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A P3 Korea Whitepaper

Exploring the Battery ESS Landscape in Korea

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1. Executive Summary

A P3 Korea Whitepaper

This whitepaper offers a holistic look into the battery energy storage systems (BESS) market under the specific context of South Korea. The battery and energy markets are complex, and the highly intertwined intricacies embedded within can often obscure what the most important progressions in the industry are. In this sense, the goal of the whitepaper is to dust off irrelevant complexities, to provide a targeted and focused look into the Korean BESS market, and to identify the next set of trends that will shape its development in the coming years.

Korea's Power Mix

Korea's power system has changed more in structure than in size. Coal is in decline, nuclear has regained the top position, and renewables have surpassed the 10% mark in portion within the power mix for the first time in 2024. At the same time, electrification, data centers, and advanced technology manufacturing are lifting demand and making flexibility of the grid a more valuable trait. Given these circumstances, the key to these rising constraints may be in a successful integration of BESS into the grid.

The Basic Plan of Long-Term Electricity Supply and Demand

The 11th Basic Plan of Long-Term Electricity Supply and Demand sets the direction of policies surrounding the supply and demand of electricity in Korea until 2038. A key takeaway is in its reorientation of the power mix for placing a heavier emphasis on the role of nuclear and renewables, and in introducing the plan to incorporate clean hydrogen ammonia as part of the non-carbon power source portfolio. Specifically, the 11th Plan lays out a goal of having nuclear and renewables provide around one third of electricity generation by 2038, while the portion of coal and gas together shrink to about one fifth. Storage technology is written into this trajectory as a core enabler, with BESS expected to cover all new storage needs through the mid-2030s and then sharing the long duration role with new pumped hydro in the longer run. The 12th Plan is expected to push climate targets higher, accelerate offshore wind, and lean more on storage and grid investment while relying on life extension of existing nuclear reactors. In this policy frame, it is becoming more evident that BESS is not an optional add-on but is hardening its stance as a central tool for meeting energy security and climate commitments.

Repositioning of Korea's BESS Industry

Korea's battery industry has progressed around high-energy-density nickel chemistries (NCA/NCM) for electric vehicles, with stationary storage deemed mostly as an auxiliary outlet. While Korean firms predominantly optimized for safety and energy density, the global utility-scale market was shifting toward cost advantageous options of lithium iron phosphate (LFP) and standardized, containerized systems led by global incumbents.

As the call for renewables integration rises, and as the grid increasingly needs reliable, multi-hour storage, more demand will now accrue in the deliverance of safe, cost-effective, long-duration systems that integrate smoothly with the power system. In this sense, Korean players will need to move beyond the legacy strategy of providing pure high energy density cell chemistries, and toward equipping stronger and more innovative capabilities in system integration, controls software, project delivery, and long-term operation and maintenance for their next steps.

Software: The Next Frontier

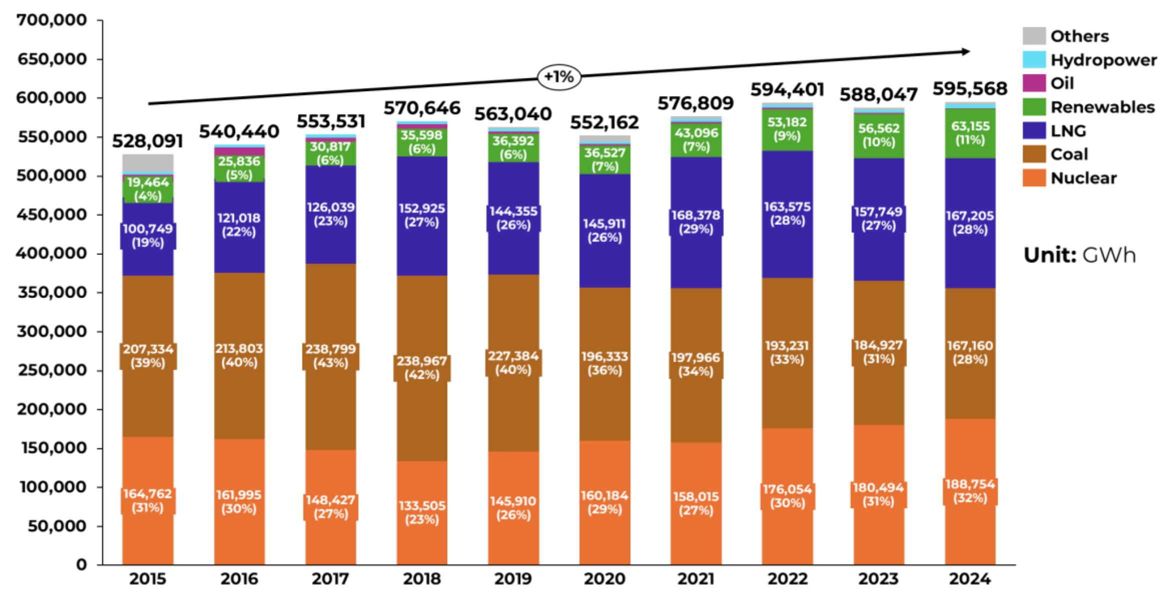
The technology trend for BESS has had a consistent and incremental lean toward the stability and cost efficiency of LFP chemistries. While the industry looks toward emerging options like vanadium redox flow and sodium-ion for future differentiation, the immediate commercial reality is defined by the mass standardization of LFP chemistries. With this consolidation having turned battery hardware into a commodity, opportunities for innovations and competitive edge have now migrated from the cell production line to the system integration layer where plant-level energy management systems (EMS) platforms determine how batteries interact with electricity supply and demand, grid signals, and the variability of renewable integration.

The strongest tests for Korea's BESS strategy will now come from how well it links these commoditized batteries with flexible demand and aggregated portfolios of small assets. Demand Response mechanisms demonstrate that consumers and industries can act as part of the resource mix, while Virtual Power Plants turn scattered batteries and loads into something that behaves like a single dispatchable plant. Ultimately, the success of the industry will depend on its ability to transcend hardware manufacturing and to gain proficiency in achieving this connectivity that transforms isolated assets into a unified and responsive reliability resource.

2. South Korea's Power Mix in a Nutshell

2.1. Power Mix Decomposition

Korea's Power Mix



Source: P3 illustration with data from KEPCO Korea Electric Power Statistics

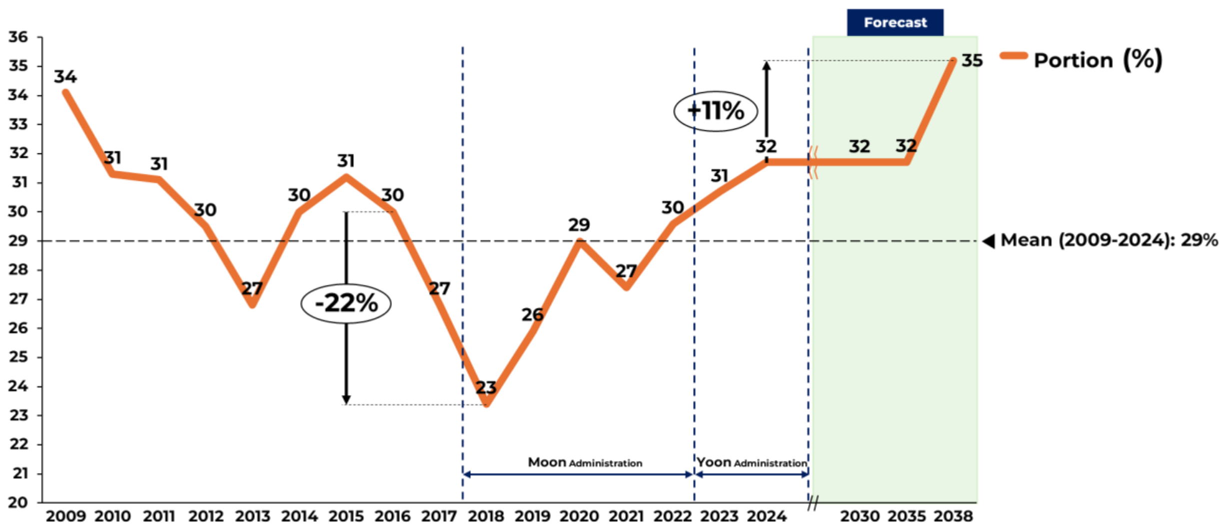
Figure 1. Korea's Power Mix Historical Trend 2015-2024

Over the past decade, Korea's electricity generation has changed more in its composition than in its size. As shown in Figure 1, the amount of electricity generated has increased at a 1% CAGR from 2015 to 2024. However, coal-fired generation has been on a steady decline, gradually retreating from its dominant role within the system. Nuclear output, by contrast, has climbed back and now exceeds coal as the primary source of electricity. Renewables, while still a small share, have increased remarkably in absolute generation, working their way up in the mix.

On the surface, the general trend looks like a textbook energy-transition storyline, with coal phasing out and cleaner sources of energy gaining more traction. However, Korea's power system can be more complex, and it is imperative that we take a more microscopic view to assess whether the system is robust enough to take on external challenges such as the rise in electricity demand stemming from AI and data centers, and the need for better renewable integration to the grid.

With the goal of better understanding the complexly intertwined details of the matter, the first section of this whitepaper disaggregates Korea's power mix into time-series profiles for selected generation sources. By specifically tracing how the shares of nuclear and renewables have evolved within the power mix over time, we aim to unravel both the evident and hidden trends embedded within and set as building blocks for the next sections of this paper.

Nuclear



Source: P3 illustration with data from KEPCO Korea Electric Power Statistics. Forecast data extracted from the 11th Basic Plan of Long-Term Electricity Supply and Demand

Figure 2. Nuclear Energy Portion in Korea's 2024 Power Mix

According to the International Atomic Energy Agency, there is a total of **26 operational nuclear reactors** in Korea that provide almost **a third of the nation's electricity**. From a supply-stability standpoint, the importance of nuclear energy has been paramount for its core role in the South Korean electricity supply security calculus. However, in the past decade, nuclear energy policy has experienced almost three structural shifts.

During President Moon Jae-In's term in office, Korea held a firm stance on completely phasing out of nuclear energy. The portion of nuclear in the power mix went down to 23% in 2018 as part of this effort, and this was the lowest rate to have been achieved between the years 2009 to 2024. This policy was turned over following the election of President Yoon Suk-Yeol, who set renewed targets to provide at least 30% of electricity through nuclear energy by 2030. Accordingly, the portion of nuclear energy was restored with active government support between the years 2022 to 2024.

Starting in 2025, newly elected President Lee Jae-Myung is mainly emphasizing the need to keep nuclear capacity at status quo rates, as opposed to an explicitly expansionary or contractionary nuclear policy. This indicates that the driver of change for the shift in nuclear shares for Korea's power mix has mostly been based on political agenda, rather than for its intrinsic value as a source of energy. Forecasts from the 11th Basic Plan indicate that **nuclear energy will continue to play a significant role** in electricity generation until 2038, as its portion **grows by 11%** compared to that of 2024.

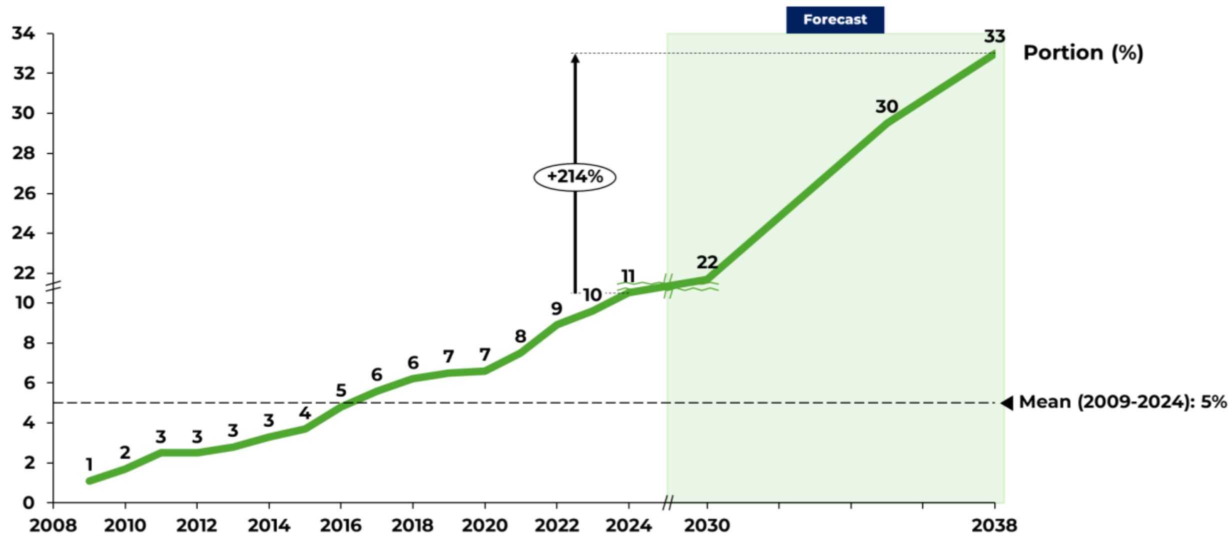
Coal and LNG

Coal has entered a declining trend. In 2024, it **slipped below 30% of electricity generation** and lost its long-standing lead as nuclear moved to the top. The 10th Plan set had out goals to cut the coal portion to roughly one-fifth by 2030, and the newly finalized 11th Plan drives it a step forward to about one-tenth by 2038 through retirements, conversions, and limited seasonal operation. Ammonia cofiring is being piloted under the clean hydrogen program with a goal of a 20% blend at many units later this decade, but economics and local air impacts will determine how far it goes. The system now leans on coal mainly for winter security while market and policy signals steadily reduce its hours.

With the enlistment to the Powering Past Coal Alliance at COP30, the Korean government declared that it will **not build any new coal power plants that lack greenhouse gas reduction equipment**. This reinforces the claim to shut down 40 coal fired power units by 2038 and has stirred up concerns regarding baseload stability when viewed in light of Korea's reserved stance for new nuclear power build ups. However, as Korea has set clear international vows to phase out of coal, there is now less time to lose in discussing why we are doing this. Instead, we should now focus more on how we are going to optimize given the new and updated constraints and promises made.

LNG has been the balancing workhorse in Korea's power mix throughout the decade. In 2024, it supplied just under a third of the power mix, and carried most of the ramping duty as coal ran fewer hours. The 10th Plan has gas near the lower **20% range by 2030** and the 11th Plan guides it toward about **one-tenth by 2038** as nuclear and renewables expand at bigger rates.

Renewables



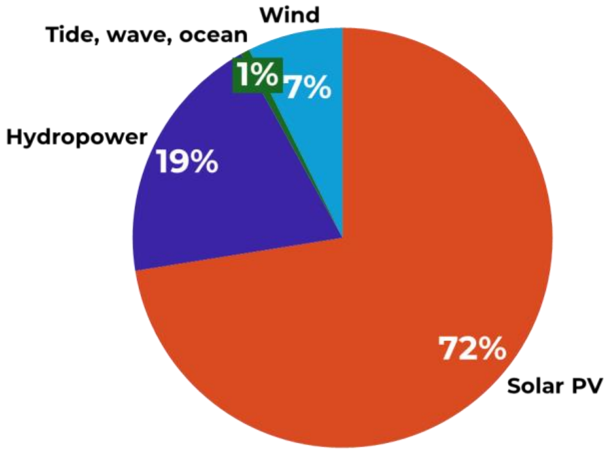
Source: P3 illustration with data from KEPCO Korea Electric Power Statistics. Forecast data extracted from the 11th Basic Plan of Long-Term Electricity Supply and Demand

Figure 3. Renewable Energy Portion in Korea's 2024 Power Mix

Renewables have crossed an important threshold in 2024 as total electricity generation from renewables passed **10% for the first time in the nation's history**, although we must not forget that the relative position of South Korea for its renewable energy penetration rate is one of the lowest among OECD countries. Regardless, the main force that led this growth has been **solar**, taking up almost 72% in the Korean renewable generation mix in 2024, and with 29 GW of cumulative installed capacity in place. However, more than 70% of the module market is already dominated by Chinese manufacturers, leaving Korean firms with shrinking presence in the sector.

Going further, Korea's narrow land area and mountainous terrain limit the scope for large onshore solar projects, whereas its three-coast geography gives it significant offshore wind potential. Offshore wind typically delivers higher utilization and efficiency than solar, and can be developed as large-scale clusters that realize economies of scale, making it a natural next candidate to play a larger role in Korea's future renewable mix.

The emerging trend of 2025 is that Korea is trying **to carve out RE100 industrial belts by tying together massive offshore wind, grid, and storage buildout**. The government is putting KRW 1 trillion into RE100 industrial complexes and planning 14.3 GW of offshore wind by 2030, a program that implies close to KRW 100 trillion of CAPEX when one gigawatt costs about KRW 7 trillion to build. Alongside, there is a KRW 20 trillion U-shaped subsea HVDC "energy highway" and a 540 MW grid scale BESS project of roughly KRW 1 trillion set to come underway. As such, the industrial upside is expected to be concentrated in offshore wind, cables, transformers, and storage.

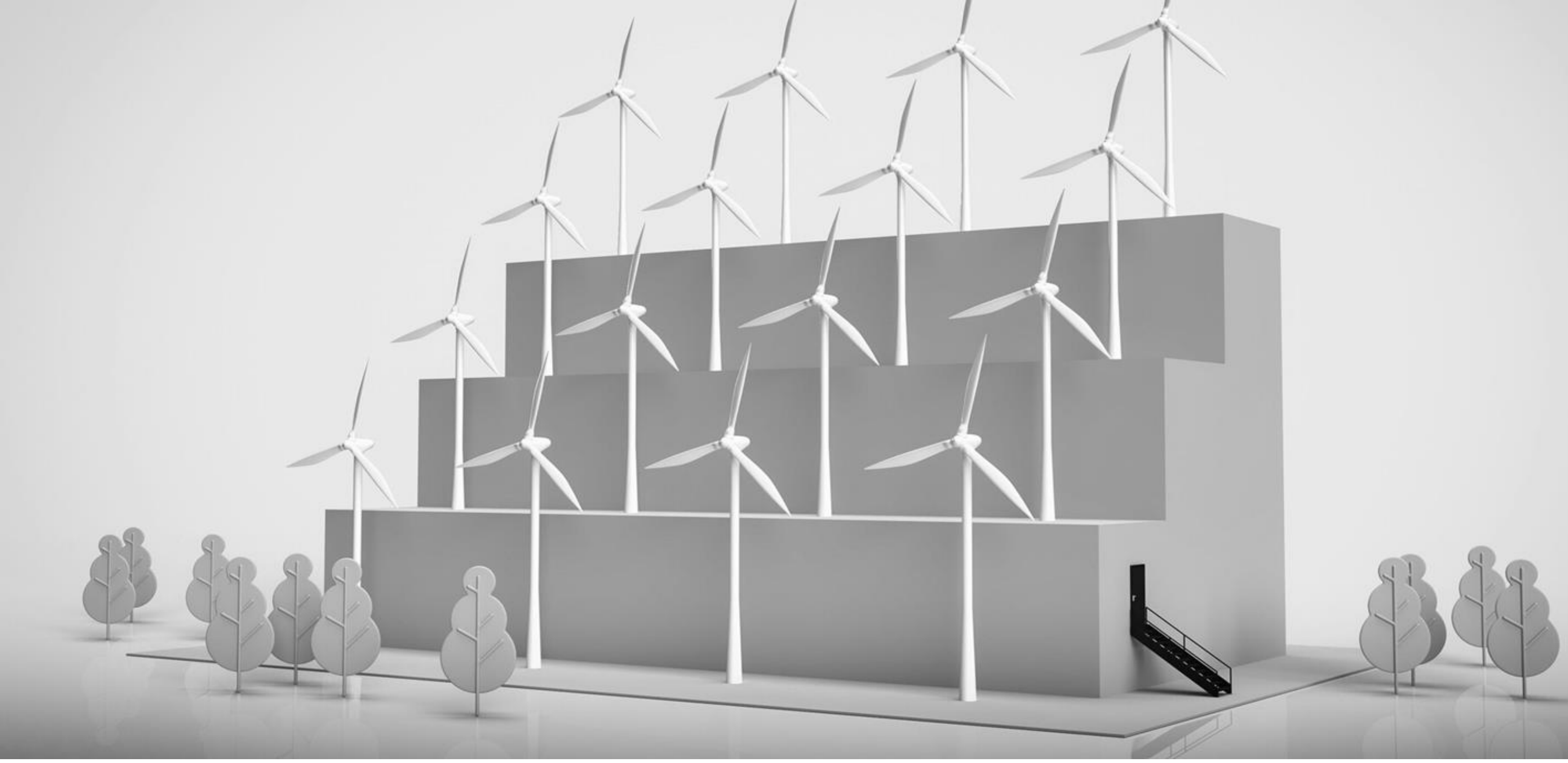


Source: P3 illustration using data sourced from the International Energy Agency

Figure 4. Korea's 2024 Renewable Electricity Generation Mix

The main bottleneck to deeper renewable integration is that **renewables like solar and wind are variable resources** whose output is inherently intermittent, meaning that supply might not always be aligned with demand. This variability translates directly into an **energy security challenge** at times of supply uncertainty, such that when renewable output drops or fails to match peak demand, the grid must rely on other resources to maintain system stability and adequacy. A key lever to addressing these shortfalls is the deployment of battery energy storage systems (BESS).

BESS can charge when renewable output is high and discharge over short and longer durations in current utility-scale projects when there is a shortage of supply. By buffering the variability of renewables and acting as a controllable backup resource, **BESS can help stabilize real-time grid operations and improve the adequacy of supply over longer horizons**. Put differently, when variability shakes the reliability of renewables in power-system operations, and when its uncertainty undermines the adequacy of matching power supply and demand, BESS holds the potential solution headed in the right direction to manage both such shortfalls.



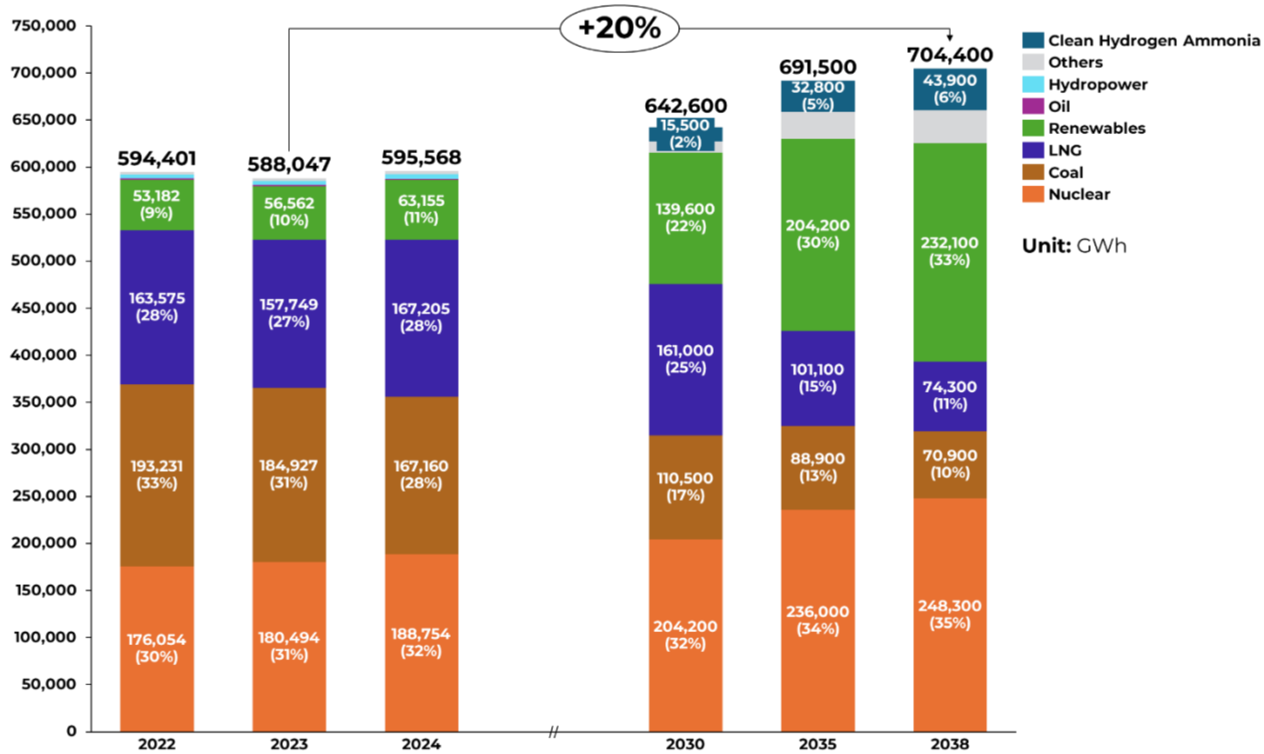
3. The Basic Plan of Long-Term Electricity Supply and Demand

3.1. Overview of the 11th Plan (2024–2038)

The 11th Basic Plan of Long-Term Electricity Supply and Demand[1], finalized February 21, 2025, is an addition to the series of a biennially published national plan that depicts the direction of policies surrounding the economics of electricity supply and demand in Korea with a 15-year scope. The first version of its series was published in 2002. The 11th Basic Plan raises the projected 2038 power demand to reflect expected growth stemming from development in advanced technology, data centers, and broader electrification trends. The 11th Plan aims to secure roughly 10.3 GW of new capacity, replace aging coal units with cleaner or carbon-free alternatives, and upgrade grid and market systems to

[1] For the entirety of this section, we will refer to the 11th Basic Plan of Long-Term Electricity Supply and Demand as "the 11th Plan."

accommodate a higher share of non-carbon power. Together, these measures form a long-term roadmap to strengthen Korea's efforts to enhancing energy security and achieving a smooth energy transition.



Source: P3 illustration using data sourced from the 11th Basic Plan of Long-Term Electricity Supply and Demand

Figure 5. Korea's Electricity Generation Growth Forecasts for 2030, 2035, 2038

Generation Capacity

By 2038, the total generation capacity in Korea is projected to be as high as **268 GW**, and up to 46% of generation capacity is planned to be for renewables. Accordingly, natural gas capacity will comprise up to 25.8% and nuclear 13.1%, while coal falls below 9%.

Electricity Generation

Generation-wise, nuclear and renewables are planned to dominate the power mix by 2038, with **35% from nuclear, 33% from renewables, and with coal and gas each around 10%.** Notably, **clean hydrogen ammonia co-firing** is expected to contribute around **6% of generation** by 2038. The 11th Plan also reaffirms nuclear power's role as a carbon-free baseload, calling for the timely completion of new reactors such as the Shin-Hanul units 3 & 4, and the development of SMRs by the 2030s.

Electricity Demand

Electricity demand is forecasted to grow at a moderate pace. Numerically, by 2038, annual power consumption is expected to reach **735 TWh**, which is about a 20% increase from 2024. Peak summer demand is projected at 145.6 GW in 2038, growing almost 2.4% per year from 2024. It is important to point out that these projections in the 11th Plan explicitly account for new drivers. Namely, electrification of transport/heating (63 TWh), booming data centers (15.5 TWh), and advanced industries like semiconductor and battery manufacturing (1.1 TWh). Over 40% of the demand growth comes from these new electricity uses.

Energy Storage Systems

Since the 9th Plan, Korea has already moved into procuring large-scale storage where up to 5.7 GW of new pumped hydro sites have been designated accordingly. The 11th Plan highlights two strategies: short-duration batteries for fast response and long-duration pumped hydro storage and long-duration batteries for multi-hour balancing. Through 2035, all new storage needs are expected to be met by BESS and emerging storage technology. However, from 2036–2038, a hybrid long-duration fleet is envisioned to be achieved, where about half of the required 7.5 GW long-duration storage is met by new pumped-hydro and the other half by large BESS or other storage. The general direction is to take a balanced approach that hedges against cost uncertainties. Today, pumped hydro is more cost-effective for bulk storage, but the Plan acknowledges that **battery storage could overtake pumped hydro in the long run with technology advancements.**

3.2. Outlook for the 12th Plan: Direction and Expected Changes

The 12th Basic Plan (2026–2040) is currently under preparation, due by the end of 2026. The 12th addition to the biennial series is expected to adjust course reflecting the new administration's priorities and the nation's updated Nationally Determined Contributions (NDC) commitments. P3 Korea expects the 12th Plan to accentuate the aspects below.

Decarbonization: The 2035 Nationally Determined Contributions were released in November 2025. The government has raised the mid-term climate target by stipulating aims to cut greenhouse emissions 53–61% by 2035 compared to 2018. The 12th Plan will include updates that will better guide policies towards these goals.

Renewables: Officials have also indicated that the 12th Plan will take into consideration the direction of President Lee Jae-Myung's aim to aggressively expand renewables. As such, we may see a 2030 renewables capacity goal nearer to tripling the 2023 level (as pledged at COP28), which was something that the 11th Plan fell short of. Going deeper, the growth of the offshore wind industry is expected to gain more momentum under the current administration. Government policy has served as the bedrock for its recent growth, and the Special Offshore Wind Promotion Act (2023) is at the core of this flow. The act has brought offshore wind a significant step forward, by streamlining previous red tape for the construction of offshore wind farms. We expect this trend to be reflected in the 12th Plan in more detail.

Nuclear: While the official 11th Plan included plans for 2 large reactors, the new plan will reconsider the necessity and feasibility of those plants considering the push for renewables. This is in line with the announcement that the government will conditionally accept the construction of new nuclear plants only after thorough scrutinization. The minister has stated that they will consider new plants if an entity "steps up with a viable proposal and site" for a new reactor. This translates to the fact that no new nuclear plants will be state-initiated, and the two new reactors penciled in the 11th Plan could be re-examined for the 12th Plan.

Notably, President Lee Jae-Myung's administration approved on November 13 the continued operation of KORI 2, the country's second commercial nuclear power plant. The plant's operating license had formally expired on April 8, 2023, when its original 40-year design life came to an end. The extension was granted after a safety assessment that lasted more than three and a half years concluded that the plant meets the requirements for continued operation. Taking all this together for nuclear energy, an obvious trend is that it will continue to hold its portion of the power mix for energy security concerns. The less obvious trend would be that most of the energy will come from extending and better utilizing existing reactors rather than building new ones.

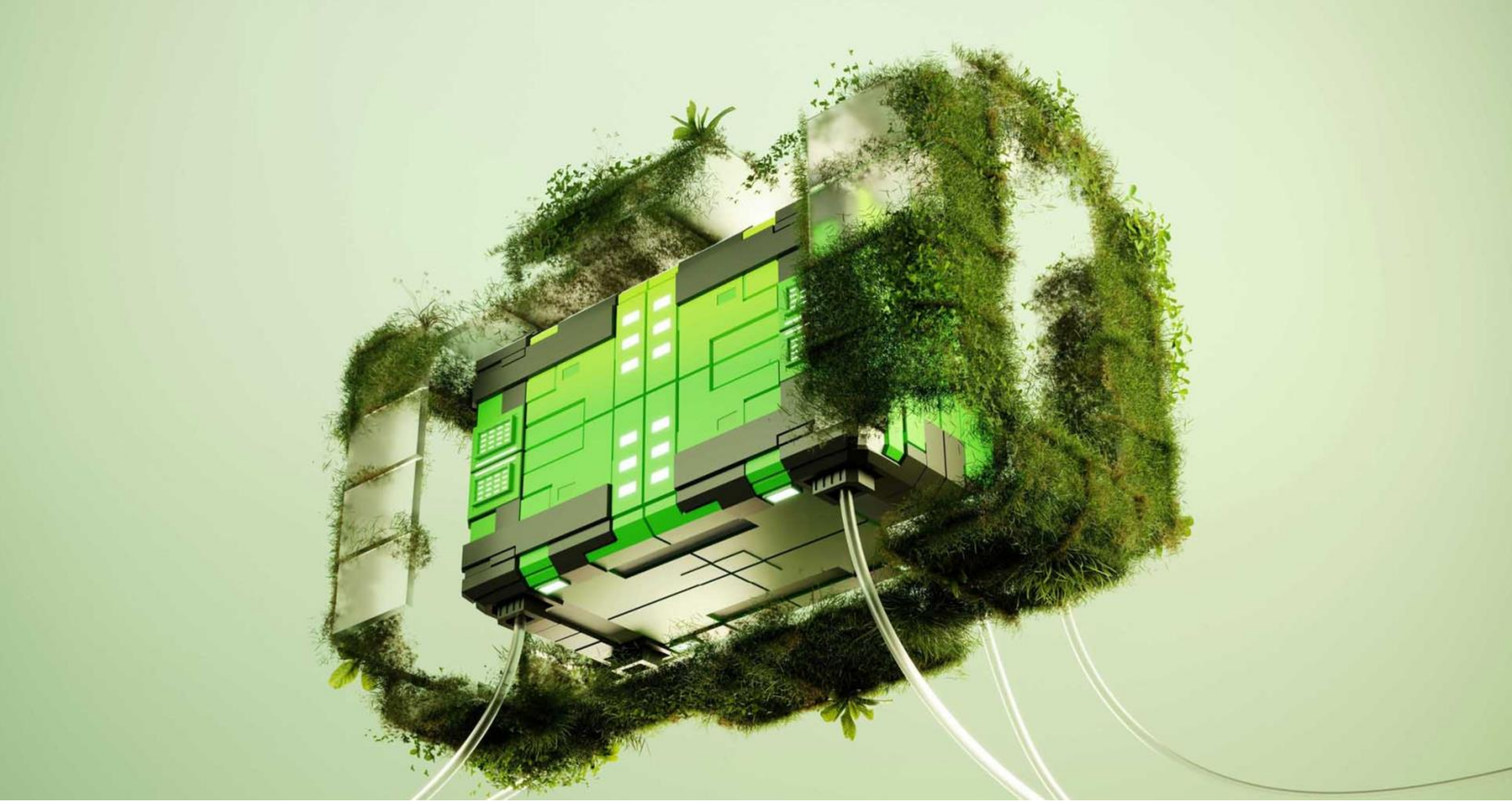
All in all, the direction of the 12th Plan will head toward achieving more ambitious clean energy targets coupled with new regulatory tools. The plan will likely strengthen the clean energy transition initiated in the 11th Plan, but with adjustments to accommodate faster renewable growth, more storage and grid investment, fewer new nuclear or coal plant commitments, and deeper market reforms to maintain the reliability of the grid.

Regulatory Change and Upcoming Milestones

To contextualize, this section lays out in a table the key policies and plans that shaped Korea's BESS industry and some future milestones.

Table 1. Korea's BESS Policy Evolution and Expectations

Year	Details
2019 to 2021	- Korea promoted ESS for grid support using frequency-regulation pilots, charging tariff discounts and high REC multipliers for PV-linked storage. - After a wave of ESS fires, authorities tightened safety rules and PV+ESS incentives, sharply slowing new subsidy-driven ESS installations. - The 9th Basic Plan raised renewables and scheduled about half of coal units for retirement or conversion by 2034.
2022	- The 10th Basic Plan shifted emphasis back to nuclear and LNG while setting the 2030 renewables target to about 21.6% of generation. - Policy restarted major reactor projects and extended existing plants, treating storage mainly as a supporting flexibility resource.
2023	- The Special Act on Promotion of Distributed Energy created a legal basis for distributed resources, stored-electricity sales and VPP-style aggregation using BESS. - KPX prepared a Jeju pilot for real-time and ancillary-service markets starting in 2024, improving future value streams for batteries and DR.
2024	- MOTIE released the draft of the 11th Basic Plan, emphasizing higher carbon-free shares by 2038 and explicitly calling for large-scale storage including BESS and pumped hydro. - The Distributed Energy Act and its rules took effect on 14 June 2024, activating distributed-energy zones and grid-impact checks for major projects. - Jeju's first central long-cycle BESS tender awarded 65 MW/260 MWh under 15–20-year term contracts, creating a model for contracted storage.
2025	- On 21 February 2025, the 11th Basic Plan (2024–2038) was finalized - KEPCO adopted an investment plan of about 72.8 trillion won through 2038 for grid and HVDC expansion, supporting renewable and storage integration. - KPX held the first nationwide ESS capacity auction at 540 MW. - Korea announced a 2035 NDC range of roughly 53–61% compared to 2018, tightening the mid-term climate ambition for the power sector.
2026	- The 12th Basic Plan is due mid-year with finalization by year end. - Policy discussions point toward more reliance on life-extended reactors plus storage, DR and grid upgrades, with careful review of further new nuclear capacity.
2027	- The East Coast to Seoul HVDC targets completion around mid-2027.



4. Korea's BESS Industry Overview

4.1. Korean BESS Industry Development

The year 2019 is when Korea's battery industry hit a clear inflection point. Up to that moment, the growth story of the industry had been dominated by electric vehicles. Specifically, Korea's major cell manufacturers expanded production around high-energy-density chemistries such as NCA and NCM, optimized for range and weight, with a specialized target to supply for automaker demand in North America and Europe. Stationary storage was treated largely as an adjacent outlet for EV-style packs rather than a distinct product segment.

China's Rise in the Global Market

Meanwhile, a different strategy was taking shape in China. After building scale on a very large domestic market, Chinese cell makers pivoted outward with lithium iron phosphate (LFP) as their workhorse chemistry. LFP is heavier per kilowatt-hour than NCA/NCM, but it is cheaper, more thermally stable, and well suited to sit in cabinets and containers for long hours. Chinese suppliers paired this chemistry choice with a systems-first approach, integrating "all-in-one" ESS containers that were simple to ship and install. As a result, global utility-scale ESS demand increasingly gravitated toward LFP-based turnkey systems, and Chinese firms rapidly captured a dominant share of new deployments. Korean players, optimized for EV-grade high energy density rather than cost and simplicity, now see their relative position weakened in the global ESS segment.

Fire Incidents and Safety Concerns

At roughly the same time, Korea's domestic ESS market faced a separate set of shocks from a series of ESS fire incidents. According to the data submitted by the office of Rep. Lee Jong-bae of the People Power Party to the Ministry of Trade, Industry and Energy, it has been reported that there were 34 cases of ESS fires from 2021 to June 2025. These events triggered a tightening of standards and investigations into safer system designs and installation practices. The response added layers of safety systems such as additional cooling, sensors, and protective hardware, thereby increasing system complexity and cost. While this was essential to rebuild trust for ESS in the domestic market, it also slowed new ESS deployments and temporarily widened the gap between what Korean products offered and what the global ESS market was looking for in robust, standardized, LFP-based container solutions optimized for stationary use.

From Short-Duration to Long-Duration System Needs

Policy and system needs have pushed the industry back onto a growth path, but with a different shape. Under both the Moon and Yoon administrations, Korea expanded renewables and recognized storage as a prerequisite for higher shares of variable generation. Early deployments focused on relatively short-duration applications. As solar and wind penetration rises and the 11th Basic Plan envisions higher renewable shares, system needs are gradually extending toward longer-duration storage, to cover evening peaks and periods of low renewable output. This shift is forcing developers and integrators to rethink system design, structurally incentivizing them to select chemistries and configurations that prioritize cost per delivered kilowatt-hour, safety, and cycle life over compactness. LFP has become the default choice for multi-hour grid storage in this context, while emerging options such as sodium-ion are being evaluated for future long-duration, cost-sensitive applications.

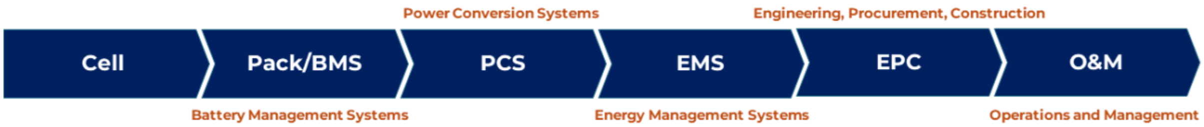
From Subsidies to a Centralized Auction-Based Procurement

Meanwhile, procurement models have evolved in parallel. Korea's first wave of ESS deployment relied heavily on targeted incentives, REC bonuses for PV and ESS combinations, and project-by-project arrangements. As the system need for storage matured, policy moved toward centralized, auction-based mechanisms, and Jeju's pilots and the early frequency regulation projects served as test beds for long-term contracts. More recently, national-scale tenders and a dedicated ESS central contract market have begun to define volumes, durations, and services at scale, with KEPCO and KPX playing coordinating roles. This transition from fragmented subsidies to structured capacity and ancillary-service procurement is and will be central to turning storage from a one-off installation into a core reliability resource in the country.

Strategic Repositioning of Korea's BESS Industry

Taken together, these developments mark a structural repositioning of Korea's BESS industry. The core competitive frontier is shifting from EV-style high-density cells toward ESS-specific solutions in LFP-based, multi-hour systems. Chemistry remains important, but system integration, safety track record, and the ability to deliver efficient and long-duration capacity are increasingly becoming decisive.

4.2. Value Chain Deep Dive

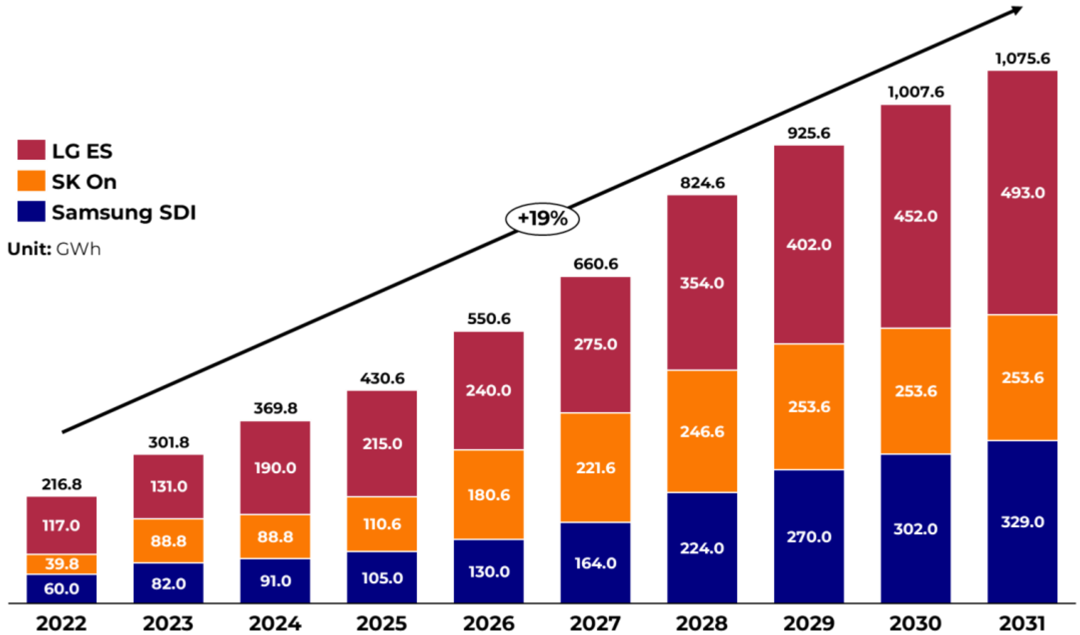


Source: P3 illustration
Figure 6. Battery Energy Storage Systems Value Chain

The BESS value chain is depicted as a flowchart in Figure 6, and the rudimentary components that constitute the BESS have been outlined. Cells refer to battery cells, which are assembled into modules or packs and further integrated into battery systems with Battery Management Systems (BMS). The Power Conversion System (PCS) converts power between DC and AC allowing for integration into the grid, while the Energy Management System (EMS) controls charging/discharging and optimizes operation. EPC denotes the actualization of projects via engineering, procurement, and construction of the BESS project, while O&M refers to the operations & maintenance after the ESS starts and continues to operate. These stages link together to construct a complete grid storage solution.

Cell

At the heart of the value chain is battery cell manufacturing. Korea's "Big Three", namely LG Energy Solution, Samsung SDI, and SK On, are the three largest cell makers in Korea. These three companies have honed their technology for over 20 to 30 years and have been at the lead of high-density nickel-based batteries (NCA/NCM) that are aimed at premium applications of battery technologies.



Source: P3 illustration with data from SK Securities (June 2025)

Figure 7. Ramp Up Trends in Korea's Big Three Cell Makers

As in Figure 7, the overall direction of the cell makers' ramp up is set to grow continuously, but this was initially set as such for the most part to procure cells for electric vehicle demand. However, as EV battery demand fluctuated in the recent years, Korean manufacturers have begun to strategically pivot into the BESS market. They are repurposing EV cell production lines and innovating new cell chemistries to serve BESS needs both domestically and internationally. This is also in line with the intensifying requirements surrounding the Foreign Entity of Concern (FEOC) constraints in the advanced technology value chain of the United States, where Korea is attempting to exert a bigger influence in the market as an FEOC-compliant partner.

LG Energy Solution is aggressively expanding LFP cell production for BESS, with plans to achieve 17 GWh by the end of 2025 and to scale to over 30 GWh by 2026 at its new Michigan lines. Samsung SDI, known traditionally for high-density NCA cells, recently dominated domestic ESS tenders with its NCA chemistries, winning 6 out of 8 government-backed projects during the first ESS central contract market in Korea. This success has been attained by reason of its superior fire prevention technology and its alignment with the market's commitment to local manufacturing. SK On, primarily an EV battery supplier, is now entering the grid storage arena by repurposing its EV cell plants for LFP-based ESS cells in the United States. The company has recently secured a deal to supply 7.2 GWh of containerized LFP batteries to Flatiron for projects in the U.S. through 2030.

Source: Samsung SDI
Figure 8. Samsung SDI Flagship ESS Samsung Battery Box (SBB) 1.5

Battery Pack and Battery Management Systems

Next, we have the battery pack, together with its Battery Management System (BMS). After cells are assembled into modules and packs, the BMS monitors every cell's voltage, temperature, and health, working to orchestrate balance and ensure safe, optimal performance. A well-designed pack and BMS maximize usable capacity and lifespan, preventing issues like over-charge or thermal runaway that can lead to failures.

Source: CATL, BYD
Figure 9. CATL TENER and BYD MC CUBE-T

The key players of the BMS segment of the value chain in Korea include the big three battery cell manufacturers, as well as system integrators. Recent achievements showcase how Korean firms are pushing BMS technology to new heights. For instance, SK On's latest ESS batteries feature heat propagation prevention systems and electrochemical impedance spectroscopy (EIS)-based diagnostics to catch any cell anomalies early. On the system integrator side, companies like HD Hyundai Electric develop their own BMS solutions for grid-scale projects.

Global competition in BMS is intertwined with battery pack competition. For example, Chinese ESS providers like CATL and BYD have raced to offer safe and intelligent battery packs as outlined in Table 2.

Table 2. Strategies by Global Incumbents in Battery Packs and BMS

Firm	Battery Pack Strategy	BMS Strategy
CATL	Standardized LFP container and rack products optimized for cost, safety, and fast deployment.	Pack and rack BMS tightly coupled to CATL cells and liquid cooling, tuned as a single integrated hardware system.
BYD	Vertically integrated LFP packs used across EV and stationary applications, with conservative designs and long cycle life.	In-house BMS tied to BYD chemistry plus remote monitoring, focused on reliability and degradation control.
TESLA	Fully integrated container including cells, inverters, cooling, and enclosure as one product.	BMS integrated with plant controls and trading stack through Powerhub and Autobidder for automated market dispatch.

Power Conversion System

The Power Conversion System (PCS) converts DC electricity from the batteries into grid-quality AC power during discharge, and vice versa during charge. It has a significant role in a BESS by regulating voltage and frequency, controlling ramp rates, and ensuring the stored energy can be deployed flexibly. Technologically, PCS units in large ESS sites are often advanced bi-directional inverters capable of near-instant response. Additionally, they not only convert power but also protect the system, islanding the battery from grid faults and executing precise commands from the Energy Management System. In short, the PCS is the bridge between battery and grid, and its efficiency and reliability directly impact how much value an ESS can deliver to the power system.

In June 2025, LS Electric signed a partnership with Power Electronics, a leading PCS supplier in North America and Europe to actively target the global ESS market. Through this agreement, LS Electric gains access to a PCS platform with a strong track record in mature ESS markets, while Power Electronics can expand deployment of its PCS together with LS Electric's distribution transformers and power solutions on project sites worldwide.

Another Korean firm that has secured a foothold in the global ESS value chain is Seojin Systems. In September 2025, the company, which built its business mainly as an ESS enclosure manufacturer, signed a supply contract with a leading US-based PCS firm to supply grid-connected inverters for battery energy storage. This deal is worth approximately KRW 33 billion, marking Seojin Systems' first large-scale entry into external PCS hardware. It is also an extension of its role into the core power-conversion equipment sector in the global ESS stack. The initial batch is scheduled for delivery through the first quarter of the following year, with further orders expected as North American projects ramp up.

Energy Management System

An Energy Management System (EMS) is the control center of a BESS, coordinating when and how the batteries charge or discharge. It comprises software algorithms and control hardware that monitor battery status, predict energy needs, and execute strategies to maximize performance and profits. In operation, the EMS considers a myriad of inputs such as electricity prices, grid frequency deviations, renewable generation forecasts, and battery state-of-charge. With this information, it decides the optimal dispatch in real time. A sophisticated EMS can make an ESS a multi-tool asset that can shave peak load, absorb excess solar power, and provide frequency support within a fraction of a second.

Korea's ESS industry has developed highly advanced EMS platforms, often bundled with complete storage solutions from major providers. Companies like Hyosung, LS Electric, Doosan GridTech, and HD Hyundai Electric each offer proprietary EMS software tailored to their hardware. Globally, a recent trend is the incorporation of AI and machine learning, and this is being led by global players such as Fluence's AI-powered Fluence IQ or Tesla's Autobidder.

Table 3. Strategies by Global Incumbents in EMS

Firm	Plant-level EMS strategy	Market-level EMS strategy
TESLA **(Megapack)**	Uses project EMS and site controllers to manage state of charge, multi-service stacking, and compliance with interconnection and grid requirements at each Megapack site.	Autobidder as a cloud-based EMS and trading layer that optimizes bids, dispatch, and revenue across one or more Megapack projects in wholesale and ancillary-service markets.
FLUENCE A Siemens and AES Company **(OS / IQ)**	Fluence OS as the primary EMS at the plant, coordinating PCS and BMS to deliver contracted services such as arbitrage, reserves, and fast frequency response.	Fluence IQ as a portfolio-level EMS layer, with applications like Mosaic and Nispera to forecast, schedule, and bid portfolios of wind, solar, and storage assets across markets and contracts.

Engineering, Procurement & Construction (EPC)

According to Hameed and Træholt (2025), under the context of BESS, the "EPC (Engineering, Procurement, and Construction) process defines the end-to-end sequence of activities required to deliver a BESS project from initial concept through ready-for-operation." In their paper the five steps identified for EPC are as follows: (1) Feasibility Assessment, (2) Permitting, (3) Procurement, (4) Construction, (5) Commissioning.

In most markets, EPC is still a highly local business. Permitting rules, grid codes, labor regulations, and site conditions can heavily differ from region to region, so building a credible on-the-ground presence is critical. Samsung SDI, for example, has traditionally been on the conservative side about moving downstream into high-risk EPC roles, where the core business logic has been to prioritize stable, hardware-focused returns. SK On has faced a different kind of constraint. Within the SK Group, SK ecoplant is a highly capable EPC contractor with experience in large infrastructure projects at home and abroad. However, the coordination between SK On and SK ecoplant has been rather limited, as SK has not presented itself to global customers as a single, tightly integrated BESS solution provider.

Tesla and CATL demonstrate the opposite model. Tesla positions Megapack as a largely turnkey product with pre-assembled and factory-tested units designed to cut onsite complexity and reduce EPC scope and cost, often combined with Tesla's own project development, software, and lifecycle services. CATL, meanwhile, has built a full stack around its cells, offering integrated energy storage systems and partnering on large grid-scale projects in ways that effectively blur the line between manufacturer, system integrator, and EPC. For project owners and investors, vertical integration as such means fewer interfaces, one primary counterparty, and a clearer allocation of technical and performance risk.

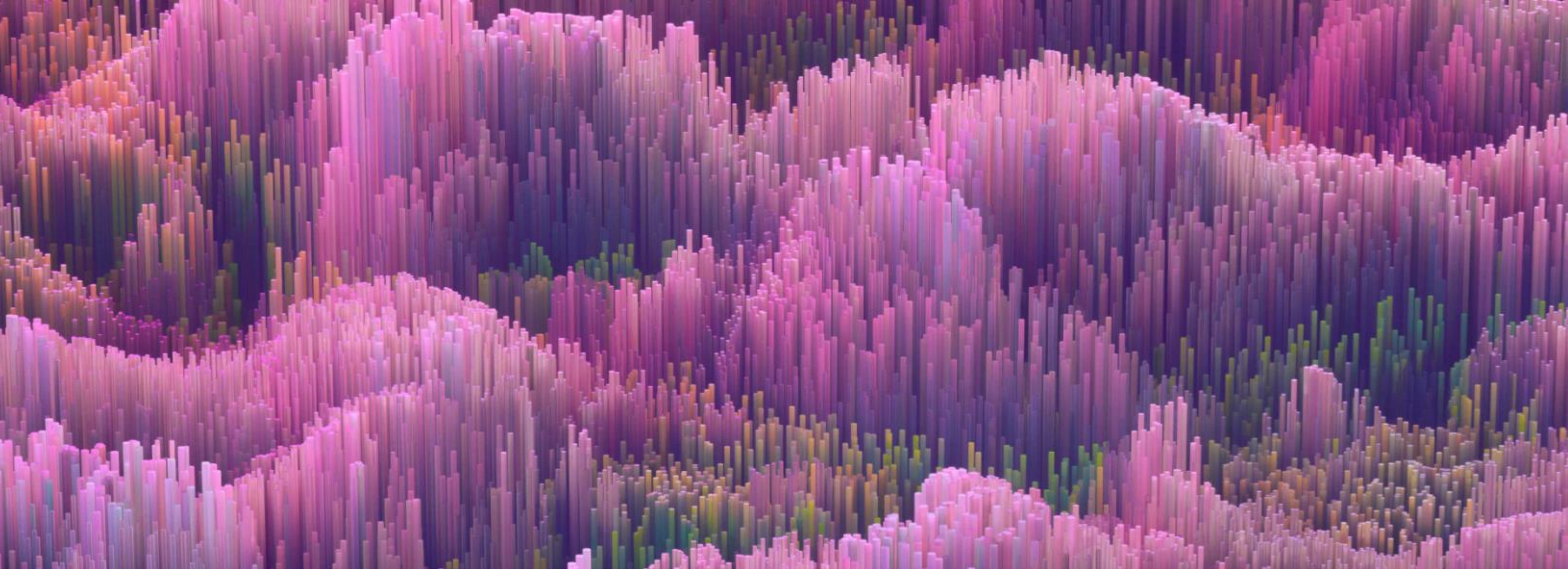
A Korean-led movement in a similar direction is the establishment of LG Energy Solution Vertech, which was set up explicitly as an energy storage system integrator targeting the North American market. The entity combined LG's cell and rack manufacturing with downstream system integration, software, and lifecycle services under a single contract structure. On the EPC front, HD Hyundai Electric is taking a similar step up the value chain as the EPC contractor for Korea Southern Power's 200 MWh Rutile BESS project in Texas, handling the full design, procurement, and construction of a roughly USD 120 million grid-scale system built with Korean technology and capital.

Operations & Maintenance (O&M)

Ensuring the deployed BESS operates reliably over its lifespan is another crucial component. The domain of Operations and Maintenance (O&M) covers everything from routine inspections, battery health diagnostics, and firmware updates to preventative maintenance on inverters and thermal management systems. Given the high stakes of a failure in the system, owners typically entrust O&M to specialized teams or the original system integrator under long-term service agreements.

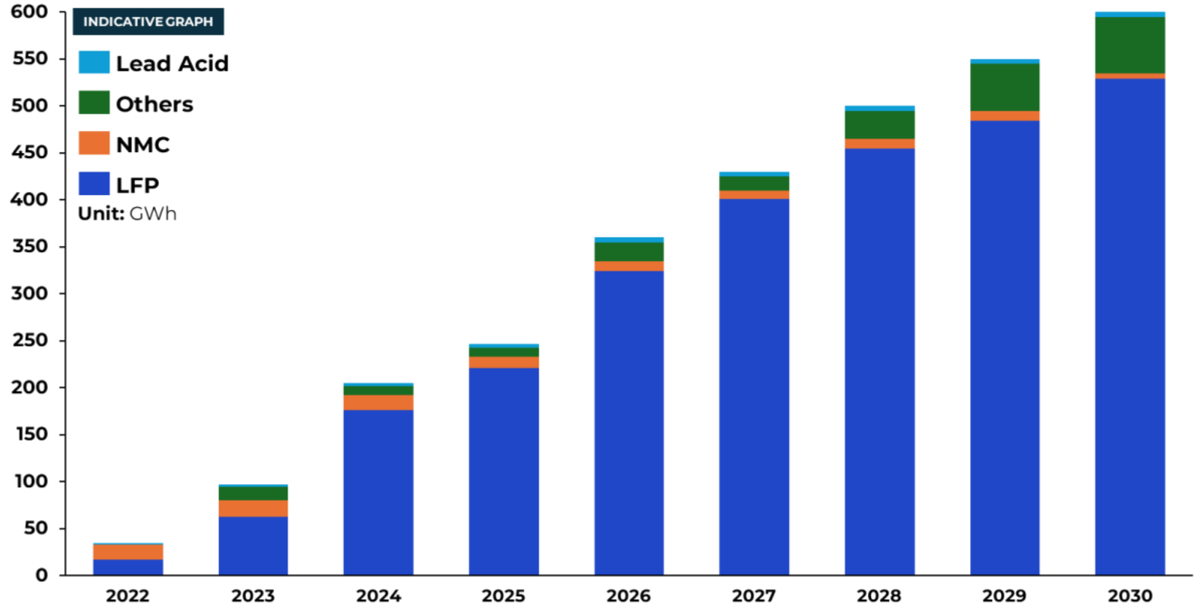
Korean companies have developed strong O&M capabilities alongside their EPC roles, often offering it as part of a turnkey package. Hyosung Heavy Industries, for example, emphasizes that its global ESS success is built on coupling EPC with diligent O&M, done via monitoring and servicing of capacity amounting to 2.7 GWh across 250 sites worldwide, from large grid installations to remote industrial microgrids. LS Electric likewise is contracted not just to build but to operate storage plants. In Japan, LS formed a consortium to handle both the construction and multi-year O&M of the Miyagi Prefecture BESS.

Advanced methods such as AI-based predictive analytics to forecast battery degradation or PCS faults have been gaining more traction in accordance with the rising call for capability to simulate and plan maintenance. Analyzing roughly 140,000 dissolved-gas-analysis records and reporting about 98% diagnostic accuracy and 87% forecast accuracy for transformer faults, Onepredict's Guardione platform has emerged as a strong AI-based predictive maintenance tool in Korea, already deployed at KEPCO and major private players such as GS Caltex, GS Power, and E1.



5. Technology and Business Model Trends

5.1. BESS Cell Chemistry Trends



Source: P3, BloombergNEF, Rho Motion
Note: Others include all non-Li-ion technologies like sodium-ion batteries and redox-flow batteries.
Figure 10. Global Newly Installed BESS Capacity by Cell Chemistry

LFP or NMC?

Korea's utility-scale BESS market has historically been dominated by lithium-ion batteries with **NMC cathodes**, valued for their high energy density. Today, however, the global market has decisively shifted

in favor of LFP cell chemistries due to a combination of cost, safety, and longevity advantages. LFP batteries are roughly 20–30% cheaper per kWh than NMC batteries, owing to more abundant, lower-cost materials. They also offer improved safety, as the thermal runaway onset temperature for LFP cells is higher.

LFP technology can be charged and discharged for over 3,000–6,000 cycles. This is almost double that of typical NMC cells under moderate conditions. These factors have rendered LFP the preferred choice for new large-scale storage deployments globally. NMC-based systems, while still used in some applications requiring maximum energy density, are increasingly limited to niches as manufacturers and developers pivot to LFP for most energy shifting needs.

Redox-flow Batteries

For long-duration storage needs, vanadium redox flow batteries (VRFB) have emerged as a credible alternative. VRFB systems store energy in tanks of liquid electrolyte, intrinsically decoupling power and energy capacity. In other words, **the tank size can be scaled up to extend discharge duration without changing the power stack.** They are also intrinsically **non-flammable** with water-based electrolytes and exhibit **no cycle-based capacity fade over tens of thousands of charge cycles**. This endurance and safety make flow batteries attractive for applications like renewable energy time-shifting and peak shaving over 8 to 12-hour periods. Their drawbacks lie in **high upfront costs**, driven by vanadium prices and lower round-trip efficiency. Nonetheless, as Korea pursues carbon neutrality, VRFB technology is on the table for providing long-duration, safe, and cycle-free energy storage.

Next Generation: Sodium-Ion?

Sodium-ion battery technology is on the industry's radar as an **emerging alternative**, but it remains in its early stage of development. Sodium is cheaper and more abundant, promising attractive long-run costs. Yet, current sodium-ion offerings lag behind LFP in energy density and durability. In fact, to achieve comparable performance, today's sodium-ion batteries end up being costlier than LFP. It is reported that sodium-ion battery costs today can be nearly double those of LFP for similar energy output.

As shown in Figure 10, the LFP dominance in the BESS sector is expected to continue throughout the next decade. However, anticipation surrounding next-generation ESS battery chemistries is expected to grow over time, and whether sodium-ion batteries will develop and actualize the proposed benefits in the BESS sector is a key factor that every player is keeping an eye on.

5.2. Business Model Trends

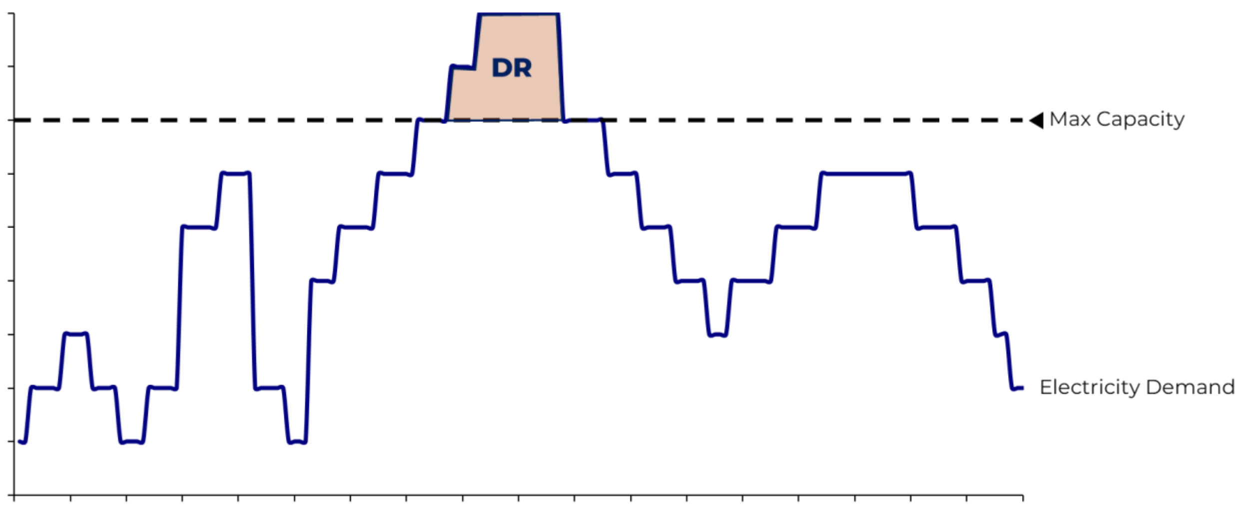
The competition for supremacy in the BESS sector is no longer just a hardware race centered on who can supply the cheapest or highest-capacity battery packs. While in the past the focus was on engineering better cells and racks, today's market leaders in Korea must seek ways to **differentiate their positions through software intelligence and innovative business models**.

In an environment where capacity and upfront cost are increasingly commoditized, asset owners now seek to maximize performance and revenue over the system's life. As one industry analysis put it, "software is stepping in to fill the gaps and provide the tools the energy industry needs to serve the next chapter of the electric grid."

5.3. Rising Dimensions: Demand Response and Virtual Power Plants

Demand Response

One of the fastest-growing grid-side opportunities linked to energy storage is **Demand Response (DR)** programs. According to the Department of Energy, demand response "provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives." Simply put, demand response is a means of **influencing the consumers of electricity to reduce consumption when the grid is under stress**, instead of forcing utilities to fire up power plants.



Source: P3 illustration
Figure 11. Demand Response Mechanism

There are two main types of demand response markets:

1. Reliability Demand Response
2. Economic Demand Response

Among the two, the concept of incentivizing consumer action is a common trait, but the main difference lies in **voluntary participation**. Reliability DR is a compulsory scheme, where the main objective is to raise the reliability of the grid by ensuring participants comply with the guidance of the power exchange at times of electricity supply emergencies. Economic DR is a voluntary scheme, where individual participants bid their preferred price and amount of electricity consumption to be curtailed. By providing consumers with the chance to participate in the market and get paid for reducing electricity consumption at peak times, the schemes work to contribute to making the grid more efficient at the end of the day.

Source: Yonhap News, Korea Power Exchange
Figure 12. Korea Power Exchange Central Power Control Center

One study shows that in practice, **demand response works best when it is coordinated with on-site renewables and battery systems**. According to Zahari et al. (2024), integrating solar PV, BESS, and DR can significantly reduce industrial peak demand, energy costs, and CO_2 emissions. The authors also mention that high upfront storage costs, limited DR participation, and the lack of explicit CO_2-focused optimization are the constraints of achieving wider adoption.

The **global appetite for DR is also ramping up quickly**. In North America, Enel has dispatched its DR resources by over 400 times and delivered over 11,000 MWh of energy over 1700 hours during the summer of 2024. In the UK T-4 (2028/29) auction, DR accounted for 4.2% of awarded capacity (up from 2.6%). Singapore is also scaling DR through regulatory sandboxes, achieving savings of $740 million in Singaporean currency.

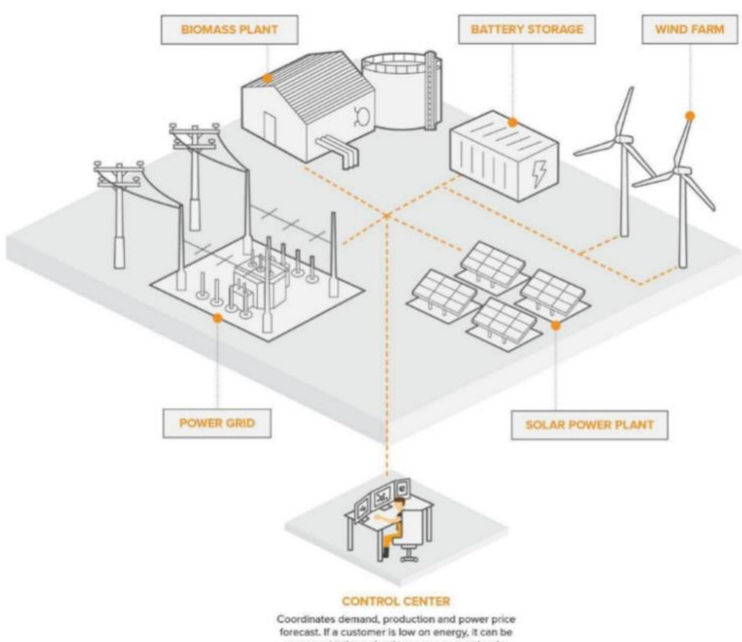
Korea has been an early mover in this field and operates one of the largest demand response portfolios in the world. In fact, as of late 2022, Korea had roughly 4.9 GW of registered demand response capacity enrolled in its programs, and this is one of the largest DR portfolios in the world. The impact was substantial. In December 2022 alone, about 43 GWh of consumption was avoided during peak hours under Korea's voluntary DR programs.

A related concept is reverse demand response, which aims at the opposite situation. This refers to a DR scheme, where consumers are incentivized for purchasing more electricity when the output from renewably sourced plants reaches a surplus. As early as 2017, Arizona Public Service pioneered the announcement and the use of this concept with the goal of managing excess power generated from solar and wind. As Korea's solar and wind capacity grows, there will be more periods when generation outstrips demand. Rather than waste this energy, programs can refer to reverse demand response mechanisms to incentivize consumers to increase usage or charge batteries when surplus exists.

A Korean example is Jeju Island's "Plus DR" initiative introduced in 2024. Under Plus DR, businesses or consumers are rewarded for using additional electricity (or storing it in EVs/ESS) during predicted renewable oversupply periods. Participants register as a Plus DR resource via a platform provided by a startup called VPPlab in Jeju Island, and they receive compensation for adjusting their consumption upward according to plan.

Virtual Power Plants

As Korea sets out to raise the share of renewables amidst a rise in electricity demand, an effective optimization scheme must be set in stone. To do this, a Virtual Power Plant (VPP) uses software to link many small non-traditional energy assets such as rooftop solar, commercial batteries, electric vehicles and flexible loads so that they can be dispatched together like one power station. Instead of operating many small generators and storage units separately, the VPP aims to **plan, bid, and control them in an integrated way** as one power plant, to maximize profit and at the same time improve system stability. The platform forecasts generation and demand and then instructs each asset when to charge, discharge or reduce consumption, so that from the system operator's view the portfolio behaves as a single controllable resource that can deliver energy, capacity and frequency services.



Source: 60 Hertz Energy
Figure 13. Virtual Power Plants Mechanism

Essentially, the clear difference between a conventional power plant and a VPP is whether there is a **physical entity** of the plant per se. This connects to the market and non-market economic benefits of a VPP installation, where there will be no large-scale physical construction costs incurred, along with a positive externality incurred by avoiding the costs of degrading the environment through the construction of conventional power plants.

Table 4. Comparison between Conventional Power Plants and Virtual Power Plants

Aspect	Conventional Power Plant	Virtual Power Plant (VPP)
Operation	• A power plant located in a specific physical space that generates electricity according to dispatch instructions	• A plant that aggregates many distributed resources and supplies electricity by forecasting and controlling them using ICT technologies
Energy source	• Nuclear, coal, LNG combined cycle, etc.	• PV, WT, ESS, FC, mCHP, EV, DR, EE, etc.
Economics	• (Cost) Large investment for a single operator due to construction of large-scale generation facilities and long-distance transmission lines	• (Cost) Costs of installing ICT equipment such as platforms and control systems and technical costs such as forecasting and optimal bidding to coordinate and operate existing small-scale generation facilities
	• (Benefit) Supplies energy at low cost with economies of scale earnings (amount differs depending on the primary energy source)	• (Benefit) Avoids construction of large-scale facilities, contributes to grid stability, and yields environmental benefits
Applied technology	• Traditional power source in the power system	• In some countries with a high share of renewable energy supply, VPPs compete on equal terms with conventional power plants
	• Generation system based on synchronous machines	• Grid-stabilizing technologies like grid-forming still require R&D
Characteristics	• Participates in the power market as a centrally dispatched power plant	• As a dispatchable resource, can participate in power markets or trade directly with consumers at the local level
	• Faces issues related to siting and environmental issues	• Resources can be utilized flexibly without geographical or spatial constraints

Source: Introduction to Distributed Energy Systems (Won et al., 2025)[2]

The technical features of a VPP translate into a different revenue profile from that of a single power station. A conventional plant is usually paid for bulk energy and, in some cases, for capacity. A VPP can stack several income streams by combining energy sales, peak shaving, participation in demand response programs and provision of frequency and voltage support. From the asset owner's perspective, the platform opens a route to markets that would be inaccessible for a rooftop system or a standalone

[2] 분산 에너지 시스템 개론 : 에너지 혁신 기술과 비즈니스 모델 / 원동준 [외]지음

commercial battery. The result is that many small devices which were previously passive become part of an active portfolio that earns fees for flexibility.

VPPs are known to fall into three archetypes:

- **Supply-focused VPPs** aggregate distributed generators and storage and behave mainly as a virtual power station that follows dispatch instructions.
- **Demand-focused VPPs** start from flexible loads in buildings and industry and monetize their ability to reduce or shift consumption in response to price or grid signals.
- **Hybrid VPPs** combine both sides of the meter and can shape net load more deeply.

International experience shows that VPPs tend to scale once market rules recognize distributed resources as eligible providers of energy and system services. In Europe and the United States, regulatory changes have allowed aggregators to bid portfolios of small assets into wholesale and balancing markets, and several gigawatts of flexible capacity are now operated through VPP structures.

Korea's journey to realizing VPPs has been a staged progression. Policy directions have moved initially from accrediting small and distributed energy resource aggregation, to incentivizing forecast accuracy, and then to today's renewable bidding system in Jeju that makes aggregated renewables compete in bidding frameworks like that of conventional generators.

1) Small-Scale Aggregation

The first institutional step in Korea's staged progression toward VPPs was via the opening of the Small Electricity Aggregator Market in February 2019. With this framework set in stone, licensed aggregators could collect 1 MW or smaller resources via rooftop solar, small wind, ESS, EVs, and register them as aggregated resources to participate in the power market.

2) Forecast Accuracy Incentives

With the rising call for renewable energy, KPX announced the Renewable Energy Generation Forecasting Scheme, where participants were to submit day-ahead hourly forecasts on their renewable output to receive additional settlements paid according to their prediction accuracy.

The pre-defined settlement was as below:

- 4 KRW/kWh when the forecast error was less than or equal to 6%
- 3 KRW/kWh when the error was between 6% and 8%
- 0 KRW/kWh when the error exceeded 8%

These portions are paid in addition to the normal SMP and REC revenues such that operators and aggregators were effectively positioned to earn a forecast premium should their output prediction be accurate enough. In practice, participation in the forecasting scheme has been dominated by distributed solar portfolios and small-scale aggregators, making it a natural pre-stage for a VPP-type model. In its June 30, 2021 Distributed Energy Activation Promotion Strategy (MOTIE), the government outlined the introduction of a renewable generation forecasting scheme and a renewable bidding scheme, alongside real-time and ancillary service markets.

In June 2025, this scheme has tightened in line with the growing call for more effective renewable penetration. For solar resources, and with a one-year grace period for wind, the settlement thresholds moved tighter as outlined below:

- 4 KRW/kWh when the forecast error was less than or equal to 4%
- 3 KRW/kWh when the error was between 4% and 6%
- 0 KRW/kWh when the error exceeded 6%

The tightening of forecast accuracy will now essentially nudge aggregators and VPP operators to invest in more advanced forecasting models and portfolio control to gain a competitive advantage for higher margins.

3) Jeju's Renewable Bidding and Real-Time Market Pilot

Jeju's renewable bidding system began pilot operation in February 2024. In this pilot, renewables that meet certain technical and capacity thresholds can be registered as dispatchable renewables and bid into the day-ahead market much like conventional generators. Going beyond the incentivization of accurate forecasting, Jeju has also introduced an explicit imbalance penalty for these dispatchable renewables, which are penalties activated when the day-ahead output schedules submitted by operators deviate from the specified tolerance band.

All in all, for the Korean ESS industry, the rise of VPPs shifts the focus from supplying hardware to supplying software-based innovations. Essentially, batteries in a VPP are not installed only to reduce a single site's bill, but they must respond to dispatch instructions, deliver multiple services with clear performance guarantees and interface smoothly with the VPP's energy management software. This raises the value of advanced EMS, forecasting tools and cyber-secure communications, and favors players that can bundle cells, power conversion systems and software into an integrated offer. As Korea's power system leans more on renewables and storage, the competitive edge will lie in orchestrating distributed assets as one coherent resource, not merely in adding more megawatts of equipment.

6. Conclusion

Korea's power system is developing in accordance with the trend for electrification, higher electricity consumption stemming from data centers, renewable integration to the grid, and the ramp up of advanced technology industries. Coal use is winding down, and climate targets have been set with stronger commitments for the next decade. Nuclear, renewables, and storage will rise in importance, and the policy direction in the 11th Basic Plan makes it clear that battery storage is expected to cover an important part of the grid's flexibility gap.

Players in Korea's BESS value chain are swiftly moving to match the rising global and domestic demand surrounding BESS. Cell producers are scaling LFP lines for multi-hour storage, pack and BMS providers are tightening safety and diagnostics, PCS manufacturers are partnering with global players to enter mature markets, while domestic engineering, construction and operations and maintenance players are conducting more projects abroad.

The core message of this whitepaper is straightforward. Korea must expand its presence in the battery storage game not only in hardware but also in software. Consequently, the ability to continue leveraging its current industrial advantages in the next chapter of the energy infrastructure landscape will depend on whether the key players can successfully set reliable and software-defined electricity storage and deployment capacities at the core of their strengths. The Korean models and groundwork for DR and VPPs are set in stone, and the leaders will be those that stay a step ahead in innovatively advancing the discourses in the BESS software integration game.

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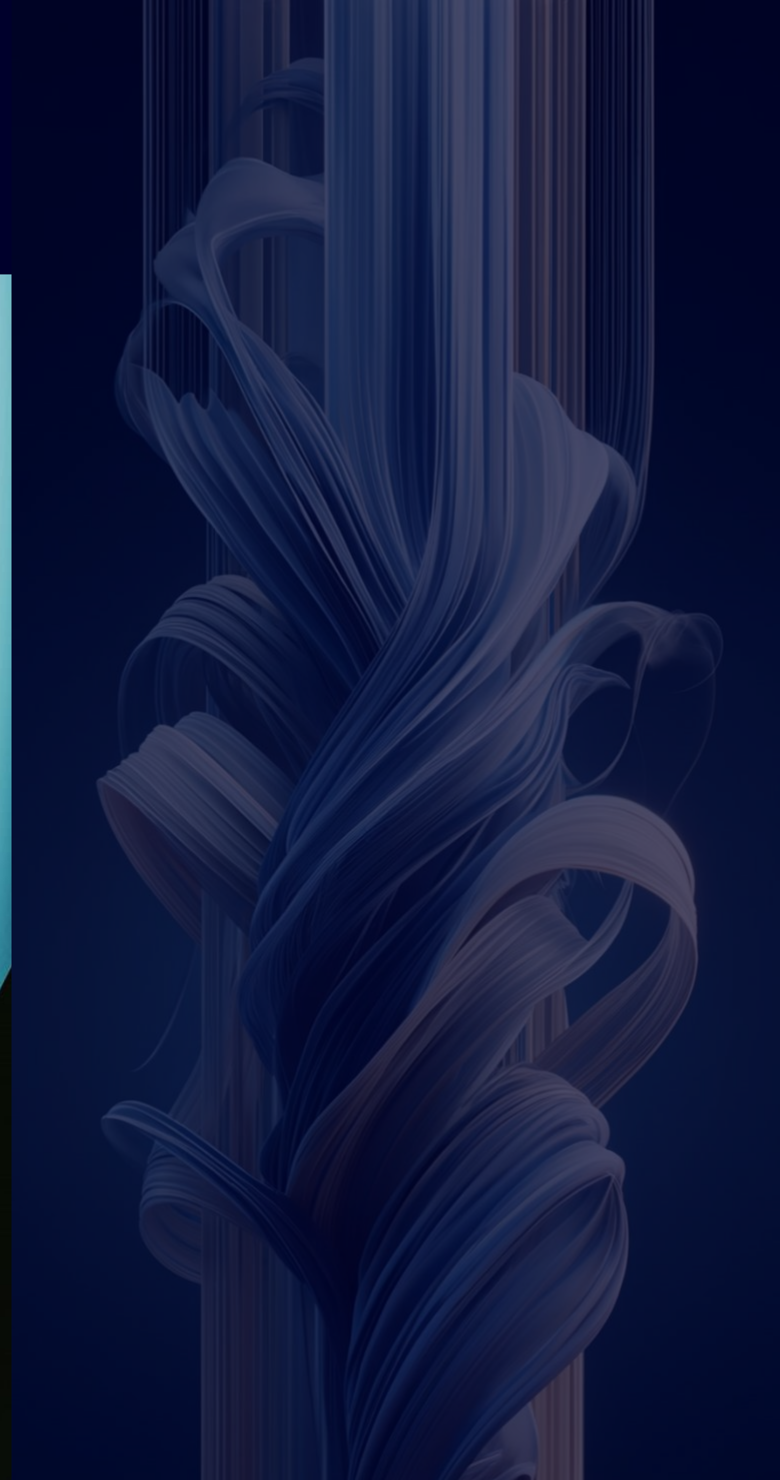

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