Driving Thailand's Power System Transformation: Unlocking the Potential of BESS

Final report summarising the key findings from the seminars and workshop, including recommendations for Thailand's power system planning

Partnerships to Accelerate the Global Energy Transition (PACT)
Thailand Component

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Registered Offices:
Bonn, Eschborn, Bangkok

193/63 Lake Rajada Office Complex, 16th Floor
New Ratchadapisek Road
Klongtoey, Bangkok 10110, Thailand

T +66 2 661 9273
Email: giz-thailand@giz.de

Project Description:
Partnerships to Accelerate the Global Energy Transition (PACT) – Thailand Component

Authors:

Dr. Eckehard Tröster, Energynautics

Editors:

Chatchanis Kasemwong, GIZ

Prin Kesapabutr, GIZ

Lars Allerheiligen, GIZ

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List of Abbreviations

Abbreviation	Definition
ACC	Annualised Cost of Capacity
BESS	Battery Energy Storage System
BMS	Battery Management System
BOOT	Build–Own–Operate–Transfer
BOS	Balance of System
CAPEX	Capital Expenditure
CAISO	California Independent System Operator
CCGT	Combined-Cycle Gas Turbine
EGAT	Electricity Generating Authority of Thailand
ENTEC	National Energy Technology Centre
EMS	Energy Management System
EPC	Engineering, Procurement and Construction
EPPO	Energy Policy and Planning Office
ERC	Energy Regulatory Commission
ESB	Enhanced Single Buyer
Ft	Fuel Adjustment Tariff
GWh	Gigawatt-hour
IBR	Inverter-Based Resource
IPP	Independent Power Producer
IAC	Integration and Controls
ITC	Investment Tax Credit
kW / kWh	Kilowatt / Kilowatt-hour
LCOS	Levelised Cost of Storage
LCOE	Levelised Cost of Energy
LNG	Liquefied Natural Gas
MEA	Metropolitan Electricity Authority
MW / MWh	Megawatt / Megawatt-hour
NMC / LFP	Nickel Manganese Cobalt / Lithium Iron Phosphate
OCGT	Open-Cycle Gas Turbine
PACT	Partnerships to Accelerate the Global Energy Transition
PEA	Provincial Electricity Authority
PHS	Pumped Hydro Storage
PDP2024	Power Development Plan 2024
PCS	Power Conversion System
PPA	Power Purchase Agreement
RoCoF	Rate of Change of Frequency
SOC / SOH	State of Charge / State of Health
VRE	Variable Renewable Energy

Executive Summary

Thailand's electricity sector is entering a decisive decade of transformation. As the country pursues the draft Power Development Plan 2024 (PDP2024) and its clean energy targets, the ability to integrate growing shares of variable renewable energy (VRE) will depend on the deployment of reliable, flexible, and cost-effective Battery Energy Storage Systems (BESS). This report provides a comprehensive assessment of BESS technologies, costs, applications, safety considerations, and business models, alongside tailored recommendations for Thailand's regulatory and system context. It draws on global experience, expert consultations, and the outcomes of stakeholder workshops conducted through the Partnerships to Accelerate the Global Energy Transition (PACT) project and with support from GET.transform's Leveraged Partnerships.

The Role of BESS in Thailand's Power System Transformation

Battery storage is no longer a peripheral technology—it has become a critical enabler of secure and affordable clean energy systems worldwide. In Thailand, BESS can play a pivotal role in maintaining system stability, supporting frequency and voltage control, managing congestion, and providing evening peak capacity as the share of renewables generation expands. The growing need for synthetic inertia and grid-forming capabilities underscores the importance of strategically sited, utility-scale BESS to safeguard reliability while advancing decarbonisation.

Two deployment pathways are central to Thailand's strategy: (1) network-sited, centrally dispatched BESS located at substations, and (2) hybrid PV+BESS systems co-located with renewable generation. While hybrid projects are suitable for firming renewable output, their flexibility is limited by generation constraints. In contrast, network-sited BESS—owned and operated by the system operator—can provide multiple stacked services, optimise dispatch, and relieve transmission bottlenecks. This approach aligns with Thailand's Enhanced Single Buyer (ESB) market structure and current regulatory framework, where EGAT, PEA, and MEA retain primary responsibility for system security.

Technical and Economic Context

The report reviews global cost and market trends showing a steady decline in BESS costs, now averaging around USD 115/kWh for Li-ion cells. technological advancements, economies of scale, and supply-chain maturity are driving competitiveness, with new chemistries such as sodium-ion and solid-state batteries emerging for specific use cases. Safety performance has also improved significantly, supported by stricter international standards and advanced monitoring systems.

For Thailand, economic analysis indicates that BESS can lower system operating costs and reduce tariff sensitivity to LNG price volatility by enabling energy shifting from midday solar surpluses to evening demand peaks. Over time, PV+BESS will achieve cost parity with gas-fired generation during peak hours, unlocking a sustainable pathway to lower-carbon, lower-cost electricity.

Recommendations and Roadmap

The report outlines a phased roadmap aligned with the draft PDP2024, designed to build technical capacity, manage risks, and scale investments progressively:

- **Phase 1 (2026–2028): Setting the Foundation**

  Finalize technical specifications for network-sited BESS covering grid-forming capability, communications, protection, fire safety, and state-of-charge readiness. Conduct a system-severity analysis to identify and prioritise substations and corridors based on inertia, fault levels, congestion, and restoration needs. Procure and commission the first utility-owned pilot systems under EPC + LTSA arrangements with standardised measurement, verification, and settlement procedures.

- **Phase 2 (2029–2032): Scaling and Market Testing**

  Expand deployment to hybrid and centrally dispatched systems while introducing pilot auctions for third-party participation under clearly defined, performance-based contracts. Develop standardised templates for contracts, settlements, and tariff impact assessments to ensure least-total-system-cost outcomes and protect end-users under the single-tariff framework.

- **Phase 3 (2033–2037): Expansion and Optimisation**

  Scale investments where proven value is highest, refine locational procurement signals, and adjust PDP targets based on operational evidence. Prepare for gradual market evolution towards competitive tenders and open participation of storage assets in system services.

This staged approach lowers investment risk, strengthens institutional experience, and allows for adaptive policy evolution as technologies mature and costs decline.

Outlook and Strategic Value

Implementing this roadmap will enable Thailand to stabilize electricity tariffs, reduce fuel dependency, and increase renewable integration while maintaining grid reliability. Early investment in system-critical BESS assets will also provide the foundation for future private-sector participation under clear technical and contractual frameworks.

Beyond system benefits, Thailand's BESS rollout can foster domestic industrial development, skills growth, and regional leadership in clean energy integration. The recommendations in this report therefore represent not only a technical pathway but a strategic opportunity to accelerate Thailand's clean energy transition—ensuring a resilient, modern, and affordable power system for the coming decades.

1 Introduction and Contextual Background

Creating a Thailand BESS strategy requires identifying the benefits of BESS by providing in-depth capacity building on the implementation, economics, safety, and regulatory considerations associated with BESS deployment in Thailand. A series of workshops were organised in collaboration with the Partnerships to Accelerate the Global Energy Transition (PACT) project and with support from GET.transform's Leveraged Partnerships, bringing together representatives from key Thai energy institutions including the Energy Policy and Planning Office (EPPO), Energy Regulatory Commission (ERC), Electricity Generating Authority of Thailand (EGAT), Provincial Electricity Authority (PEA) and the National Energy Technology Centre (ENTEC), to exchange insights on the evolving role of BESS in ensuring power system flexibility and reliability. These workshops served as a knowledge-sharing platform for disseminating international best practices and aligning stakeholder understanding with global technical standards and market developments for Thailand's grid conditions.

International experiences shared during the workshops underscore the critical importance of integrated policy, technical standards, and performance-based investment models in fostering sustainable BESS markets. This report consolidates the findings of these technical exchanges to offer a structured analysis and strategic guidance tailored to Thailand's evolving energy transition framework.

Battery Energy Storage Systems (BESS) have emerged as a pivotal energy storage technology enabling higher shares of variable renewable energy (VRE), reducing curtailment, and enhancing system flexibility. Global battery developments by market share have changed drastically over the past five years, as shown in Figure 1. It is noticeable that BESS share of total battery deployments has doubled from 7% in 2020 to 15% in 2024, while EVs still dominate the battery market with around 72% share. Of the 15%, utility-scale accounted for over 85% of the BESS market in 2024, up from 62% in 2023 and is on track to overtake Pumped Hydro Storage (PHS) in power capacity, standing at ~180 GW in 2025.

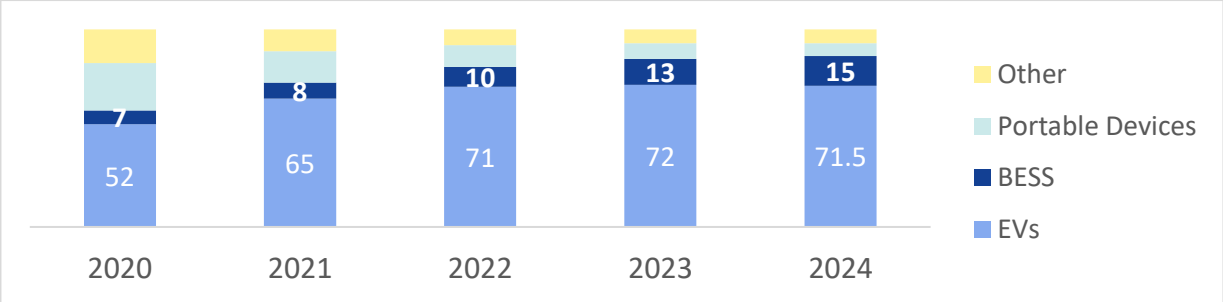


Figure 1: Global battery deployments by market share (%) from 2020 to 2024
(source: *Volta Foundation Battery Report 2024*)

Figure 2 below shows the growth of global BESS deployments from 2020 for power and energy capacity. 2024 saw a substantial increase of 76% in global battery storage power capacity and an increase of 87% in energy capacity. Additions continue to exceed expectations with 69 GW / 169 GWh of new BESS added and cumulative BESS reaching 159 GW / 363 GWh in 2024. Grid-scale BESS was the fastest growing energy technology in 2023 with 68% y-o-y growth with Li-ion batteries representing over 98% of utility-BESS installations in 2024. The main drivers for this growth were falling battery costs, government policy incentives, and increased availability of financial incentives for BESS.

There are many different battery energy storage technologies, but only lithium-ion has so far reached an advanced commercial stage. It offers a fundamental advantage over older battery chemistries (e.g. lead acid) and other alternatives owing to its much higher energy density, efficiency, and longer cycle life. There are several varieties of Li-ion batteries which continue to evolve as a result of research and development to improve energy densities, charging times, safety and lifetime use while cutting costs. The main chemistries are Lithium-Iron-Phosphate (LFP) and Nickel-Manganese-Cobalt (NMC). LFP

overtook NMC in 2021 as the leading BESS chemistry mainly due to improved safety and higher cycle life.

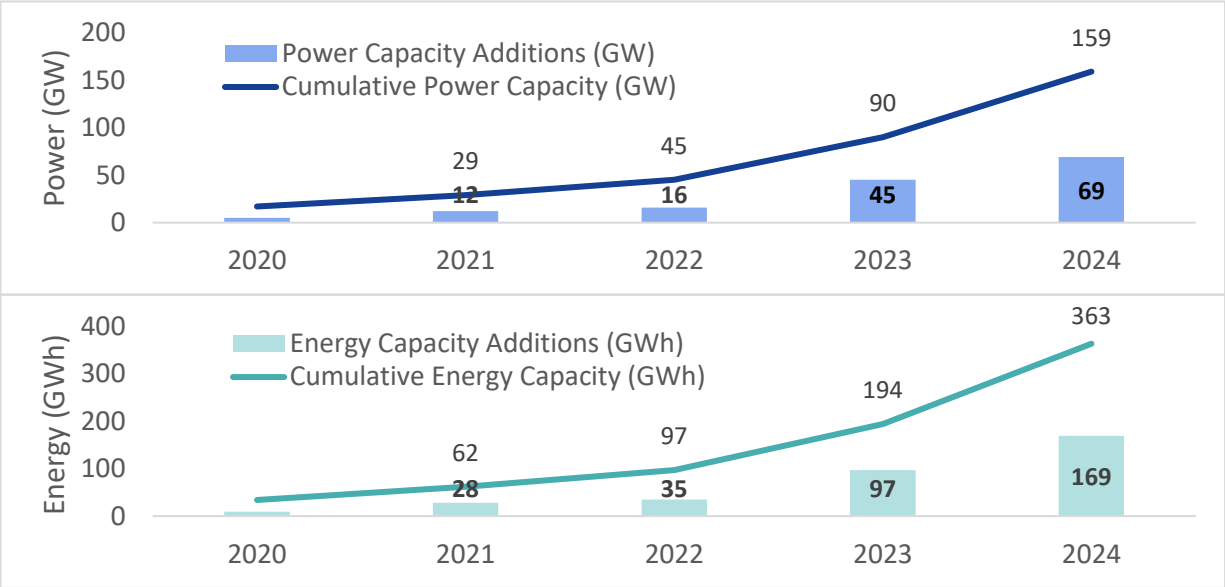


Figure 2: Global BESS deployment of power (blue) and energy (green) capacities from 2020 to 2024 (source: *ESS News*, *Volta Foundation Battery Report 2024*)

LFP accounted for over 80% of stationary BESS in 2024. Li-ion BESS is currently the most cost-effective for demand-supply matching ranging from seconds to 1 hour and for energy arbitrage applications (buy energy/charge when it is cheap and sell/discharge during higher-price periods). Currently Li-ion is only cost effective for storage durations below 6–8 hours while other battery storage technologies such as redox flow or iron-air favour longer storage durations covering days or weeks.

Though Li-ion is presently the dominant BESS technology, improvements in cost, safety and performance of competing chemistries and technologies may challenge lithium's dominant position. For example, sodium-ion (Na) is slowly gaining traction as an emerging battery chemistry particularly presenting lower power densities but not requiring any critical materials.

Battery storage is highly versatile and can provide a wide range of (>20) services across locations within the power system, covering generation, network (transmission and distribution), and consumption shown in Figure 3. As previously mentioned, front-of-the-meter (utility-scale) applications have been the main focus of recent deployments (in the red dotted line) and the main utility-scale applications are highlighted with a red outline. Due to increasing VRE integration and the small size of ancillary services markets, energy shifting and peak capacity are becoming the primary applications for utility-scale BESS since 2020, reaching ~85% of utility-scale capacity additions in 2023.

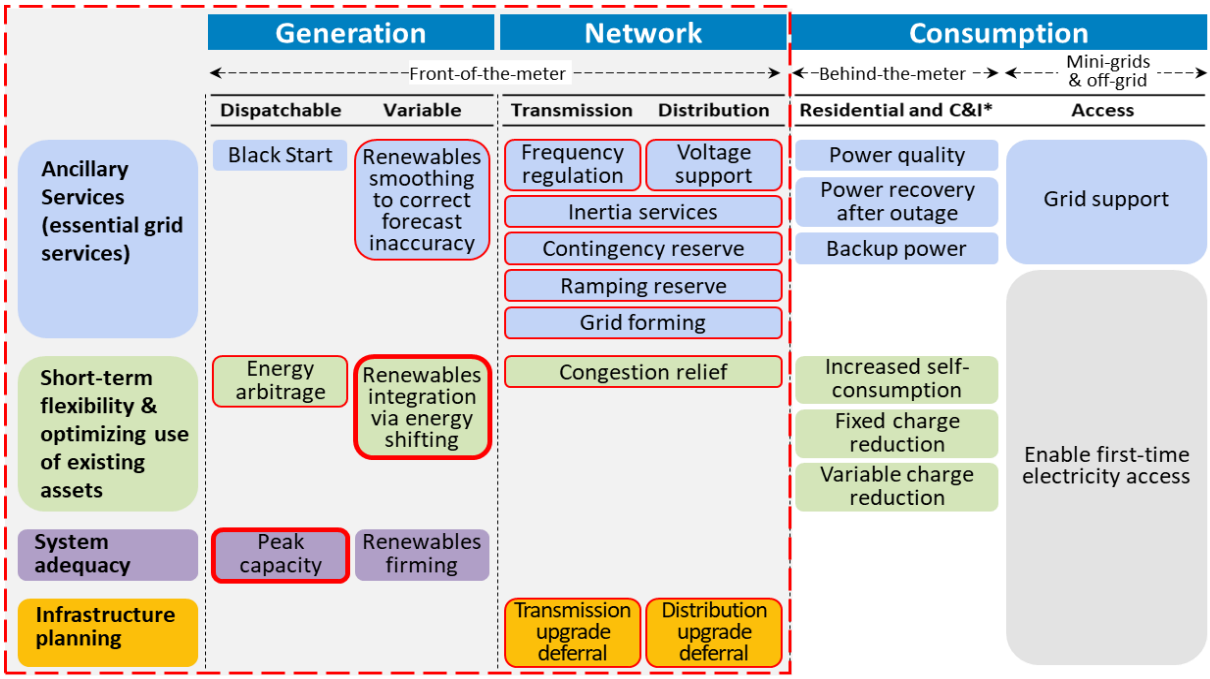


Figure 3: Overview of the 23 most common electricity storage applications along the location within a power system (source: *IEA – Batteries and Secure Energy Transitions*)

2 Technical Components and Layout of BESS

The specific designs and features in a BESS container can differ based on manufacturer choices, target applications and regulatory requirements. The core technical components are shown in Figure 4: 1. Battery cell (smallest energy storage unit), 2. battery pack/module (group of cells), 3. rack (group of packs/modules), 4. battery-management system (BMS), 5. sub-control box (controls individual packs/modules), 6. main control box or energy-management system (EMS), 7. Power-conversion system (PCS), 8. heating-ventilation-and-air-conditioning (HVAC) unit, 9. fire-suppression system (suppresses fire or thermal runaway), 10. off-gas detector (detects the release of gases).

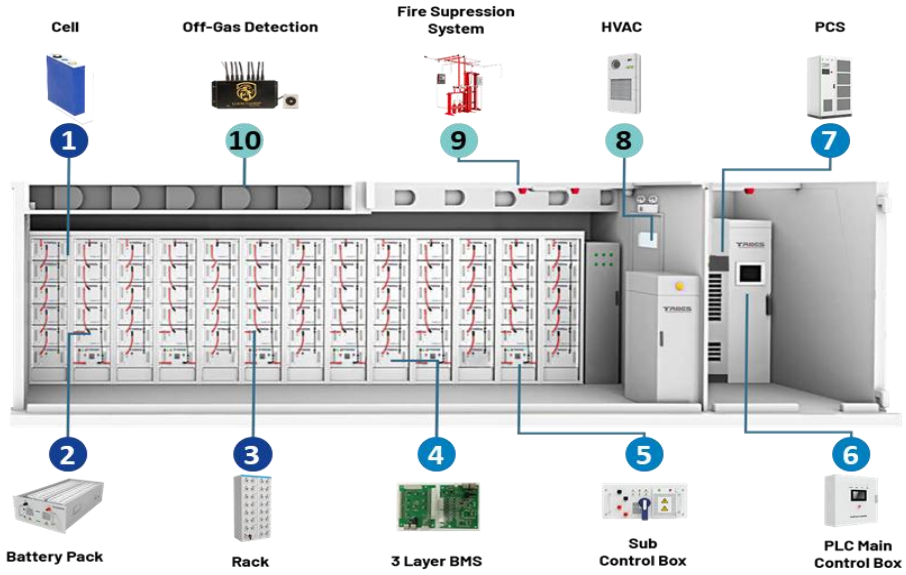


Figure 4: Ten core technical components of a containerized BESS
(source: *Accure*, *Power Sonic*, *Troes Corp*)

The major BESS components are the battery modules, the BMS, the PCS and the EMS as shown in Figure 5. The respective descriptions and functions of each are described in detail below.

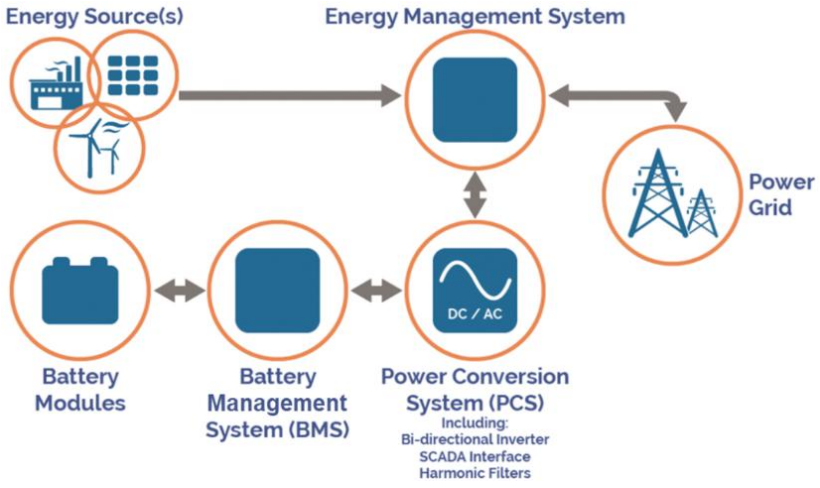


Figure 5: Simplified layout of BESS major components
(source: *TLS*)

The battery-management system (BMS) is a micro-processor-based subsystem that continuously monitors voltage, temperature, current, and state-of-charge at cell, pack, and rack levels. The specific functions of a BMS include: cell monitoring, cell balancing, protection and safety enforcement, thermal

management, state estimation, power-flow management, communications, fault logging, and embedded data analytics for predictive maintenance. BMS architecture has four topologies, namely centralised, modular, primary/subordinate, and distributed. Each topology has its advantages and disadvantages depending on different criteria such as scalability, redundancy, troubleshooting complexity, integration and cost. Predominant balancing method for BMS is active balancing which can be further split into capacitor-, inductor-, and converter-based subtypes for different applications.

The power-conversion system (PCS) is characterised as a bidirectional inverter that mediates DC/AC and AC/DC exchanges, synchronizes with grid voltage and frequency, supplies reactive power, filters harmonics to satisfy grid codes, manages semiconductor junction temperatures, and can operate in grid-forming mode to deliver synthetic inertia.

The energy-management system (EMS) is the overarching software-based control system of a BESS that coordinates all subsystems and optimises battery operation to maximise performance and revenue. It schedules charge and discharge, applies stochastic optimisation based on weather and load forecasts, stacks multiple revenue streams, enforces grid-code requirements, and logs operational data for diagnostics. Automated bidding routines are considered integral for participation in contemporary energy and ancillary-service markets.

3 Cost Trends and Value Chain Structure of BESS

The global market for Battery Energy Storage Systems (BESS) has experienced a rapid transformation, driven primarily by declining costs, maturing supply chains, and increasing deployment volumes. The main drivers for cost reduction are manufacturing overcapacity, economies of scale, low raw material costs, adoption of lower-cost LFP batteries and a slowdown in EV sales growth.

Data from BloombergNEF, Wood Mackenzie, and IEA, indicate that the cost of lithium-ion battery packs has declined by over 89% since 2010, reaching a weighted average of approximately USD 115/kWh in 2024, a record low. This has led to a significant cost reduction of battery enclosures + PCS reaching to an average of 165 USD/kWh in 2024 (excluding EPC and grid connection). Moreover, in China the cost for a BESS enclosure + PCS had an average price of 66 USD/kWh. The cost trends are shown in Figure 6 and Figure 7 for cells and modules, and enclosure with PCS, respectively.

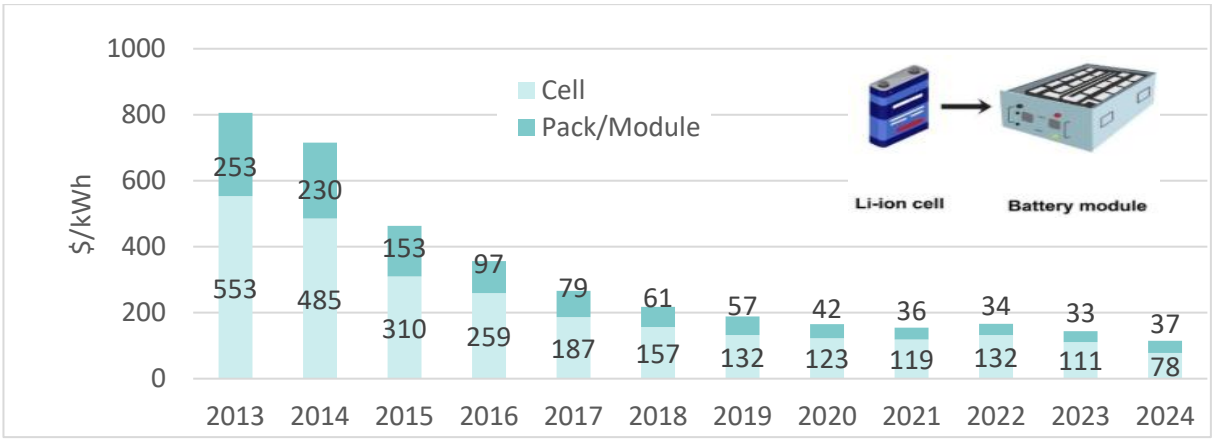


Figure 6: Li-ion battery cell and module prices from 2013-2024
(source: *BNEF*)

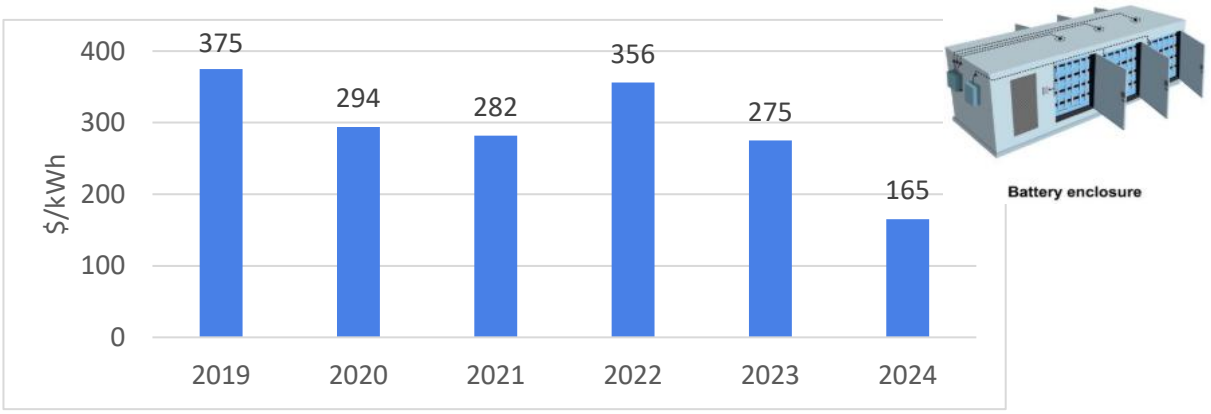
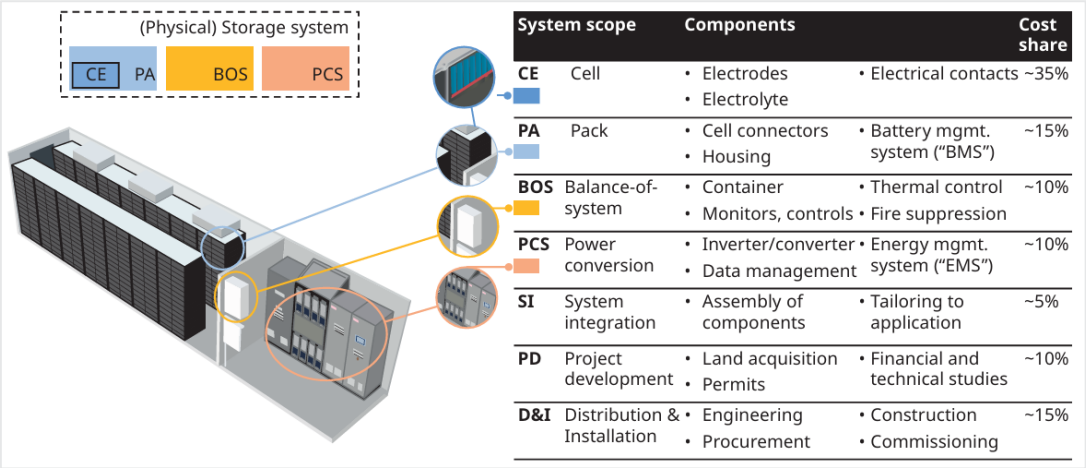


Figure 7: Cost of battery enclosure + PCS from 2019-2024
(source: *BNEF*)

A rough cost structure is illustrated in Figure 8, identifying major cost shares such as the battery cells and packs (~50%), balance-of-system (~10%), power conversion systems (~10%), system integration (~5%), project development (~10%), and distribution and installation (~15%). The costs for project development and distribution and installation are both highly location dependent and may vary significantly between projects. Among these, economies of scale, especially in PCS and BOS, have demonstrated the highest cost-saving potential, reinforcing the competitiveness of containerized modular systems. Supply chain convergence on 20-foot shipping container formats delivering >5 MWh has further enabled streamlined logistics, optimised storage density, and simplified site deployment.



System scope		Components		Cost share
CE	Cell	• Electrodes • Electrolyte	• Electrical contacts	~35%
PA	Pack	• Cell connectors • Housing	• Battery mgmt. system ("BMS")	~15%
BOS	Balance-of-system	• Container • Monitors, controls	• Thermal control • Fire suppression	~10%
PCS	Power conversion	• Inverter/converter • Data management	• Energy mgmt. system ("EMS")	~10%
SI	System integration	• Assembly of components	• Tailoring to application	~5%
PD	Project development	• Land acquisition • Permits	• Financial and technical studies	~10%
D&I	Distribution & Installation	• Engineering • Procurement	• Construction • Commissioning	~15%

Figure 8: Approximate cost shares of containerized BESS scopes
(source: Monetizing Energy Storage)

The above cost structure only represents investments costs and does not determine the commercial viability of a BESS project as it requires a lifetime cost assessment.

The Levelised Cost of Storage (LCOS) serves as a key metric in evaluating economic feasibility by dividing lifetime incurred costs by cumulative delivered electricity (USD/MWh). It is sensitive to several factors including lifetime, usage cycles, round-trip efficiency, and energy capacity. LCOS varies considerably by use case with frequency regulation and peaking applications typically yielding higher returns than arbitrage or capacity deferral services, particularly in immature markets with limited ancillary revenue streams. Another lifetime cost assessment is the Annuitised Capacity Cost (ACC) which is similar to LCOS but instead divides lifetime incurred costs by power capacity and lifetime (USD/kW-year). Figure 9 displays LCOS and ACC US data on a 100 MW project with and without Inflation Reduction Act (IRA) grants.

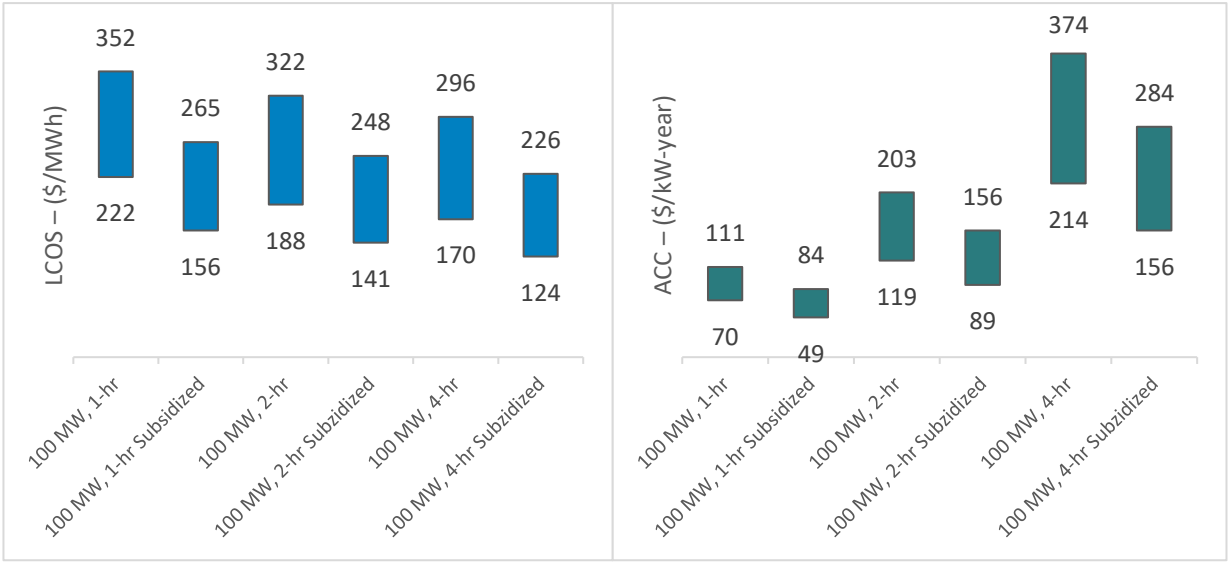


Figure 9: LCOS for 100MW project with 1,2,4-hr durations and IRA subsidies (left) and ACC for 100MW project with 1,2,4-hr durations and IRA subsidies (right)
(source: Lazard 9.0)

Investment models indicate that BESS viability is tightly coupled with capital cost reduction, tax credits, and capacity payments. In the US, for example, the IRA has enabled standalone BESS projects to benefit from up to 30% Investment Tax Credit (ITC), which greatly enhances project economics.

4 Use Cases, Market Considerations and Business Models

As previously mentioned in Chapter 1, BESS use cases vary considerably and can play multiple roles in power systems. The energy transition is causing power systems to shift from a traditional system based on thermal power plants' synchronous generators to an emerging system based on high shares of variable renewable energy (VRE). The increasing shares of VRE sources are introducing new challenges to the power system such as reduced inertia, higher voltage fluctuations, and increased grid congestion. These challenges and others are driving the need for additional BESS to balance the system and mitigate inverter-based impacts.

4.1 Use Cases

Some use cases that BESS offer in response to the mentioned challenges are outlined below:

1. **Frequency regulation**
    - BESS absorbs or injects active power in seconds to counteract deviations from nominal grid frequency, enabling higher VRE shares without compromising reliability
2. **Grid Forming / Inertia Services**
    - Fast and highly controllable capabilities of inverters make it possible for BESS to emulate inertia
    - BESS in grid forming mode provides "synthetic inertia", dampening Rate-of-Change-of-Frequency (RoCoF) and stabilising frequency
    - Grid forming BESS inverters autonomously create and regulate their own AC voltage waveforms enabling them to operate without an external grid reference support
3. **Congestion relief**
    - BESS installed at bottlenecks absorbs local congestion, deferring network upgrades and reducing congestion costs
4. **Energy Arbitrage/Shifting**
    - BESS charges during low-price periods and discharges at high-price peaks, capturing difference margin and flattening load curves
5. **Peak Capacity Shifting**
    - BESS stores midday excess and discharges during evening peak, reducing peak load and deferring costly generation or network upgrades

4.2 European Market Conditions and Emerging Economies

The type of BESS use case is dependent on the availability of attractive markets which create the decisive opportunity for developing viable business models. An attractive market depends on the existence of clear regulatory frameworks, beneficial tariffs and pricing, open market access, an streamlined permitting and grid connection. These four criteria vary by country and across the different available markets within that country. Figure 10 depicts the eligibility of utility scale BESS across major countries based on their type of use. While focuses on the market criteria of the three most attractive markets in Europe: United Kingdom, Germany, and Italy as shown in Table 1.

Figure 10: Utility-scale BESS eligibility by country
(source: *IEA – Batteries and Secure Energy Transitions*)

Table 1: BESS market criteria of United Kingdom, Germany, and Italy
(source: GOV.UK, Baker Mckenzie, Timera Energy, Bundesnetzagentur, Lexology)

	United Kingdom	Germany	Italy
Regulatory Frameworks	Defined legal classifications for storage assets enable smoother licensing and market entry	Strong policy initiatives and updated grid codes support BESS participation in ancillary services and market operations	Recent reforms encourage integration of storage through tailored incentives and pilot projects
Tariff and Pricing	Efforts to eliminate or reduce double charging on grid tariffs cut costs	Progressive tariff schemes reward dynamic performance (e.g., load shifting and frequency regulation) and offer better market signals	
Market Access	BESS operators can access ancillary services and capacity markets more readily	Improved market mechanisms enable BESS to contribute effectively to grid balancing and energy arbitrage	Successful BESS integration into competitive procurement processes and local flexibility markets
Permitting and Grid Connection	Streamlined interconnection and permitting procedures compared to many emerging markets, reducing project delays and uncertainty		

BESS is also starting to play a bigger role in emerging economies where adoption is accelerating due to policy incentives and investment momentum. Experience from the Philippines shows that formal ancillary service frameworks and a reserve market facilitate bankable revenues for storage. Frequency regulation procurement through the Ancillary Services Procurement Agreement and Reserve Market provides clear pathways for batteries to be paid for response accuracy and availability (ngcp.ph). South Africa is emerging as Africa's continental leader in utility-scale BESS, with the main driver being Eskom's requirement for fast-response storage to mitigate load shedding during peak demand and support VRE integration for grid stability. South Africa's Eskom programme demonstrates multi-site storage deployment for peak shaving and grid support across constrained nodes, with Phase 1 and Phase 2 totalling 343 MW and 1,440 MWh (eskom.co.za, Energy-Storage.News). India's BESS growth is

driven by the urgent need to integrate 500 GW of renewable energy by 2030, ensure grid stability, and manage peak demand. Furthermore, India's central auctions for 1,000 MW and 2,000 MWh provide a template for long-term contracts that can reduce revenue volatility and unlock lower financing costs, with recent tariff outcomes signalling improving competitiveness (seci.co.in, SolarQuarter). Vietnam's pilots illustrate a pathway from small retrofits to programme-level scale where curtailment mitigation and peak support are the initial priorities (energyalliance.org, sia.net.tw).

These case studies are relevant to Thailand because they combine regulated procurement for system services with limited merchant exposure, a similar starting point for market design and utility ownership, and a thermal-dominant generation mix.

4.3 Revenue Stacking

BESS generates value through various service applications across wholesale, retail, ancillary, and capacity markets. The monetisation of BESS depends on local market design, policy incentives, and operational optimisation. In mature markets where regulations allow, 'revenue stacking' models can be adopted in which multiple applications, such as frequency regulation, energy arbitrage, and capacity provision, are delivered from a single asset to hedge against single long-term contracts.

These hybrid models are designed to improve project bankability and mitigate volatility in any one revenue stream. However, revenue stacking requires a more complex EMS as it increases the complexity of the business case and makes the prediction of revenues irregular. Furthermore, the increased dispatch frequency from revenue stacking can accelerate asset degradation.

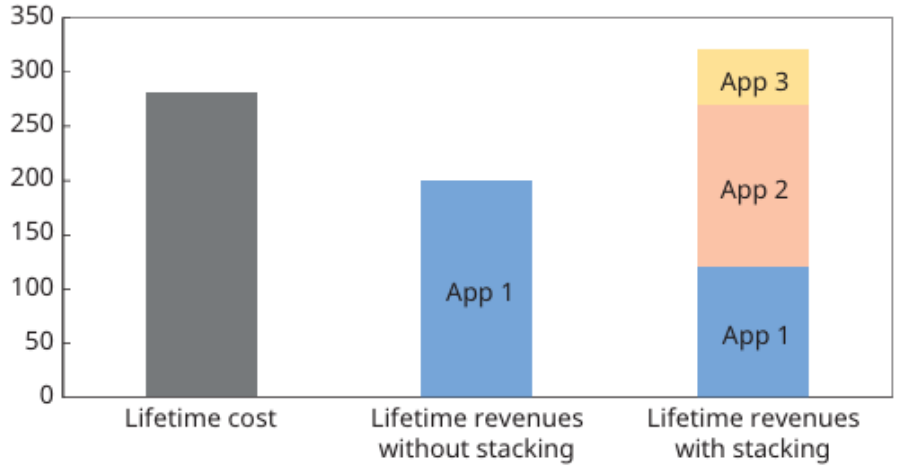


Figure 11: Conceptual depiction of revenue stacking
(source: *Monetizing Energy Storage*)

Four different strategies for revenue stacking are described and shown in Figure 12:

- **Sequential stacking**: The same power capacity is provided to different applications in different time periods
- **Sequential stacking in opposite directions**: Similar to sequential stacking but covering periods of both charging and discharging
- **Parallel stacking**: Power capacity is separated into individual parts that serve different applications simultaneously
- **Dynamic/overlapped stacking**: The same power capacity is provided to multiple applications at the same time

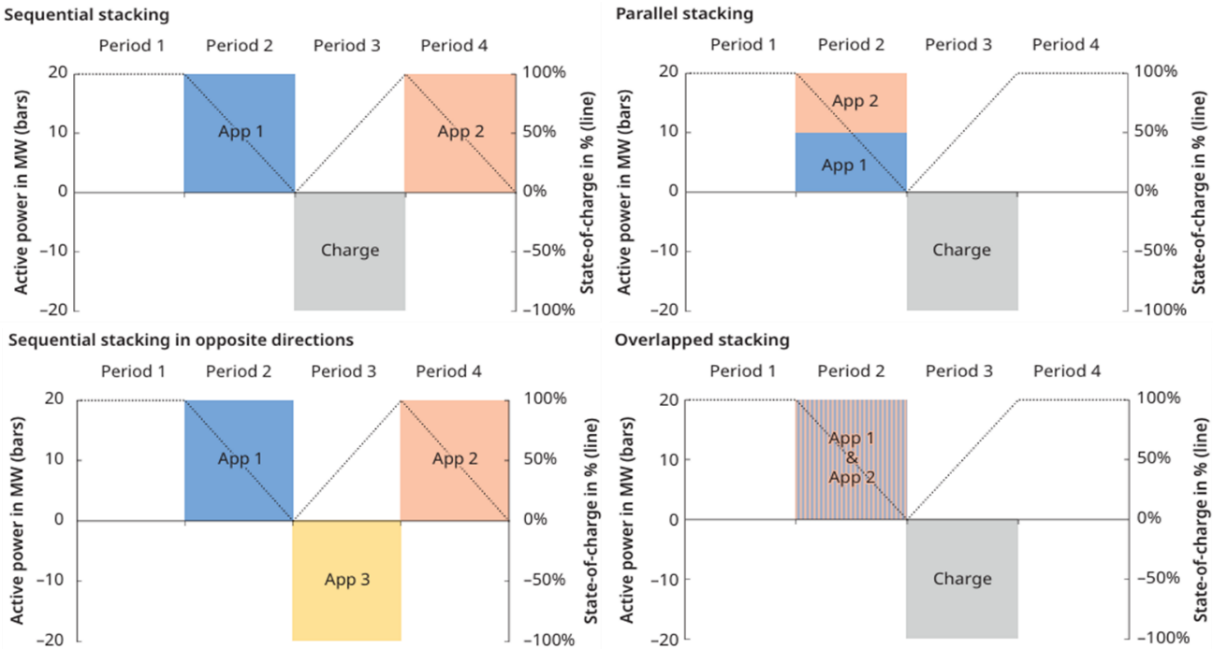


Figure 12: Revenue stacking strategies for BESS
(source: *Monetizing Energy Storage*)

Some key characteristics should be taken into consideration before providing revenue stacking services. These include technology capability, lifetime and system degradation, contractual timelines, regulatory rules, counterparties influence, and grid connection level.

Under Thailand's Enhanced Single Buyer (ESB) power sector structure, contracting developers to deliver a full suite of useful BESS functions at a reasonable tariff can be challenging. A small pilot auction for utility-scale BESS, with defined service specifications and performance metrics, can be used to assess market interest and price levels prior to a wider roll-out.

4.4 Business Models

In relation to revenue stacking, BESS services can be acquired through different business models. These range from contract-driven models based on a third-party supplying services to a utility that doesn't own the BESS, to merchant-driven models where a developer bids in a national energy market competing with other BESS projects. Another business model involves a utility-owned BESS where a system operator or utility invests in, owns, and operates the BESS, enabling full operational flexibility to support system needs. The decision depends on several factors such as financial goals, risk tolerance, market regulations, market conditions, location, operating strategy, and project size. However, most BESS projects in 2024 used a combination of contract and merchant-driven business models by providing multiple applications (revenue stacking). Table 2 contrasts the difference between the three business models.

Table 2: Business model comparison for utility-scale BESS
(amended from *Volta Foundation Battery Report 2024*)

Mechanism	Contract-Driven (Third-party)	Utility-Owned (System Operator)	Merchant-Driven (Developer)
Revenue Stability	Predictable income: long-term service agreements with fixed rates	High: cost recovery via tariffs or internal budgeting	Variable income: earnings depend on market fluctuations
Market Exposure	Limited exposure to price volatility	Minimal exposure with dispatch guided by system needs rather than prices	Full exposure to market dynamics and prices
Risk Level	Low risk with guaranteed payments	Low risk: asset and performance risk sit with the utility	High risk due to unpredictable market fluctuations
Profit Potential	Consistent but lower returns	Value realized via cost avoidance and reliability (not profit-oriented)	Potentially higher profits during favourable conditions
Key Revenue Streams	Tolling (fixed payments), Capacity, Energy Hedging	Avoided congestion/redispatch, reliability and resilience, ancillary services	Energy markets, Capacity Auctions, Ancillary Services
Investor Profile	Risk-averse investors prioritising stability	Utilities/system operators prioritising security flexibility, and standards	Investors with higher risk tolerance seeking higher returns

Considering that Thailand doesn't have a national energy market, a purely merchant-driven model isn't applicable. However, contract-driven and utility-owned models can both play an important role especially in early market phases such as Thailand. When the market is not yet fully developed, BESS assets directly controlled by the utility/system operator enable timely and flexible dispatch to address system emergencies, such as stability issues or transmission congestion, without delays from procurement processes. Relying solely on private procurement of ancillary services may not ensure the availability of all critical services while maintaining a proportion of utility-owned BESS helps guarantee essential system security services are consistently available. Moreover, direct investment and operation by the utility establishes a national benchmark for technical standards, operational practices, and cost structures. This can strengthen regulatory frameworks and encourages private sector participation over time as the market grows and matures. Therefore, both contract-driven and utility-owned models can balance the promotion of private roles with the utility's core responsibility of safeguarding overall power system security and to operate BESS assets flexibly according to grid requirements.

4.5 Contract Structures

Contract structure refers the specific commercial and legal design used to buy BESS capacity and services. It sets out who owns and operates the asset, who holds dispatch rights, where the BESS is sited, what services are being bought, how charging energy is sourced and metered, how payments are made (capacity/availability, performance bonuses/penalties), and how risks and responsibilities are shared. The contract-driven business model generally follows a competitive bidding procedure by a utility for third-party developers. The third-party BESS model will involve a BESS developer with whom the utility will enter a long-term contract for the storage capacity or services. The utility is responsible for paying fixed or variable charges to the third-party and scheduling a dispatch from BESS as per the operational requirements. The third-party developer is responsible for procurement, construction and other related installation works, operation and maintenance of BESS for its overall useful life from date of commissioning, and operation of BESS as per the dispatch schedule given by the utility. The revenue

streams for a third-party ownership model depend on the type of contract. Although there are various discrepancies in contractual agreements, the following are most commonly used structures:

1. **Tolling Agreement**
    a. Developer is responsible for developing, operating, maintaining, and owning the BESS
    b. The utility shall pay the developer a **fixed capacity charge** for its right to use the battery's capacity and a **variable operating charge for dispatching the energy**
    c. The developer does not bear the cost of the electrical energy input
2. **Capacity-based agreement**
    a. Only the capacity and capacity attributes of the BESS will be sold to the utility
    b. The utility shall pay the developer **a monthly capacity charge** but no variable or energy charge and has the assurance that capacity is available when it's needed
    c. The developer is responsible for the sale of energy and all costs associated, including the costs of the required energy procured from the utility
3. **Build-Own-Operate-Transfer (BOOT) agreement**
    a. The developer is responsible for developing, owning, operating and maintaining the BESS, **similar to the tolling agreement**
    b. Unlike a tolling agreement, however, **once the project achieves commercial operation, the developer sells the project to the utility**
    c. This provides the utility with long-term ownership but without the risks inherent in project development and construction
4. **Hybrid Power Purchase Agreement (PPA)**
    a. Developer installs and operates RE + BESS (typically co-located)
    b. Developer controls the BESS discharge/charge, respecting PPA conditions **but is free to use any surplus/deficit for other services**
    c. Revenue stacking from PPA with utility and energy market revenues

A simplified schematic of third-party ownership is depicted in Figure 13 below:

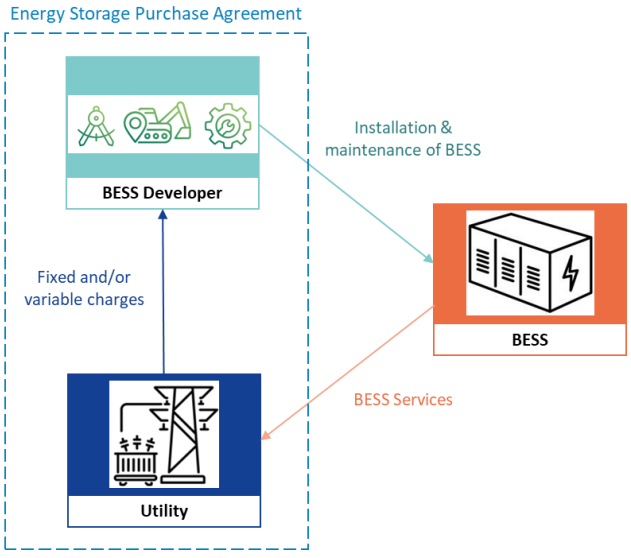


Figure 13: General model of third-party ownership for BESS (source: Energynautics GmbH)

4.6 Thailand Relevant Applications

The potential applications of BESS in Thailand extend well beyond generic grid services. In the Thai power system, BESS can provide frequency and voltage regulation, primary reserves, congestion

management, energy arbitrage, and peak shaving services which are critical to accommodate growing shares of solar PV. A particularly important role is grid-forming operation, where inverter-based resources (IBR) provide synthetic inertia and instantaneous voltage support. These functions would be essential for managing reduced inertia and system stability under Thailand's draft PDP2024 renewable expansion.

Thailand's power system remains centrally coordinated with a single-buyer backbone and regulated tariffs overseen by the Energy Regulatory Commission (ERC). The ERC launched the 'ERC Sandbox' in 2019 which operates as a proof-of-concept program that provides a controlled environment where companies can test and pilot their innovations with temporary regulatory flexibility, under the supervision of the ERC. The ERC Sandbox includes projects which do not generate commercial profit, and which are focused on the following areas of innovation: REC trading platforms, smart grids, innovative forms of PPAs (Virtual PPA, Sleeved PPA), Green Innovation and Green Regulation. Under this framework, EGAT is testing additional BESS functions at its own substation with the scope being of a purely technical nature.

Implementation to date includes grid-scale, standalone BESS pilots at EGAT's Bamnet Narong (16 MW/16 MWh) and Chai Badan (21 MW/21 MWh) substations. These projects target renewable energy management and transmission congestion relief and are located at substations rather than co-located with power plants. In parallel, system security services are presently delivered by the three public utilities, namely EGAT, PEA, and MEA. No BESS auction has been held so far due to the current market structure (no ancillary services market). One contract-driven example exists under PEA supervision: a BESS at PEA's Samui Island substation operated by PEA ENCOM to defer submarine cable expansion while covering rising peak demand.

For hybrid PV+BESS, the Partial-Firm initiative launched by ERC is a pilot designed to test approaches that mitigate renewable variability. The BESS units deployed under this pilot are relatively small compared with contracted daily energy volumes, and operational flexibility is constrained by the contract; the system operator addresses residual variability with other equipment. Looking ahead, Thailand plans to expand grid-scale BESS at substations to manage fluctuations in a centralised manner. In this early phase, approaches that preserve maximum system-operator flexibility in BESS dispatch are prioritized. Given Thailand's ESB structure and the absence of an ancillary services market, the near-term BESS applications are those that directly support system security and grid operations. Priority uses include fast frequency response and frequency containment, voltage control and reactive support, congestion management, and evening peak shaving with limited energy shifting to integrate solar PV.

Delivery should therefore rely on system operator owned assets at substations, or regulated service arrangements with state utilities and their subsidiaries. However, while the hybrid PV+BESS partial-firm scheme remains a pilot with small batteries and constrained operating flexibility, aiming for large-scale batteries can provide further operational advantages such as efficient grid interconnection usage, firm renewable output, reduced curtailment and improved fast-frequency response. The main focus shifts to grid-scale BESS sited where they relieve constraints and potentially provide grid-forming capabilities.

Because it is difficult at present for Thai utilities to contract developers to deliver useful BESS functions at a reasonable tariff, a small pilot auction for utility-scale BESS with clear technical specifications and performance metrics could be used to assess market interest and price levels. The findings would inform tariff design, procurement rules, and the future scale-up of centrally dispatched storage. This approach aligns with current practice in which EGAT, PEA, and MEA retain operational control to deliver system security services without depending on a commercial market.

5 BESS Safety Analysis: Failures and Mitigation Strategies

Battery safety remains one of the most critical aspects of large-scale BESS deployment. Historical incidents, such as thermal runaway, fire propagation, and gas accumulation, have prompted the evolution of safety standards, integration protocols, and risk assessment practices.

The EPRI failure incident database contains several statistics revealing that overall BESS Li-ion safety has drastically improved over the years. A total of 81 incidents have occurred between 2018 and 2024 for Li-ion BESS. An incident is classified as any occurrence caused by a BESS system or component failure that results in increased safety risk; typically, a thermal risk such as a fire or explosion for Li-ion BESS. Global grid-scale battery storage deployment and failure statistics are shown in Figure 14. The overall failure rate, defined as the number of failure incidents divided by cumulative deployment in GWh, dropped by 98% from 2018 to 2024 (orange line). The sharp decrease is attributed to lessons learned from early failures that have been incorporated into the latest designs and best practices.

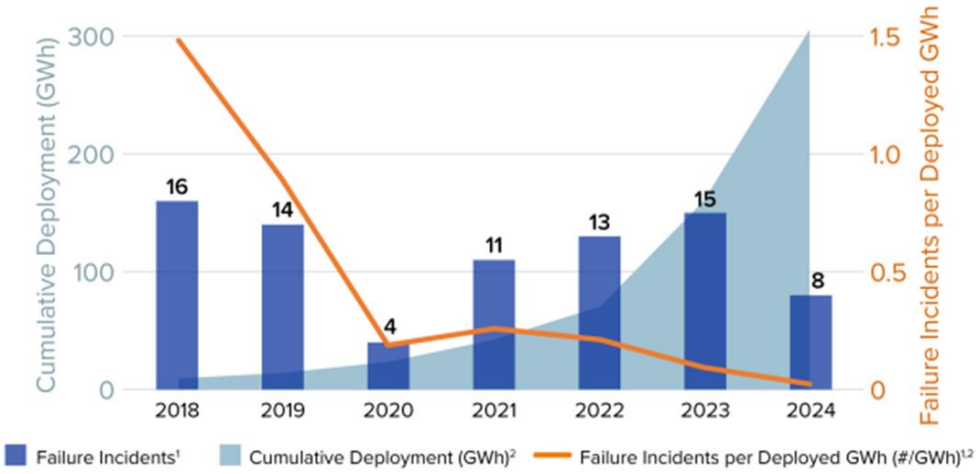


Figure 14: Global grid-scale battery storage deployment and failure statistics
(source: *EPRI Failure Incident Database*)

A detailed review of the incidents revealed several insights. Out of the 81 incidents that happened since 2018, only 26 have had their root cause identified, with 55 incidents having unknown root causes. This limited transparency on causes of failures arises because OEMs and BESS integrators are reluctant to disclose information about incidents with many reports being hidden from the public. In addition, legal complications also prevent site owners or manufacturers from revealing information on cause of failure. Figure 15 below displays how the majority (72%) of failures happen during construction, commissioning, or within the first two years of operation.

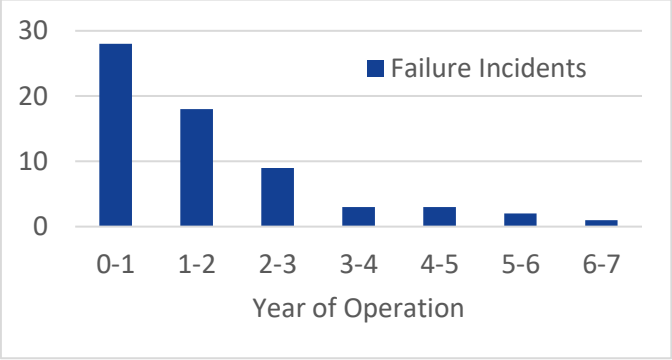


Figure 15: Li-ion failure incidents by year of operation
(source: *EPRI Failure Incident Database*)

The 26 known failure incidents can be classified by root cause and failed element. Root causes can be split into four failure types described below:

- **Design**: Failure due to planned architecture, layout, or functioning of the individual components or the energy storage system as a whole
- **Manufacturing**: Failure due to a defect from the manufacturing process, such as the addition of foreign material into cells, forming to incorrect physical tolerances, or missing or misassembled parts
- **Integration, Assembly & Construction (IAC)**: Failure due to poor integration, component incompatibility, incorrect installation of elements of an energy storage system or due to inadequate commissioning procedures
- **Operation**: Failure due to the charge, discharge, and rest behaviour of the system exceeding the design tolerances of an energy storage element or the system as a whole

Failed elements fall under three types described below:

- **Cells/Modules**: Failure originating in the cell or battery module, the basic functional unit of the energy storage system
- **Controls**: Failure in the sensing, logic circuits, and communication systems including the BMS, EMS, plant controllers, and any subsystems
- **Balance Of System (BOS)**: Failure in any of the other BESS elements including busbars, cabling, enclosures, PCS, transformers, fire suppression systems, HVAC, or liquid cooling systems

Figure 16 provides a detailed analysis of the trends for root causes (above) and failed elements (below). Two incidents were classified with dual root causes (Design and IAC), leading to the discrepancy of 28 instead of 26 incidents. IAC was the most common root cause of failure while BOS and controls account for most of the failed components. Many of the failures classified as controls were due to operational issues aimed at restricting cell state-of-charge (SOC) due to cell limitations.

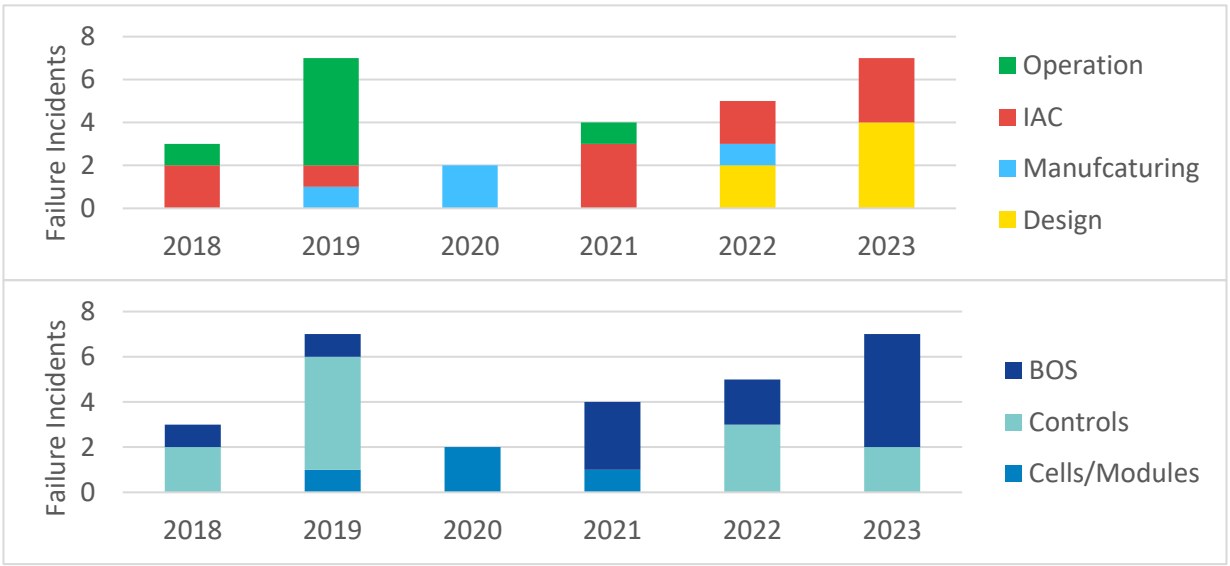


Figure 16: Trends for root causes (above) and failed elements (below)
(source: *EPRI Failure Incident Database*)

Bulk of operational failures occurred in 2018-2019 when many BESS in South Korea experienced fires because the battery SOC was higher than recommended limits (>90%). Most integration-related failures are due to poor BOS build quality with some failures occurring during the commissioning phase when monitoring & communications were offline, allowing leaks or failures to turn into fires. Most design failures are also BOS related (75% in 2023 caused by enclosure water leakage).

Preventative strategies emphasize multi-level fault detection, fire-retardant enclosures, gas extraction systems, and thermal isolation of battery racks. Advances in module-level BMS design and the inclusion of predictive analytics have shown promise in minimizing risk and improving incident response time. The inclusion of deflagration vents, temperature and off-gas sensors, and external emergency shutdown interfaces has been identified as minimum requirements for all commercial-scale installations. General mitigations for root causes include but are not limited to:

Design:

- Enforce compliance with the latest codes/standards that incorporate lessons learned from past failures
- Conduct site specific hazard assessments to consider all risks and failures
- Integrate robust sensing and monitoring to provide early alert for design failures

Manufacturing:

- Increase manufacturing quality controls
- Request supplier quality verification
- Guarantee robust system specifications
- Provide factory acceptance testing

Integration, Assembly and Construction:

- Incorporate workforce training and quality checks during commissioning and installation
- Conduct system-level failures analysis, especially for interfaces between components

Operation:

- Ensure battery monitoring and analytics supplement BMS operation, generating trends and predictive analyses to identify potential failures early on

The National Fire Chiefs Council (NFCC) in the UK and the Fire and Rescue NSW (FRNSW) in Australia have outlined some safety requirements when it comes to BESS unit distances and layout.

- The NFCC recommends BESS projects maintain **a minimum of 25 meters from occupied buildings to mitigate risks** from thermal events and facilitate emergency response.
- For distances between BESS containers, FRNSW guidelines state that BESS units must be segregated into clusters, with **each cluster not exceeding 50 meters in length on any side**.
- **A minimum of 1 meter should be maintained between containers**, particularly along sides with access panels or vents.
- For units **larger than 50 kWh or with less than 1 meter separation, UL9540A testing is required** to assess fire propagation risks.
- As for site layout, **BESS units should be at least 6 meters away from site boundaries, buildings, or other fire sources** to prevent fire spread.

It is crucial to advise that these requirements serve as guidelines only and that **a site-specific risk assessment should always be conducted to determine appropriate safety distances and protocols**. A site-specific risk assessment includes incorporating fire-rated barriers if standard separation distances cannot be maintained, adhering to safety codes such as NFPA 855 (US) for comprehensive safety measures, and ensuring clear access routes for firefighting and emergency services around BESS installations.

6 BESS Standards and Regulations

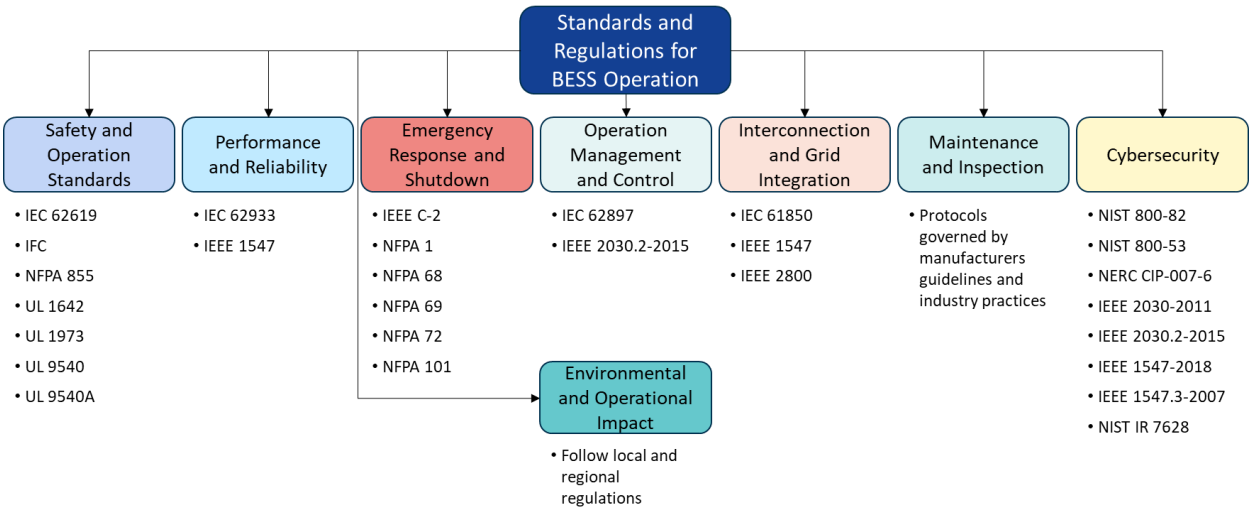


Figure 17: Standards and regulations for BESS operation
(source: *Sandia Energy Storage Safety*, *Underwriters Laboratories Standards & Engagement*)

Globally, standards and regulations are forming the backbone of safety and performance assurance for BESS projects. They cover best practices for design, testing, thermal runaway containment, fire detection, and emergency response protocols. Figure 17 outlines a non-exhaustive list of the major standard and regulations' codes split by category. Brief descriptions of the most common codes are outlined below:

Safety & Operation Standards

- *IEC 62619*: Defines safety tests for Li-ion cells and modules under abnormal conditions (overcharge, short-circuit, thermal stress)
- *NFPA 855*: Specifies siting, container separation, fire detection/suppression, and emergency-response planning for stationary energy storage
- *UL 9540A*: Requires thermal-runaway testing at cell, module, and system levels to assess fire-propagation risk and inform spacing or barrier design

Performance & Reliability

- *IEC 62933*: Establishes performance requirements and test methods for stationary battery systems (capacity, efficiency, life cycle)
- *IEEE 1547*: Sets inverter ride-through, anti-islanding, and voltage/frequency response requirements so BESS operates reliably when connected to the distribution grid
- *IEEE 2800:* Sets minimum technical requirements for the interconnection of large IBRs to the transmission grid (fault ride-through, reactive power support)

Emergency Response & Shutdown

- *IEEE C-2*: Provides guidelines for rapid de-energization protocols and safe shutdown procedures in substation and storage environments
- *NFPA 1 & NFPA 101*: Provide building- and fire-protection code requirements for egress, fire barriers, and occupancy safety when BESS units are installed and during a thermal or electrical event
- *NFPA 68*: Specifies how to design vent panels and ducts in BESS containers to relieve pressure safely if a cell undergoes thermal runaway
- *NFPA 69*: Provides guidance on preventing deflagrations in battery rooms by controlling ignition sources, ventilation, and gas detection
- *NFPA 70*: Establishes wiring methods, disconnect requirements, and safety signage specific to energy storage installations, ensuring safe access for first responders

- *NFPA 72*: Establishes requirements for alarm notification appliances, control equipment, and monitoring systems to alert responders to BESS fire or gas events

Operation Management & Control

- *IEC 62897*: Specifies requirements for energy management systems (EMS) in microgrids, including forecasting, scheduling, and supervisory control of BESS
- *IEEE 2030.2-2015*: Recommends best practices for monitoring and controlling distributed energy resources, ensuring BESS can follow dispatch signals and share health data with utility SCADA

Interconnection & Grid Integration

- *IEC 61850*: Standardises substation communications (logical nodes, messaging) to ensure seamless integration of BESS protection and control equipment
- *IEEE 1547*: Governs interconnection-level requirements (e.g., fault-ride-through, reactive power), ensuring the BESS can safely synchronize with the distribution grid
- *IEEE 2800:* Sets minimum technical requirements for the interconnection of large inverter-based resources (IBRs) to the transmission grid (fault ride-through, reactive power support).

Figure 18 portrays a graphical representation of where some of the different codes and standards are applied within a BESS container as an example.

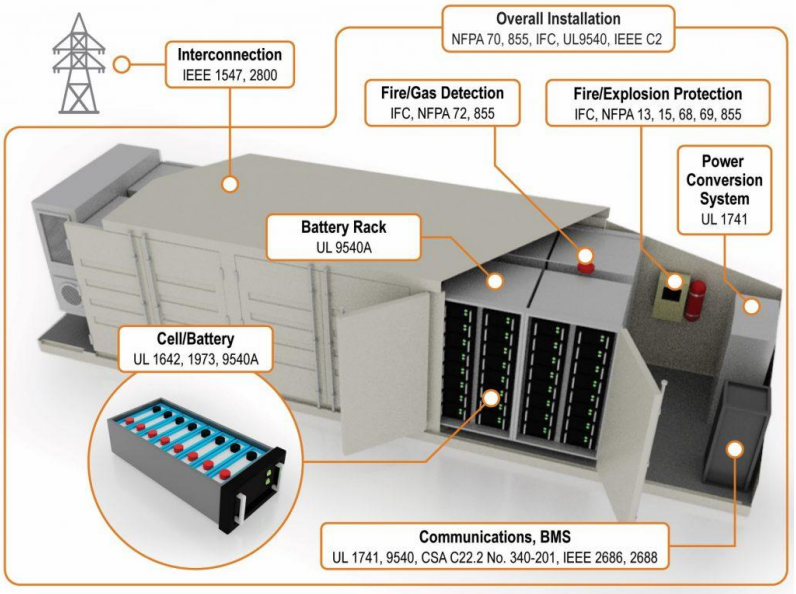


Figure 18: Example of BESS with key codes and standards
(source: *Sandia Energy Storage Safety*)

7 Future Topics and Technological Advancements

Emerging trends in the energy storage sector reflect a transition toward next-generation battery technologies, digitally enabled operation, and circular economy integration. These developments are poised to expand the role of BESS beyond traditional grid services, unlocking new applications across industrial decarbonisation, electric mobility, and data centre infrastructure.

With the rise of AI and data centres' substantial electricity consumption, major tech firms like Google, Apple and Meta are pushing the demand for BESS to reduce their carbon footprint and are committed to using only carbon-free energy by 2030. Furthermore, data centre's demand for uninterrupted power supply and increasing carbon neutrality commitments position them as natural partners for grid-connected or behind-the-meter BESS.

New battery technologies are shifting away from liquid and gel-based electrolytes. Solid-State Batteries (SSB) and Semi-Solid-State Batteries (SSSB) are emerging as next generation technologies for battery applications with multiple announcements targeting commercial readiness around 2027 to 2028 (Reuters). SSB and SSSB swap liquid electrolytes for solids to eliminate potential fire risk, extend battery lifespan and offer higher energy density (reaching 300–360 Wh/kg for SSSB) and safety.

Furthermore, new battery chemistries like sodium-ion (Na-ion) batteries are slowly rising as a key technological contender for Li-ion batteries due to their reliance on abundant materials, favourable thermal performance, and lower supply chain risks. Sodium-ion technology is accelerating with first grid-scale deployments announced in 2025 and commercial products launched for stationary applications (Energy-Storage.News). Although Na-ion systems currently exhibit lower energy density than Li-ion equivalents, their projected cost reductions and safety advantages make them suitable for stationary and high-cycling applications.

Another focal area is the utilisation of second-life electric vehicle (EV) batteries. Reuse of EV modules for stationary storage presents significant potential in terms of cost efficiency and environmental benefits. Repurposing retired EV packs for stationary storage can cut capital expenditure costs by 30–50% while still utilising 70–80% of the remaining battery capacity. However, challenges remain regarding warranty provisions, system integration, degradation characterization, and standardised testing protocols.

8 Recommendations

8.1 System Stability and Network Support: Frequency, Grid-Forming, Congestion, and Black Start

Fast-responding BESS can supply frequency regulation far more rapidly than conventional gas turbines, thereby enhancing grid stability while freeing thermal units for energy production or maintenance outages. Simulation and field studies have demonstrated that suitably sized batteries equipped with advanced power-conversion systems adhere to stringent frequency-response requirements and recover nominal frequency within the first few seconds of a disturbance; case studies in the Dominican Republic and Italy report frequency-deviation reductions of 30%–50% when BESS replaces conventional spinning reserve (ScienceDirect, ScienceDirect). CAISO data further confirm that batteries now deliver a significant share of regulation-up and regulation-down capacity, with response accuracy consistently exceeding that of thermal units (CAISO). Furthermore, in Germany primary reserve is now mainly delivered by BESS to stabilise grid frequency deviations, providing an essential service to the transmission system operator (TSO) (Gridcog). Replicating this service in Thailand would alleviate the need to run combined-cycle or open-cycle gas turbines at part load solely for contingency reserve, thereby cutting both fuel consumption and start-up emissions. A detailed study is recommended to accurately determine the fuel saving potential and assess the economic feasibility of BESS.

As inverter-based generation is expected to grow, short-circuit strength and inertia will decline. Additionally, sites with low short-circuit levels or retiring synchronous units further reduce system inertia and serve as strong candidates for the early grid-forming BESS deployments. Grid-forming inverters can support grid stability by providing inherent short circuit current and inertia. Regulations should therefore require grid forming capability of utility scale BESS.

Pilot siting should be based on a system severity analysis rather than a single use case. The analysis should rank substations and corridors using measurable indicators such as fault level, inertia shortfall, voltage excursions, congestion hours, renewable curtailment, restoration time after outages, and N-1 security gaps. Top-ranked severity locations then become candidates for pilots that address the dominant need at each site, whether voltage stability, system strength, black start, or congestion relief.

Furthermore, as PV capacity increases, congestion management at constrained substations becomes important to absorb midday surplus and discharge when capacity is free, which can defer network upgrades. Grid boosters currently being developed in Germany offer a practical example of how BESS is being used to manage congestion and optimise the power grid (Consentec).

8.2 Tailored Business Models and Procurement Pathways

For utility-scale BESS projects that provide system security services, direct ownership and operation by the system operator or utility provide maximum flexibility in deploying BESS to safeguard the power system. Delivery should follow EPC with LTSA and performance guarantees. Where private participation is considered, BOOT structures and availability-based contracts can be used for clearly defined services.

While private-sector participation can stimulate competition and innovation, potential impacts on electricity tariffs must be assessed carefully. Procurement should include tariff impact tests under the ESB and nationwide single-tariff structure, with evaluation based on least-total-system-cost and safeguards that prevent avoidable O&M and financing overheads from being passed on to end-users. Procurement documents should always include clear rules on dispatch rights, metering boundaries, curtailment treatment, state-of-charge readiness windows, and cost-sharing arrangements.

The contract structure, which outlines how BESS capacity and services are used, should also support early adopters such as data centres participating in the initial Third-Party Access pilot. Under the pilot, data centres procure renewable electricity and bear imbalance penalties payable to the system operator (EGAT) when deliveries deviate from schedule. BESS can reduce these penalties by smoothing renewable variability and providing frequency and voltage support. Suitable models include on-site or substation-sited BESS with firm evening blocks and defined response times, or tolling arrangements that give the system operator dispatch rights. Contracts should be clearly defined and include important details such as imbalance risk, performance baselines and verification, availability, ramp rate, and state-of-charge requirements that ensure the BESS is ready when needed.

8.3 Energy Shifting and Hybrid PV+BESS

Thailand's electricity system remains predominantly fuelled by natural gas; EGAT reported that gas-fired units supplied almost 60% of grid electricity in June 2025, while coal and imports contributed most of the remainder (EGAT). Because marginal prices on the Thai system are based on the marginal power plant (gas-fired plant), the system marginal cost is sensitive to international LNG prices, while retail tariffs are adjusted via the Fuel Adjustment Tariff (Ft) mechanism on a four-month cycle (Global Energy Monitor). By charging during periods of lower-cost generation (e.g., midday solar surplus) and discharging during early-evening peaks, utility-scale BESS can displace the highest-cost ramping gas units and flatten the system load curve. Experience from California shows that four-hour batteries are already being dispatched to deliver flexible-ramping and arbitrage services that suppress peak-hour prices and reduce gas-turbine cycling; CAISO's 2024 storage report attributes a measurable decline in evening net load ramps to 10 GW of operational batteries (CAISO).A comparable deployment in Thailand would be expected to lower the system's cost and reduce tariff sensitivity to LNG price spikes.

Two deployment models should be distinguished which are hybrid (PV+BESS) and standalone BESS. In a hybrid model, BESS are installed at a renewable plant to smooth that plant's output and deliver a more predictable profile. Hybrid plants can be scheduled through partial-firming PPAs to shift midday solar surplus energy to meet evening demand peaks. This would reduce the utilisation of the highest cost gas units during evening ramps and limit the number of thermal start-stop cycles.

In a centralised model, standalone BESS is sited at strategic grid locations, independent of generation plants. Dispatch is directed by the system operator to address system-wide needs across multiple renewable sources, including evening ramps, frequency response, voltage support, congestion relief and black-start readiness. For maximum operational flexibility under Thailand's ESB structure, a centralised approach provides the system operator with better utilisation of BESS assets and improved overall system performance. Short-term priority should be therefore given to centrally dispatched, grid-sited BESS that reduce system inefficiencies and support tariff stability through the Ft mechanism. For the medium-term, hybrid power plants with large-scale BESS (≥4 hours) can be introduced to further support the grid through better usage of existing infrastructure (interconnection points), reducing expensive fuel burn and start-stop cycles of highest-cost units, and provide further flexibility.

8.4 Draft PDP2024-aligned Roadmap and Competitiveness Outlook

8.4.1 Draft PDP2024-aligned Roadmap

The current draft Power Development Plan 2024 (PDP2024) raises the role of renewables and recognises the need for flexibility. PDP 2024 anticipates up to 10 GW of BESS paired with 35 GW of new renewable capacity by 2037, and nearly 1 GW of hybrid projects has already been awarded since 2022 (Asian Insiders).

The following BESS Roadmap as shown in Figure 19 is aligned with Thailand's draft PDP2024 plan and assumes that its power sector structure (ESB) will continue for the foreseeable future. Timelines are only suggested as key actions and based on checked milestones (specifications, approvals, and settlement readiness) rather than depending on reforms that are not yet in place. The Roadmap is structured in three phases that reflect technology maturity, market rules and procurement capacity.

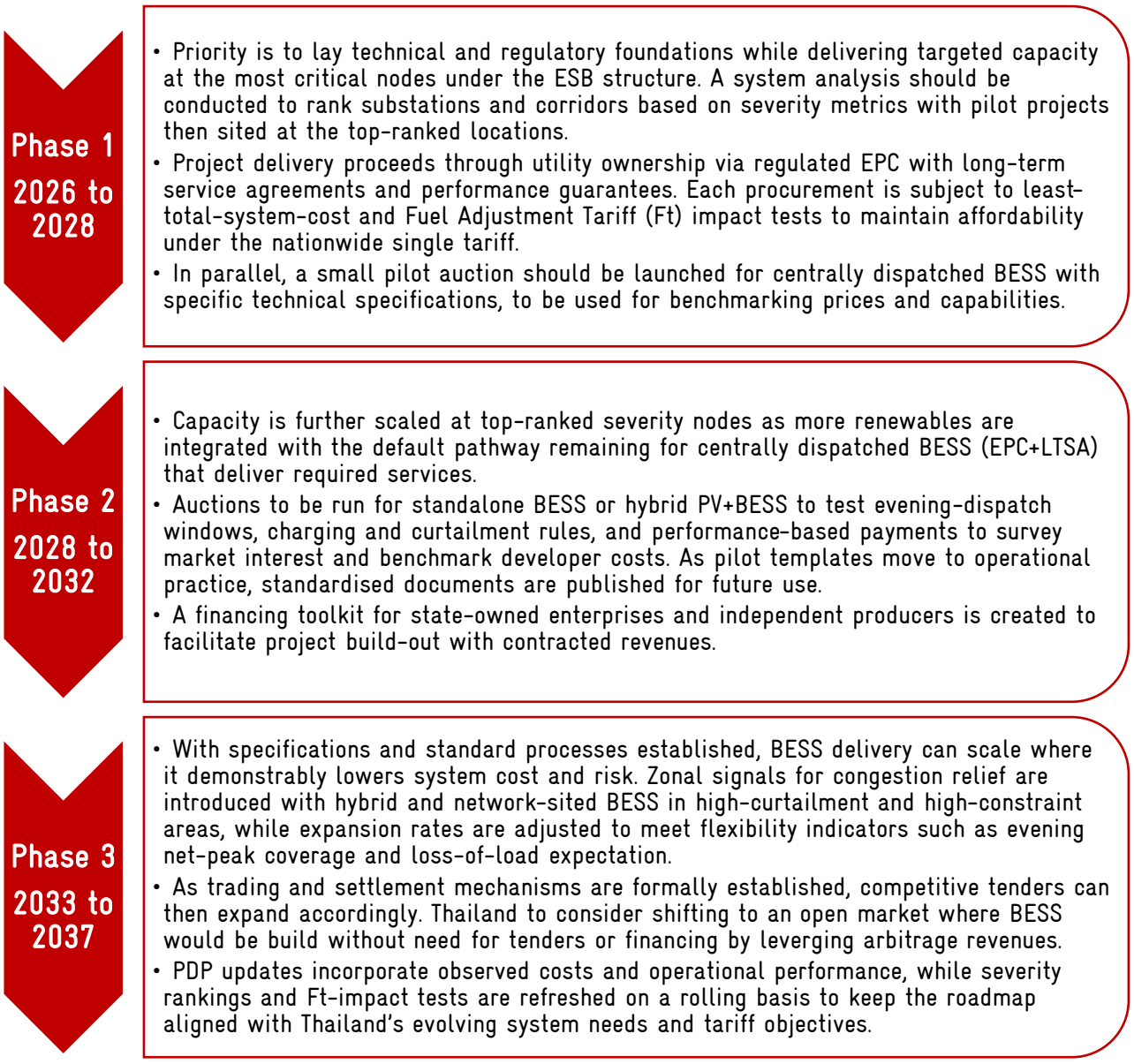


Figure 19: BESS Roadmap aligned with Thailand's draft PDP2024 plan
(source: Energynautics GmbH)

8.4.2 Competitiveness Outlook

As costs for PV and batteries decline, the relative cost of gas-fired generation during peaks can rise. Recent BloombergNEF analysis for Thailand indicates that solar, wind, and batteries can materially reduce reliance on LNG imports. This underpins the scenarios presented here and supports phased procurement of firmed renewable supply. The following matrix in Table 3 provides a simple screening framework for planners and investors. It should be combined with sensitivity tests for fuel prices, discount rates and degradation.

Table 3: Future Scenarios of PV+BESS Competitiveness
(source: *BNEF*)

Scenario	Key metric	Implication
LCOE PV+BESS < LCOE gas generation	Cost parity or advantage	New capacity tends to favour PV+BESS over gas
LCOE PV < Gas fuel cost	Fuel switch potential	PV begins to displace gas during midday peak hours
LCOE PV+BESS < Gas fuel cost	24/7 renewable option	Gas units operate mainly during extreme peaks or outages
Gas plants uneconomic at low utilisation and high fuel cost	Stranded asset risk	A transition strategy is needed for affected units

Over the next few years, this framework implies several opportunities. In practical terms, evening capacity can eventually be procured from hybrid PV+BESS rather than from new gas when price parity is achieved. Some existing gas units can shift to seasonal or reserve service. Network-sited storage in high-curtailment zones can raise effective capacity and reduce congestion costs. Delivery will also depend on clear procurement documents that define dispatch rights, evening blocks, curtailment treatment, charging energy, and capacity building for grid-forming controls, safety codes, commissioning, and contract settlement using verified data.

9 Conclusion and Outlook

Battery storage in combination with solar PV is gradually becoming a practical instrument for lowering Thailand's system costs, managing evening peaks, and supporting stability as renewable energy penetration grows. The report focuses on utility-scale storage and reflects Thailand's ESB structure where system security services are delivered by EGAT, PEA and MEA. In this context, the most valuable near-term applications are fast frequency response and frequency containment, voltage control, congestion management, and black start readiness. Grid-forming capability will be important as inverter-based generation increases and short-circuit strength falls.

Two deployment models are relevant. Hybrid PV+BESS can help shape plant output but, they are bound to specific PV systems making them less flexible. The main focus in the short-term should therefore be centrally dispatched, network-sited storage at substations. Utility ownership with EPC delivery and LTSA gives the system operator full control to stack services and respond to real-time needs. Where private participation is considered, it should be tightly scoped, performance-based and tested first at small scale. ERC Sandbox trials are providing useful technical evidence to build on. Jamaica offers an example for a single-buyer structure, where Jamaica's Public Service first commissioned a utility-owned hybrid storage system at the Hunts Bay substation for fast frequency support. Now it is procuring a 115 MW PV plant with 171.5 MW of BESS to replace the ageing Hunts Bay plant. This shows a similar path from regulated pilots to larger, centrally dispatched capacity (Jamaica Gleaner).

Business models and procurement should match the current market design while preparing for possible reforms. Performance-based contracts need clear definitions for evening delivery, response accuracy, availability and state-of-charge readiness, together with metering boundaries, cycling limits, and transparent settlement. All procurements should pass least-total-system-cost and Ft-impact tests to protect end-users under the nationwide single tariff. A pilot auction with clear technical specifications is recommended to survey market interest and enable price discovery. As costs for solar and batteries continue to fall, both hybrid and centrally dispatched storage can reduce fuel use from the most expensive gas units, cut redispatch and curtailment, and improve tariff stability.

The roadmap aligns actions with draft PDP2024 and sequences delivery in three phases: Phase 1 to set standards and run targeted pilots; Phase 2 to scale hybrid and network-sited capacity while beginning auctions; and Phase 3 to expand where proven value is highest, widen competitive tenders, and potentially shift to creating an open market where BESS can participate without the need for tenders.

The next steps would involve three key phases. First, the foundation must be set by finalising the technical specifications for network-sited BESS. These specifications should cover aspects such as grid-forming capabilities, protection, communications, fire safety, state-of-charge readiness, and response accuracy. Alongside this, a system-severity analysis should be completed to produce a ranked list of substations and corridors based on priority.

Next, delivery should begin at the most critical nodes. This involves procuring and commissioning Phase 1 utility-owned BESS at the highest-ranked sites through an EPC contract that includes a long-term service agreement (LTSA). The implementation should follow standardised measurement and verification procedures, ensure transparent settlement processes, and incorporate checks for least total system cost and feed-in tariff (Ft) impact.

Finally, efforts should focus on enabling scale-up. This includes finalising performance-based contract and settlement templates, preparing a pilot auction package with a well-defined technical scope, and developing a financing toolkit to facilitate the rapid scaling of projects from 2029 onwards.

References

Accure Blog – *The Key Components of Battery Energy Storage Systems (BESS)*. (n.d.). https://www.accure.net/blogs/battery-energy-storage-system-components

Ahmedm. (2025, September 4). *Energy Storage | UL Standards & Engagement*. UL Standards & Engagement. https://ulse.org/focus-areas/community-safety/energy-storage/

Asian Insiders. (2024, July 16). Thailand needs more battery energy storage systems to meet clean energy targets. https://asianinsiders.com/2024/07/16/thailand-battery-energy-storage-systems-future/

BloombergNEF. (2024, December 10). Lithium-ion battery pack prices see largest drop since 2017, falling to $115 per kilowatt-hour. https://about.bnef.com/insights/commodities/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/

BloombergNEF. (2025, July 11). *Solar, wind and batteries could enable Thailand to reduce reliance on LNG imports*. https://about.bnef.com/insights/clean-energy/solar-wind-and-batteries-could-enable-thailand-to-reduce-reliance-on-lng-imports/

California Independent System Operator. (2025, May 29). 2024 special report on battery storage. https://www.caiso.com/documents/2024-special-report-on-battery-storage-may-29-2025.pdf

Codes & Standards Draft. (n.d.). Energy Storage Safety. https://www.sandia.gov/energystoragesafety/codes-and-standards/

Colthorpe, A. (2025, February 5). *Behind the numbers: BNEF finds 40% year-on-year drop in BESS costs*. Energy-Storage.News. https://www.energy-storage.news/behind-the-numbers-bnef-finds-40-year-on-year-drop-in-bess-costs/

Grid Boosters as innovative solution to optimise power grids – How Storage as Transmission Assets increase the utilisation of transmission lines in EHV grids - consentec. (2024, August 5). Consentec. https://consentec.de/en/publikation/grid-boosters-as-innovative-solution-to-optimise-power-grids-how-storage-as-transmission-assets-increase-the-utilisation-of-transmission-lines-in-ehv-grids/

Cruz De Jesús, E., Martínez-Ramos, J. L., Marano-Marcolini, A., & Gómez-Expósito, A. (2025). Economic assessment of battery energy storage systems for frequency regulation reserve provision: A case study of the Dominican Republic. Energy for Sustainable Development, 88, 101749. https://doi.org/10.1016/j.esd.2025.101749

Electric Power Research Institute, TWAICE, & Pacific Northwest National Laboratory. (2024). Insights from EPRI's Battery Energy Storage Systems (BESS) Failure Incident Database. https://restservice.epri.com/publicdownload/000000003002030360/0/Product

Electricity Generating Authority of Thailand. (2025, July). Share of electricity generation by energy source in EGAT's system. https://www.egat.co.th/home/en/statistics-fuel-usage/

Energy Storage News. (2023, June 2). South Africa's Eskom confirms contract awards for 1,440 MWh battery storage. https://www.energy-storage.news/south-africas-eskom-confirms-contract-awards-for-1440mwh-battery-storage/

Energy Storage News. (2024). BESS failure incident rate dropped 97% between 2018 and 2023. https://www.energy-storage.news/battery-storage-failure-incident-rate-dropped-97-between-2018-and-2023/

Eskom. (2022). Eskom unveils a first-of-its-kind largest battery storage project in the African continent. https://www.eskom.co.za/eskom-unveils-a-first-of-its-kind-largest-battery-storage-project-in-the-african-continent/

Eskom. (2023, November 8). Eskom BESS rollout brochure [PDF]. https://www.eskom.co.za/distribution/wp-content/uploads/2023/11/BESS-eskom-brochure-Mobile-friendly.pdf

Global Energy Alliance for People and Planet. (2024, August 2). Pioneering innovation with Vietnam's BESS pilot project. https://energyalliance.org/pioneering-innovation-with-vietnams-bess-pilot-project/

Global Energy Monitor. (2024, May). Southeast Asia's energy crossroads: The cost of gas expansion versus the promise of renewables. https://globalenergymonitor.org/wp-content/uploads/2024/05/GEM_SEAsiaGasReport_2024.pdf

Gupta, M. (2024, September 16). *JSW Neo Energy and Reliance Power win 1,000 MW SECI Battery Storage Project with Record-Low Tariffs Auction*. SolarQuarter. https://solarquarter.com/2024/09/16/jsw-neo-energy-and-reliance-power-win-1000-mw-seci-battery-storage-project-with-record-low-tariffs-auction/

Hoffmann-Ostenhof, L. (n.d.). *The commercial opportunities for Utility-Scale batteries in Germany*. https://www.gridcog.com/blog/the-commercial-opportunities-for-utility-scale-batteries-in-germany

International Energy Agency. (2023). Batteries and Secure Energy Transitions. IEA. https://www.iea.org/reports/batteries-and-secure-energy-transitions

Japan's Idemitsu to build lithium sulphide plant to help support Toyota's EV plans. (2025, February 27). Reuters. https://www.reuters.com/business/energy/japans-idemitsu-build-lithium-sulphide-plant-help-support-toyotas-ev-plans-2025-02-27/

JPS spending US$300m on renewable energy expansion. (2025, May 9). Business | Jamaica Gleaner. https://jamaica-gleaner.com/article/business/20250509/jps-spending-us300m-renewable-energy-expansion

Lazard. (2024, June). Lazard's LCOE+ (including LCOS), June 2024 [Report]. https://www.lazard.com/media/xemfey0k/lazards-lcoeplus-june-2024-_vf.pdf

Maccioni, M., Lamedica, R., Lauria, S., Ruvio, A., Palone, F., & Rebolini, M. (2016). Application of a LiFePO4 battery energy storage system to primary frequency control: Simulations and experimental results. Energies, 9(11), 887. https://doi.org/10.3390/en9110887

Mercom India. (2024, November 7). IndiGrid, Kintech, H.G. Infra win NVVN's 500 MW/1 GWh battery storage auction. https://www.mercomindia.com/nvvn-1-gwh-battery-storage-auction

Murray, C. (2024, November 27). *BYD launches sodium-ion grid-scale BESS product*. Energy-Storage.News. https://www.energy-storage.news/byd-launches-sodium-ion-grid-scale-bess-product/

Nathan.Dang. (2025, June 11). *Current status of BESS applications in the Vietnamese Electricity grid - 東南亞影響力聯盟*. 東南亞影響力聯盟. https://sia.net.tw/en/vietnam-battery-energy-storage-system/

National Grid Corporation of the Philippines. (2024, March 13). Customer Bulletin 2024-12: Ancillary services [PDF]. https://www.ngcp.ph/Attachment-Uploads/2024-12%20CB_Ancillary%20Services-2024-03-13-14-54-23.pdf

National Grid Corporation of the Philippines. (2025). 2025–2034 Ancillary Service Agreement Procurement Plan (ASAPP) [PDF]. https://www.ngcp.ph/Attachment-Uploads/csp/2025-2034%20ASAPP_rev.pdf

Nian, V., Jindal, G., & Li, H. (2019). A feasibility study on integrating large-scale battery energy storage systems with combined cycle power generation – Setting the bottom line. *Energy*, *185*, 396–408. https://doi.org/10.1016/j.energy.2019.07.028

Rayner, T. (2025, July 24). *Worldwide battery storage installations up 54% in first half of 2025, June sets monthly record - Energy Storage*. Energy Storage. https://www.ess-news.com/2025/07/15/worldwide-bess-installations-up-54-in-first-half-of-2025-june-sets-monthly-record/

Renewables Now. (2022, July 28). Eskom selects contractors for 343-MW BESS project. https://renewablesnow.com/news/eskom-selects-contractors-for-343-mw-bess-project-793353/

Reuters. (2024, September 16). Thailand's PTT signs five-year LNG deal with Oman LNG. https://www.reuters.com/markets/deals/thailands-ptt-signs-5-year-lng-deal-with-oman-lng-2024-09-16/

Reuters. (2025, April 16). Thailand plans to import more U.S. LNG over next five years, says minister. https://www.reuters.com/business/energy/thailand-plans-import-more-us-lng-over-next-5-years-says-minister-2025-04-16/

Schmidt, O., & Staffell, I. (2023). *Monetizing energy storage: A Toolkit to Assess Future Cost and Value*. https://academic.oup.com/book/55104

Solar Energy Corporation of India. (2024, June 26). Request for Selection (RfS) – 1,000 MW/2,000 MWh standalone BESS (ESS-2) [PDF]. https://www.seci.co.in/Upload/Tender/SECI000160-7915545-RfS-ESS-2-final_upload.pdf

Spendiff-Smith, M. (2023, August 8). *Battery energy storage system components*. Power Sonic. https://www.power-sonic.com/blog/battery-energy-storage-system-components/

Troes. (2025, August 6). What is Battery Energy Storage? Inside the System Structure. *TROES Corp.* https://troescorp.com/what-is-battery-energy-storage/

Understanding the role and specifications of Battery Management System (BMS) in BESS containers. (n.d.). TLS Offshore Containers & TLS Energy. https://www.tls-containers.com/tls-blog/understanding-the-role-and-specifications-of-battery-management-system-bms-in-bess-containers

Volta Foundation. (2024). Battery Report 2024 (Rev. 2025030101). https://volta.foundation/battery-report-2024

Zecchino, A., Gerini, F., Zuo, Y., Cherkaoui, R., Paolone, M., & Vagnoni, E. (2021). Local effects of grid-forming converters providing frequency regulation to bulk power grids. arXiv preprint arXiv:2110.05392. https://arxiv.org/abs/2110.05392

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Sitz der Gesellschaft
Bonn und Eschborn

Friedrich-Ebert-Allee 32 + 36
53113 Bonn, Deutschland
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1-5
65760 Eschborn, Deutschland
T +49 61 96 79-0
F +49 61 96 79-11 15

E info@giz.de
I www.giz.de