energy Finance (BNEF) report (2018), Levelized Cost of Electricity (LCOE) for multi-hour LiBs is falling to the point that "solar or wind plus ESS projects are starting to compete, in many markets and without subsidy, with coal-and gas-fired generation for the provision of dispatchable power". Also, government and private companies are implementing many ESS projects home and abroad as they anticipate the rapidly growing global market and falling cost soon. The prospect for the global market seems bright as electrification of energy is progressing across all sectors with rapid renewables integration. Mackenzie & Company (2019) projected that by 2050, electricity consumption would double, and electrification of road transport, buildings and industry will rise to 27%, 45%, and 25% respectively from less than 1%, 31%, and 21% in 2016. The share of electricity in final energy consumption will reach 29%. According to the report, renewables such as wind and solar are projected to grow fast to make up over 50% of power generation by 2035, given Climate Change constraints.

PUBLIC-PRIVATE COLLABORATION

Korea had a strong manufacturing base that provided large and small companies to establish a supply chain for ESS, Samsung SDI and LG chem, frontrunners in LiB manufacturing, could develop ESS in collaboration with several SMEs in

Korea(Figure 10). Initially, most of these SMEs acquired technology through joint ventures with overseas companies.

For the lithium battery industry, securing both an appropriate market share in the forward industry such as smartphones and EV, and the technological competitiveness of the backward industry in materials and source technology is critical for their success. The government has encouraged and supported investment in the Li-ion battery industry to firmly establish a strong supply chain given the changing global landscape in automobile, and material industries. The expansion of the electric vehicle market and of the ESS market are expected to give companies in the battery supply chain an opportunity to leap forward.

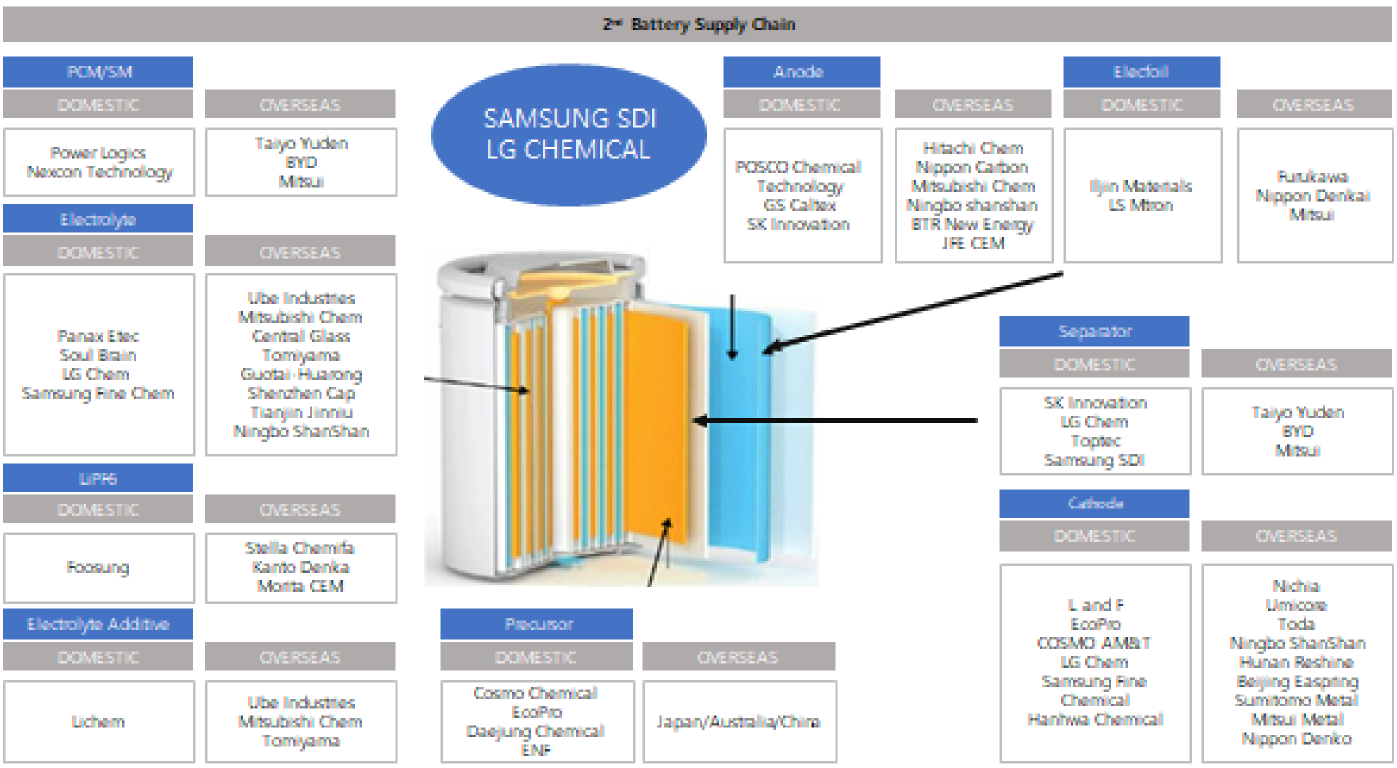
In a concerted effort with specialized SMEs, large companies such as Samsung SDI, LG Chem, Hyosung, and LSIS have become competitive global leaders in battery and power conditioning system (PCS). Table 3 shows large and small companies in the ESS supply chain by ESS components.

Table 3. ESS Industry Composition by Sub-sectors in Korea

Area		Large Companies	SMEs
Battery Manufacturing	Parts and Materials	GS Caltex and 9 others	Ecopro and 8 others
	Battery	Samsung SDI and 4 ohters	Rebo and 3 others
PCS		Hyosung and 4 others	Maxcom and 3 others
Control Devices	PMS	POSCO ICT and 1 other	Wellstelesys and 1 other
	EMS	LSIS	At Solution and 1 other
Installation and O&M	Electric Equipment	Hyundai Heavy Industry and 3 others	NamJun and 4 others
	Installation	Iljin Electrica and Besides others	Elecpower and 2 others
	Engineering	Hyosung and 1 other	Omnisystem and 1 other

Source: Compiled by the author

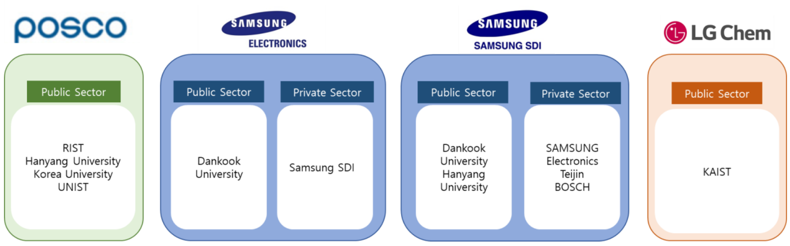
Figure 10. Secondary Battery Supply Chain



Source: Lee., et al., (2018), Translation by the author.

The R&D on source technologies for ESS has increased rapidly as the markets for electric vehicles, ESS and mobile devices have grown. They include power management system (PMS), Energy Management System (EMS), and inverters, and parts and materials such as cathode active material, anode active material, and membrane. For most R&D projects on ESS related technologies such as membrane (see Figure 11), close cooperation and collaboration among public institutes were more of a rule than an exception. Public research laboratories, private companies, and academia such as Korea University have been collaborating extensively to cope with intensifying international competition and rising investment costs in R&D.

Figure 11. Joint Domestic Industrial-Academic Research on Membrane



Source: Lee., et al., (2018), translation by the author.

There remain several challenges to sustaining the growth of Korea's ESS industry, including the establishment of model codes and standards for safety and interoperability for domestic and global market entry. A series of recent fire incidents on ESS installations have caused delays and cancellation of some ESS projects. The government launched an investigation in late 2018 and announced the results of its probe and safety measures in June 2019. The causes of the fire were classified into four categories: (i) inadequate battery protective system, for example, to protect against overvoltage and overcurrent; (ii) inadequate management of operating environment, thus exposing ESS to repeated condensation and dryness, leading to accumulated dust inside battery module and broken insulator; (iii) improper installation of ESS; (iv) lack of comprehensive protective and management system in which EMS, PMS, and BMS with different manufacturers were not operated organically by a system integration (SI) business. The safety measures include the introduction of Korean Standards (KS) standard for the entire ESS system and strengthening of Korea Certification (KC)[10] certification for safety of ESS system, ESS-related fire safety regulations, and operation and management of ESS. Further, major battery producers, Samsung SDI and LG Chem, came up with their own ESS safety measures for their products, including special fire extinguishing systems in October 2019.

CONCLUSION

Korea's ESS industry has experienced remarkable growth for the past years, with Korea's LiB ESS market size reaching about 50% of the global market in 2018. Korea's LiB ESS development is a good example of the impact of both public pull and private push factors. The government's

[10] KC is the national certification for safety and reliability of manufactured goods.

supportive policy has been the key to the rapid growth of the ESS industry in Korea. The government established a technology development platform that enabled industry-scale ESS technology development. The government implemented the "selection and concentration" strategy and put forward various policy measures considering ESS specific characteristics, market potential, and domestic industry capacity. Moreover, changes in the leadership of the government affected neither the direction of the government's long-term technology development policies nor their content and implementations.

Despite its low initial economic viability, the government had a long-term strategy to provide sustained institutional and financial support to ESS technology development and domestic market expansion, given perceived long-term future market prospects. ESS was also recognized for its potential for export, and as such the domestic market served as the test-bed for ESS technology for exports. The introduction of incentive schemes such as ESS installation subsidies, capacity charge discounts, and tariff discounts on non-household customers were critical to facilitating the commercialization of ESS.

There are several lessons learned from Korea's relatively successful experience in developing and deploying ESS. The government played a pivotal role as a technology developer as well as a market creator for ESS. It took a holistic approach to promoting the ESS industry, providing institutional, economic, financial and technical support to reduce the early stage risks in ESS technology R&D. It promoted close cooperation and collaboration among multiple public and private stakeholders. It also took a long-term outlook to the development of the industry and addressed recent fire safety issues by tightening regulations and standards.

- The government laid out a clear, long-term roadmap for ESS development, supported by long-term public financing, and regular progress monitoring. This sent a strong, public signal of its firm and sustained commitment to the development of the industry and technology. This is critical because ESS development requires huge investment costs over a long period and takes significant market risks.

- Public-private collaboration was critical for ESS technology development. The government promoted coordination among public organizations, academia and private companies in technology R&D and subsequently helped establish a domestic industrial ecosystem for coordinated investments, that promoted forward and backward linkages and a domestic supply chain of materials, parts and finished products, by securing patent rights through cooperation with academia.

- Korea successfully used special REC weight to promote demand for ESS. The additional revenue by special REC weight, five times higher than the typical REC, considerably improved the economics of PV+ESS projects and contributed to the sharp increase of ESS system during 2017-2018 period. Korea's special REC weight (5.0) for PV+ESS projects could be benchmarked by other countries.

- Lack of due processes for technical verification, standards enforcement, and safety procedures for manufacturing, transportation, installation, and operation of ESS led to recent fire incidents and delay in new ESS installations and temporary shutdown of existing ones in public facilities such as department stores. In response, the government has tightened regulations, standards, procedures and enforcements and allowed the resumption of ESS operation only if safety measures are implemented. The government also decided to provide financial support for implementing safety measures.

It seems likely that the energy storage market will continue to expand with the growing deployment of renewables worldwide and that the core component of ESS, Li-ion battery, will become a staple part of automobiles, mobile devices, and many other applications. An increase in demand for electricity, expansion of renewable energy sources, and expansion of distributed power systems can be expected to drive the growth of ESS in the future. According to a BNEF report (2018), LCOE for multi-hour LiBs is falling to the point that "solar or wind plus ESS projects are starting to compete, in many markets and without subsidy, with coal-and gas-fired generation for the provision of 'dispatchable power'." The rapid LiB ESS cost decline is likely to also expand ESS deployment in developing countries. PV plus ESS projects are spreading rapidly globally due to their improved economic viability through cost-saving measures such as co-locating of PV and ESS.

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