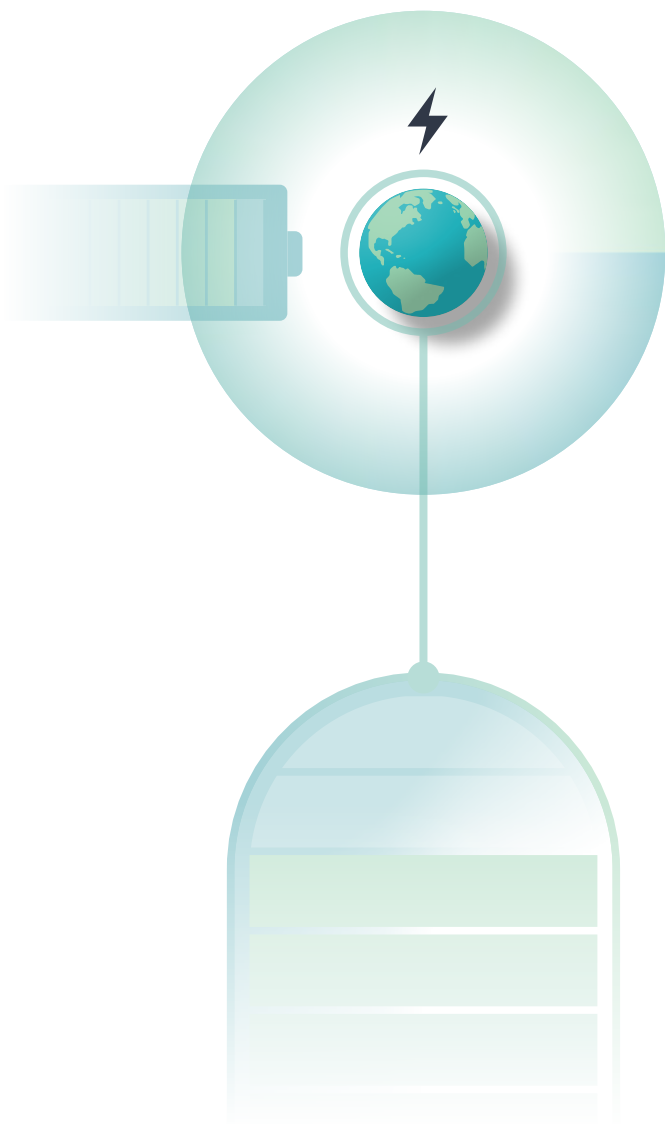


WHITEPAPER EXPLORING THE VALUE OF ELECTRICITY STORAGE: A COMPREHENSIVE INTERNATIONAL OVERVIEW



WHITEPAPER

EXPLORING THE VALUE OF ELECTRICITY STORAGE: A COMPREHENSIVE INTERNATIONAL OVERVIEW



**SUPERCHARGING
BATTERY STORAGE**

AN INITIATIVE OF THE CLEAN ENERGY MINISTERIAL

The Clean Energy Ministerial (CEM) is an international clean energy leadership platform that brings together a large community of global clean energy transition experts around the world¹. With the aim to advance clean energy technology, a high-level global platform is provided that advances policies and programs, and shares lessons-learned. The CEM consists of 29 member countries and 26 participant countries.

At COP28 (Dubai, 2023) the Supercharging Battery Storage (SBS) initiative was launched, with the aim to advance battery storage on a global scale and meet the 2050 net-zero goals. This initiative is co-led by the governments of Australia and the European Commission, supported by the USA, Canada and the Netherlands. Specifically, the initiative was started to remove barriers and advance further upscaling of utility-scale battery storage. The mission of the initiative is to boost stationary battery

storage development and deployment and reduce technology cost, through international cooperation and alignment as appropriate, to build a diversified, sustainable, responsible, secure and transparent supply chain, to promote grid stability and reliability and to support the integration of renewable energy globally². Its key activities are centered around the following three pillars:



Figure 1 The three pillars of the Supercharging Battery Storage initiative to boost stationary battery storage development and deployment

A key focus of the SBS initiative is to focus on international collaboration and knowledge-sharing practices. This report highlights international exhibits of worldwide cases where the value of energy storage is demonstrated and storage assets are properly integrated into the energy system.

The SBS Initiative would like to sincerely thank each contributing organization that provided exhibits to this report.

Community members

Co-leads



Australia



European Commission

Participants



Canada



United States

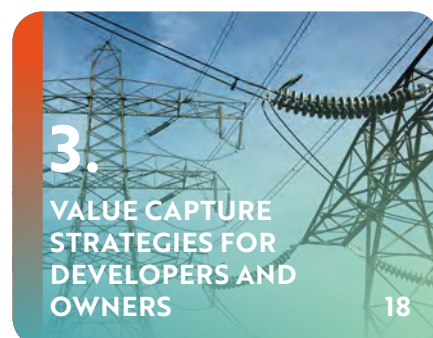


The Netherlands

The contents of this document are not to be necessarily construed as endorsements by, or reflective of, the official positions of member governments or the contributing organizations.

CONTENTS

1. INTRODUCTION	6
1.1 The Worldwide Need for Energy Storage	7
1.2 Energy Storage Portfolio and Functions	7
1.3 Valuing Electricity Storage: a Framework and International Examples	9
2. THE VALUE OF ELECTRICITY STORAGE IN DIFFERENT SYSTEMS AND CONFIGURATIONS	11
2.1 Introduction: System Value of Electricity Storage	12
2.2 Quantifying System Value and Societal Benefits	13
2.3 Diverse Roles of Electricity Storage Technologies	14
2.4 Benefits for stakeholders across the value chain	15
3. VALUE CAPTURE STRATEGIES FOR DEVELOPERS AND OWNERS	18
3.1 Revenue Generation	19
3.2 Value Stacking Strategies	21
3.3 Market Conditions Enabling Value Capture	22
4. THE ECONOMIC GAP IN ELECTRICITY STORAGE PROJECTS	23
4.1 Market Failure for Electricity Storage is Looming in Transitioning Markets	24
4.2 Projects Costs Hinder a Viable Business Case	24
4.3 Uncertainty in Revenue Streams Hinder Long-Term Project Viability	25
4.4 System Cost Benefit Gaps that Hinder a Viable Business Case	26
4.5 Key Market Design Limitations	27
5. ACTIONS TO BRIDGE THE ECONOMIC GAP	28
5.1 Actions to Close the Project Gap: Decrease Project Costs	29
5.2 Actions to Close the Project Gap: Increase Project Revenues through Market Risk Mitigation	30
5.3 Actions to Close the System Gap: Implement Market Reform Strategies	31
6. CONCLUSION & WAY FORWARD	34
Policy actions	35
Supply chain actions	35
Financing actions	35
7. INTERNATIONAL EXHIBITS ON ELECTRICITY STORAGE	36
Exhibits chapter 1: Introduction into the energy storage portfolio and functions	37
Exhibits chapter 2: The value of electricity storage in different systems and configurations	43
Exhibits chapter 3: Value capture strategies for developers and owners	47
Exhibits chapter 5: Actions to bridge the economic gap	52
Endnotes	56



1. INTRODUCTION



1.1 The Worldwide Need for Energy Storage

At COP29 in Azerbaijan, global organizations have signed the Global Energy Storage and Grids Pledge, committing to deploy 1500 GW of energy storage in the power sector by 2030³. This pledge aims for a six-fold increase in installed capacity in 2030 compared to 2023 (see *Figure 2*), mainly driven by the large roll-out of utility-scale batteries. This drastic increase highlights the need for innovation and investment to support the global trend of higher rates of electrification of the energy system.

Investments in energy storage, particularly batteries, have exponentially increased over the past decade. As visualized in *Figure 3*, these investments nearly add up to the current investments in natural gas, most likely exceeding them in the next years to come. The investments are quite equally spread between the US, China and Europe. On the right part of *Figure 3*, a near equal division in behind-the-meter and utility-scale investments on battery storage is shown, highlighting the multi-faceted positioning of electricity storage within the energy system.

Energy storage is a critical component in the current and future energy systems, providing numerous benefits across various configurations and systems, including the electrification of energy use and the diversification of energy sources. As renewable energy generation

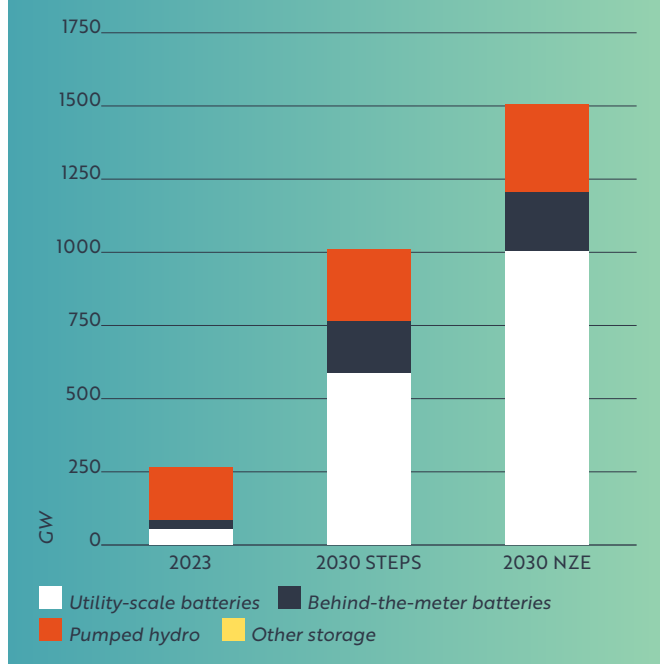
grows, energy storage, as a key provider of non-fossil flexibility next to demand-response signals, will play a key role in addressing intermittency issues, reducing curtailment, balancing electricity prices and enhancing overall grid stability. By shifting consumption to periods of low electricity prices and supplying energy during peak demand, the energy system can be used more optimally. This not only stabilizes prices but also supports viable business models for both commercial as well as residential users. Energy storage also enables the optimization of existing energy infrastructure and even deferral of investments in new power plants or grids, saving money, time and critical resources.

Beyond direct technical and financial benefits, energy storage can also strengthen energy independence. Energy storage provides critical backup during system emergencies and brings resilience to the energy system with economies and societies that rely on it. It can reduce the reliance on foreign imports and thereby enhance energy system resilience, particularly in rural or remote areas. An important factor to monitor and steer is a storage portfolio approach which includes material supply chain diversification for storage systems to mitigate risks and reduce dependencies on supply chain disruptions. Together, these benefits can enable an affordable, reliable and sustainable energy system.

1.2 Energy Storage Portfolio and Functions

Within the broad domain of energy storage, this whitepaper focusses on electricity storage. It builds further on previous work in the Battery Storage Unlocked report from the CEM SBS Initiative on lessons learned from electricity storage for emerging economies⁶. To ensure a stable and flexible energy supply, a diverse range

Figure 2 Globally installed energy storage capacity for batteries, pumped hydro and other storage for 2023 and two scenarios for 2030, where one would adhere to the 1500GW target in 2030⁴. Figure adapted from IEA, 2025.



*Australia Yadlamalka Energy-Spencer Energy Project
Image credit: ARENA*



of energy storage technologies is needed, ranging from short-term, fast-response systems like batteries, to long-duration, high-capacity solutions such as underground hydrogen storage. These technologies play a pivotal role in balancing the intermittent nature of renewable energy sources (RES) within an integrated energy system. Shaping this entire portfolio is critical not only for maintaining grid resilience, but also for ensuring strategic energy autonomy in the transition to a sustainable energy future.

Figure 4 depicts the portfolio of energy storage technologies and their respective operating time dimensions and power capacities. These technologies differ in terms of scale, response time, and suitability for short- and long-duration storage.

While electricity storage is the primary focus of this paper, it is important to acknowledge that other forms of energy storage, such as thermal and molecular (e.g., hydrogen) storage, also play crucial and complementary roles in the energy transition. Thermal storage technologies, including sensible heat storage systems, phase change materials, and thermochemical systems enable efficient heating and cooling management, particularly in the built environment and industrial processes. Hydrogen, on the other hand, offers long-duration and cross-sector storage potential, supporting applications in heavy industry, transport, and seasonal balancing. Together with electricity storage, these technologies enhance system-wide flexibility, resilience, and sector coupling.

➔ For an overview of some energy storage portfolio examples, see the following exhibits:

- Australia Yadlamalka
- Canada Lhu'ààn Mân N'tsi Project
- Spain Alcántara II reversible hydroelectric power plant
- Singapore Seatrium Floating Living lab
- Samsung SDI Ulsan Solid-State Battery Line
- USA Willow Rock Energy Storage Center
- USA Iron-Air Battery Deployment

Compressed Air Energy Storage (CAES) explained.
Image Corre Energy.

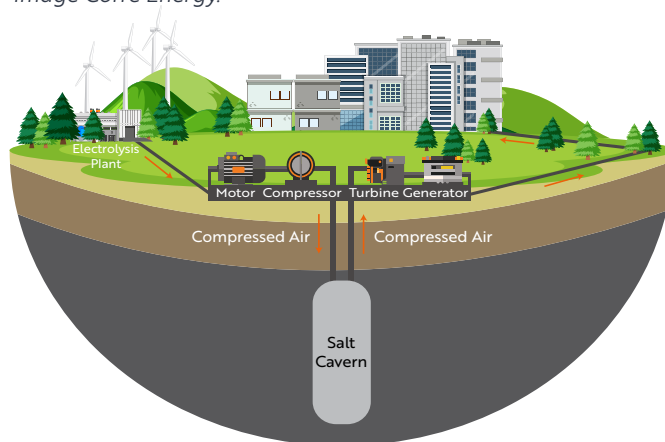
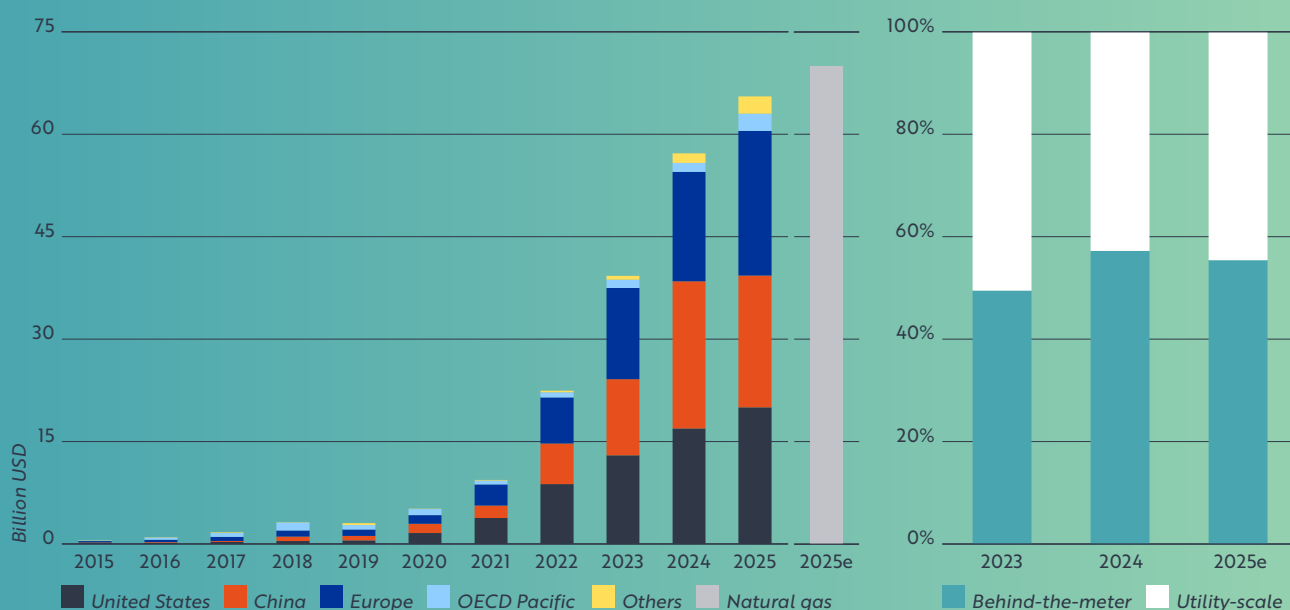


Figure 3 Worldwide battery storage investments in the past decade, together with a differentiation between behind-the-meter and utility-scale investments⁵. Figures adapted from IEA, 2025.



1.3 Valuing Electricity Storage: a Framework and International Examples

Despite the wide range of functions electricity storage can provide within the system, many of its services remain undervalued and underutilized. Societal benefits such as energy independence, avoided CO₂-emissions, air pollution or other environmental impacts and grid reliability are often not monetized, even though its added value towards an affordable, reliable and sustainable energy system is substantial. This creates an economic gap between project costs and revenues, hindering the large-scale adoption of electricity storage.

To address this, this whitepaper examines strategies to bridge the economic gap, following an approach inspired by IRENA's Electricity Storage Valuation Framework⁷. With



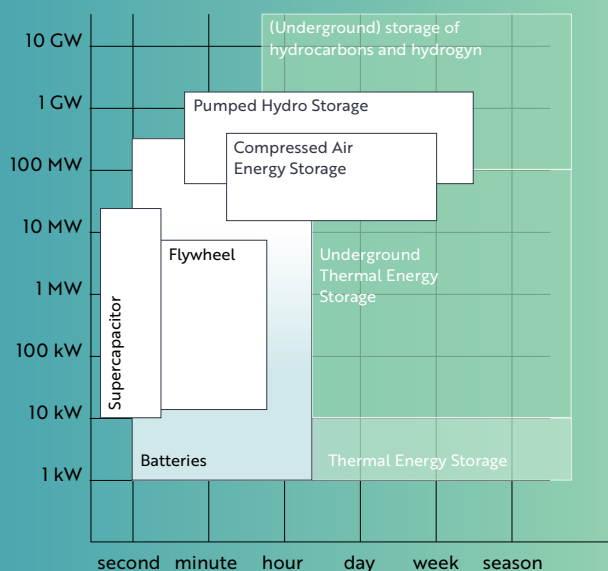
this approach it is possible to indicate the economic viability of electricity storage and show possible market failures; when the net system benefits are higher than the costs of storage but revenues do not translate into a business case. This whitepaper explores the multifaceted value of electricity storage, examining its economic and non-economic (operational) benefits, value capture strategies, and examples of market conditions across the globe that make electricity storage projects viable.

This whitepaper showcases international exhibits that illustrate how the value of electricity storage is demonstrated throughout the world in all its diversity. The whitepaper contains several sections supported by exhibits provided by CEM SBS partners or derived from literature. These are included to spur discussion and can serve as an inspiration for other countries and project developers. An overview of these international exhibits is visualized in *Figure 5* and listed in Table 1. Learning from these examples will help the valuation of electricity storage and help closing the business gap for project developers.

The structure of the whitepaper is as follows:

1. [Introduction](#)
2. [The Value of Electricity Storage in Different Systems and Configurations](#)
3. [Value Capture Strategies for Developers and Owners](#)
4. [The Economic Gap in Electricity storage Projects](#)
5. [Actions to Bridge the Economic Gap](#)
6. [Conclusion & Way Forward](#)
7. [International Exhibits on Electricity storage](#)

Figure 4 Portfolio of energy storage technologies and their range of power capacity and storage duration (source: adapted from IEA)



This whitepaper showcases international exhibits that illustrate how the value of electricity storage is demonstrated throughout the world in all its diversity.



Figure 5 Graphical overview of the international electricity storage exhibits highlighted in this whitepaper

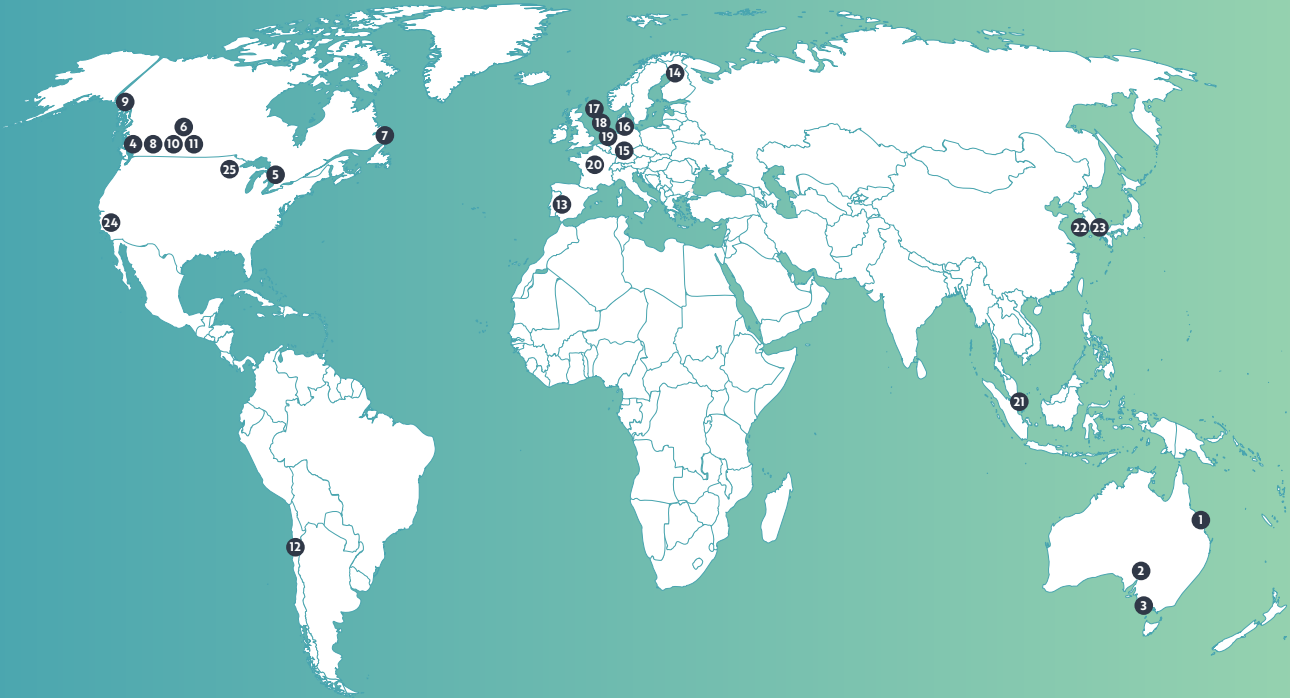
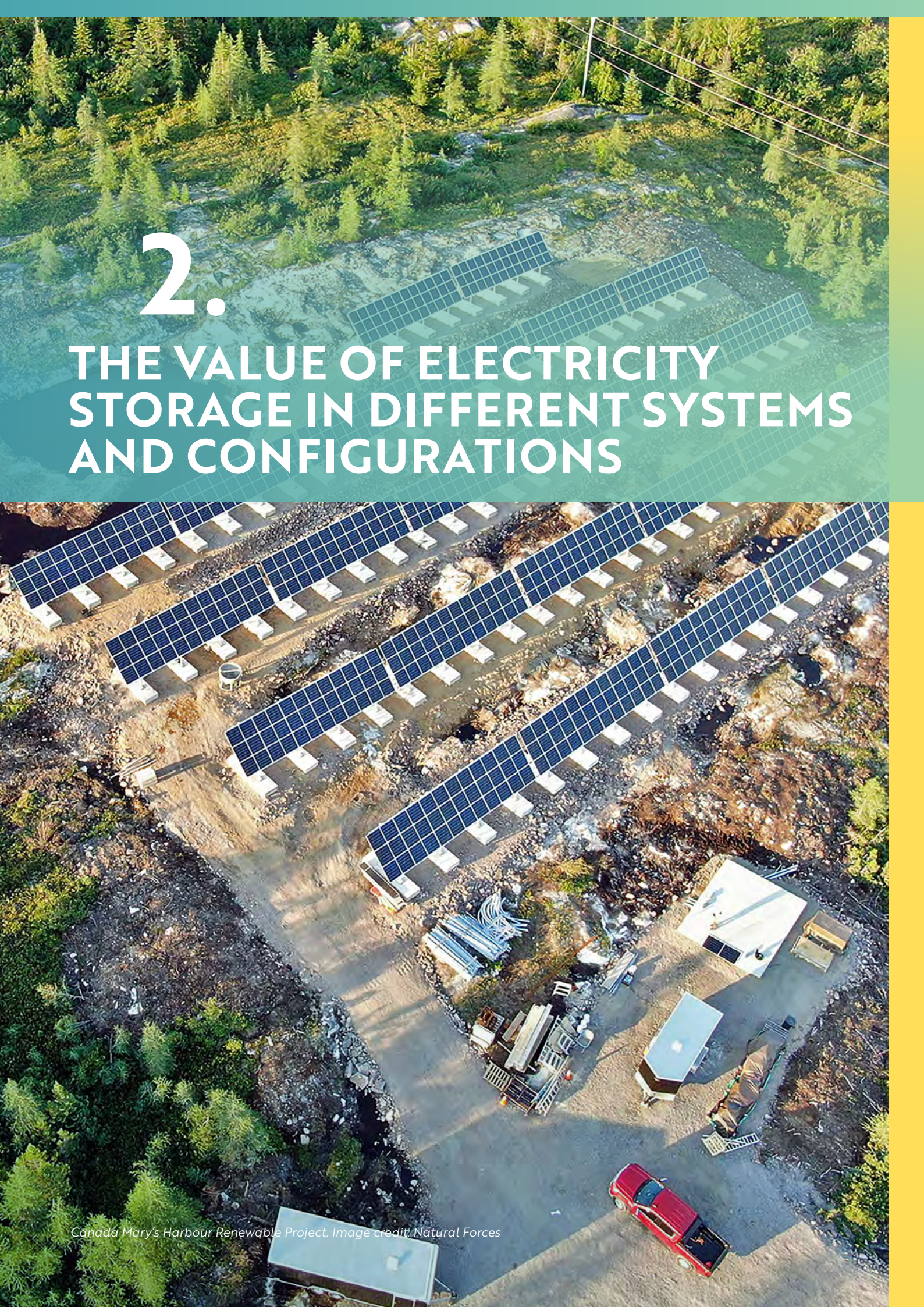


Table 1 List of all international exhibits related to electricity storage

#	Country	Title	#	Country	Title
1	Australia	Bouldercombe BESS	16	Germany	Eco Power One
2	Australia	Yadlamalka Energy-Spencer Energy project	17	The Netherlands*	FlevoBESS
3	Australia	Flinders Community Battery	18	The Netherlands*	RWE inertia battery
4	Canada	Canada's targeted programs supporting energy storage projects	19	The Netherlands*	Value of electricity storage
5	Canada	Oneida Energy storage	20	EU*	EnTEC study on energy storage
6	Canada	Alberta eReserve	21	Singapore*	Seatrium Floating Living Lab
7	Canada	Mary's Harbour Renewable Project	22	Republic of Korea*	Miryang ESS
8	Canada	Summerland Solar and Storage Project	23	Republic of Korea*	Samsung solid-state battery line
9	Canada	Lhu'ààn Mân N'tsi Project	24	USA*	Willow Rock Compressed Air Storage
10	Canada	Alberta Restructured Energy Markets	25	USA*	Form Energy's Iron Air battery
11	Canada	Ancillary Services in Alberta			
12	Chile*	AES Andes - Pampas hybrid park			
13	Spain*	Alcántara reversible pumped hydro storage			
14	Finland*	Kurkiaska Supercapacitor Integration			
15	Germany *	Study on the value of large battery storage			

*literature based exhibit

An aerial photograph of a solar farm. The solar panels are arranged in long, parallel rows, tilted at an angle. They are situated in a cleared area within a forest. The surrounding landscape is covered with green trees and vegetation. The sky is not visible, but the lighting suggests a bright day.

2.

THE VALUE OF ELECTRICITY STORAGE IN DIFFERENT SYSTEMS AND CONFIGURATIONS

2.1 Introduction: System Value of Electricity Storage

Electricity storage has the potential to play an important role in the global transition to a clean, secure, and affordable energy system. Apart from the technical benefits storage can add to the electricity sector, integrating electricity storage in the energy system can also deliver environmental, economic, and societal benefits. These benefits can accelerate the road towards reducing emissions, enhancing energy security, and improving affordability of energy. Next to this, as the deployment of renewable and often more intermittent energy sources, such as wind and solar, increases, electricity storage becomes indispensable for maintaining system stability, flexibility, and resilience.

SECURITY OF SUPPLY AND SYSTEM RESILIENCE

Electricity storage enhances the integration of a more diverse supply mix while maintaining a reliable and resilient power supply⁸. Modern energy systems typically shift from demand driven systems to supply driven systems, where supply becomes more variable than demand. Electricity storage can assist in balancing the power on the grid. It can support critical infrastructure during emergencies, enable grid independence through microgrids, and cushion price volatility. This makes energy systems more robust, self-sufficient, and better equipped to handle disruptions. Additionally, electricity storage provides resilience during extreme weather events, providing backup power and stabilizing the grid. The societal benefits of storage are evident in its capacity to prevent blackouts and ensure continuity of service. Recent grid disturbances in Spain (2025), Portugal (2025) and Pakistan (2023) illustrate the vulnerability of electricity systems to sudden imbalances. Storage can act as a buffer, absorbing surplus energy and releasing it during shortages, thereby reducing the likelihood of system failures, associated economic losses and impact

Electricity storage has the potential to play an important role in the global transition to a clean, secure, and affordable energy system

on society. Post failures it can provide emergency back-up generation for critical functions in society (e.g. hospitals, emergency response services, communication) and black start capabilities.

IMPROVED GRID QUALITY

Storage systems enhance grid quality by providing frequency regulation, voltage support, and reactive power compensation. These ancillary services help maintain power quality and grid stability, especially with the growing share of variable renewable energy sources. As highlighted in ENTSO-E's 10-Year Network Development Plan, electricity storage can mitigate issues like voltage sags and harmonics, ensuring secure and efficient grid operation⁹. Moreover, fast-responding storage technologies such as batteries, are increasingly used to stabilize the grid in real time, reducing strain on aging infrastructure.

REDUCED IMPORT DEPENDENCY

Further integration of electricity storage reduces national dependencies on imported energy by enabling a better use of domestically generated renewable electricity. When renewable output is high, surplus energy can be stored and used later, decreasing reliance on foreign fossil fuels during peak demand or supply shortages. Therefore, electricity storage can improve energy self-sufficiency, and strengthen resilience against international supply disruptions¹⁰.

CO₂-EMISSIONS REDUCTION

Electricity storage can play a pivotal role in decarbonizing the energy system. By shifting surplus renewable generation (e.g. solar and wind) to periods of high demand, storage reduces the need for fossil-fuel generation and reduces renewable curtailment. IEA scenarios show that about 60% of the CO₂ emissions reductions in 2030 in the energy sector are associated with batteries, making them a critical element to meeting globally shared climate goals (in the NZE Scenario)¹¹. Close to 20% are directly linked to batteries in EVs and battery-enabled solar PV. Another 40% of emissions reductions are from electrification of end-uses and renewables that are indirectly facilitated by batteries.

AIR QUALITY IMPROVEMENT AND OTHER ENVIRONMENTAL FACTORS

Integrating electricity storage contributes to improved (local) air quality by reducing the need for fossil-fuel-based generators or peaking plants, which are typically used during high-demand periods and emit typically high levels of air pollutants such as NO_x and particulate matter. By enabling greater use of renewable energy and reducing reliance on diesel generators or gas and coal-fired backup, storage systems help not only lower emissions in densely populated or industrial areas, but also in remote settings relying on diesel generation. A study by the

International Energy Agency notes that reducing fossil-based peaking power in urban regions can significantly improve public health outcomes due to decreased air pollution exposure¹².

Storage could also decrease (cooling) water consumption associated with thermal power plants, which is particularly valuable in water-stressed regions. Additionally, by minimizing the need for new peaking plants and transmission infrastructure, storage can reduce land use impacts and habitat disruption. Finally, storage systems can result in lower noise levels and (hazardous) waste compared to conventional backup generators, further reducing the environmental footprint of the energy system.

LOWER ENERGY PRICES

Electricity storage can contribute to lower wholesale and retail electricity prices by reducing peak demand and enhancing market flexibility, while avoiding negative prices to stabilize markets. A German study shows that storage can decrease the electricity price by providing electricity in times of high demand, thereby stabilizing the market¹³. This price moderation benefits consumers and reduces the need for expensive grid upgrades or emergency capacity mechanisms.

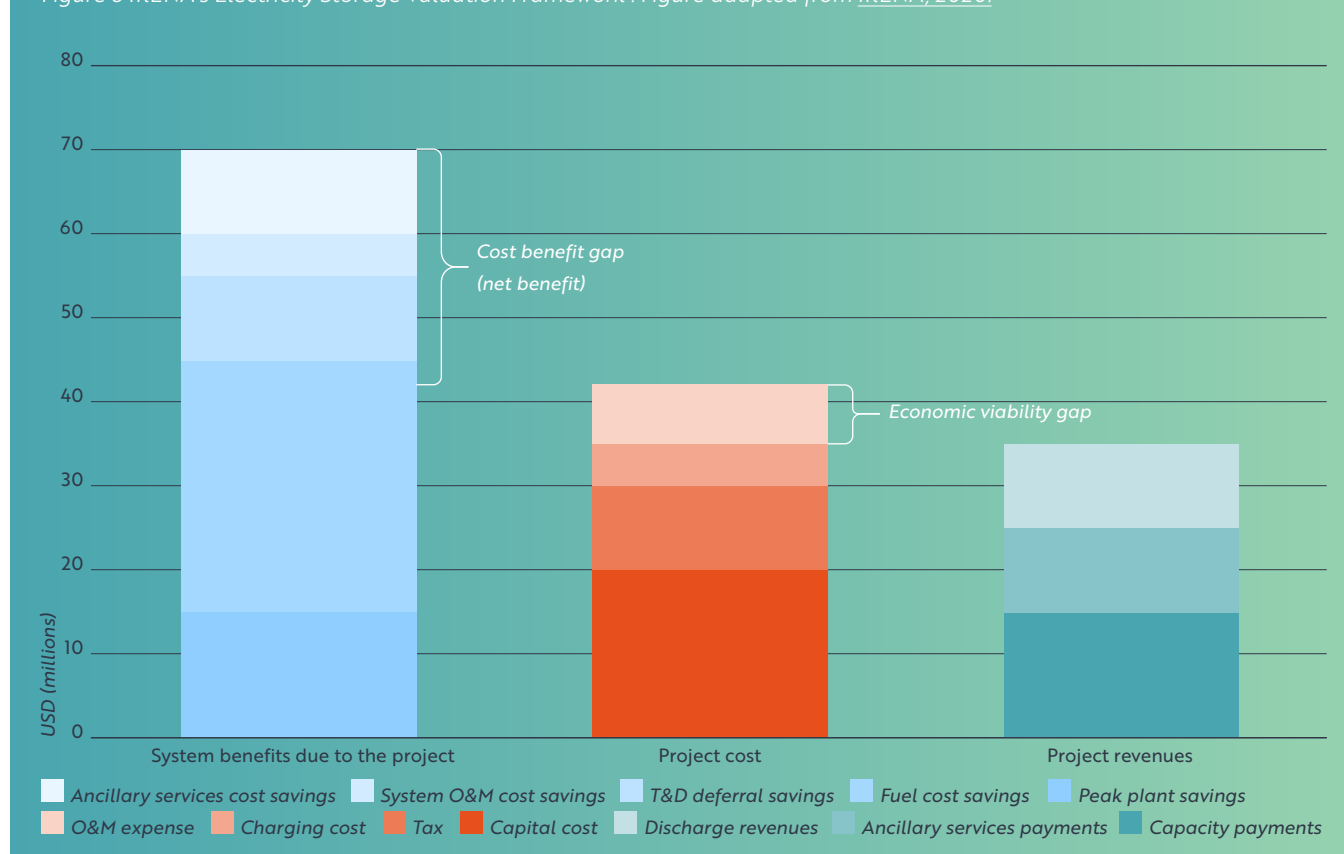
2.2 Quantifying System Value and Societal Benefits

While some aspects of the system values can be qualitatively approached as in section 2.1, others can be more quantitatively approached. For the latter, the International Renewable Energy Agency (IRENA) has developed the Electricity Storage Valuation Framework (ESVF), which provides a methodology for assessing the value of storage, accentuating the need to integrate technologies according to system needs¹⁴.

This framework considers system-wide values, cost structures and revenue strategies for worldwide electricity storage projects and technologies. *Figure 6* highlights the difference between a project gap (the economic viability gap) and a system gap (cost benefit gap or net system benefit). Project gaps generally focus on either increasing project revenues or decreasing project costs (both CAPEX and OPEX), whereas system gaps relate to monetizing or valuing a function of electricity storage for the system as a whole.

A key challenge that remains is to apply an integrated methodology to actually assess the benefits and costs of electricity storage including the benefits discussed

Figure 6 IRENA's Electricity Storage Valuation Framework⁷. Figure adapted from IRENA, 2020.



above. Despite the challenge, several studies aimed to quantify the system value of electricity or battery storage for a country aligning investment incentives with broader societal benefits.

A Dutch study shows that scenarios with the adoption of electricity storage result in benefits across multiple markets, services and stakeholders (see exhibit The Netherlands Study on the Value of Energy Storage) indicating it is possible to find positive system benefits for battery deployment in the range of hundreds of millions of Euros per year (i.e. 315 million EUR/yr in a scenario for 2035¹⁵) yet a market configuration with potentially negative business cases for projects inhibits commercial deployment. Furthermore, a German study found that storage could lower energy system costs with a potential economic benefit of approximately €12 billion by 2050 in Germany¹³.

➡ For examples on previous studies on the value of energy storage, see the following exhibits:

- EU EnTEC Study on Energy Storage
- The Netherlands Study on the Value of Energy Storage
- Germany Value of Large Battery Storage

Despite these benefits, current market structures often fail to reflect the full system value of storage. This disconnect, explored further in Chapter 4.1, creates a gap between the societal value of storage and the business case for storage project developers. Bridging this gap requires policy frameworks that internalize environmental and societal benefits, reward flexibility, and support a diverse portfolio of storage technologies.

The value of storage can be measured directly or indirectly through the benefits to the power system and society in general.

2.3 Diverse Roles of Electricity Storage Technologies

Electricity storage technologies serve a wide array of roles across the energy system, each matched to specific technical requirements, timeframes, and sectoral needs. Their diversity is a key strength, enabling them to address challenges from second-by-second frequency regulation to seasonal energy balancing.

Short-duration technologies, particularly lithium-ion batteries and supercapacitors, are well suited to fast-response applications (Figure 4). Their high efficiency and rapid dispatch capabilities make them ideal for frequency regulation, voltage control, and short-term load shifting. In contrast, long-duration storage technologies like pumped hydro storage (PHS) and compressed air energy storage (CAES) are critical for large-scale balancing to even seasonal energy shifting. These technologies can store energy for days or weeks, providing flexibility in systems with high shares of intermittent sources. For example, Germany's Goldisthal PHS facility, with over 1 GW of capacity, plays a central role in balancing seasonal fluctuations¹⁶.

Electricity storage plays a vital and diverse role across multiple locations in the energy system, enhancing energy efficiency, resilience, and affordability while enabling deeper integration of renewables. The locations of electricity storage can vary depending on this role, and they can be distinguished as front-of-the-meter and behind-the-meter (see Figure 7).

FRONT-OF-THE-METER

Front-of-the-Meter (FTM) systems are utility-scale batteries connected directly to the grid before the energy reaches end-users¹⁹. These systems are designed to perform services such as energy arbitrage (buying low-cost power and selling it at peak prices), load-following (matching supply with demand in real time), frequency and voltage regulation, and providing reserve capacity and renewable firming. They also help resolve transmission and distribution deferral and congestion relief issues, and can even enable black-start capabilities after grid outages. FTM storage helps stabilize the grid, integrate high volumes of renewables, and delay or reduce upgrades to large-scale power infrastructure. Large-scale battery installations in countries such as Australia and the United States have demonstrated their value in stabilizing wholesale markets and deferring grid infrastructure investments¹⁸.

BEHIND-THE-METER

Behind-the-Meter (BTM) systems are installed on the consumer side of the meter, serving residential, commercial, or industrial facilities. These systems empower users to store surplus solar generation ("solar-

plus-storage”), manage time-of-use pricing by load shifting, and reduce peak demand charges. They support critical onsite applications like EV charging, demand-side response, and uninterruptible power supply (UPS). It enables self-consumption of locally generated renewable energy, provides backup during outages, and allows participation in demand response programs. In industrial applications, it helps reduce peak demand charges and improves power quality for sensitive equipment. Additionally, BTM setups can be part of microgrids, offering resilience and operational control during outages (e.g. in hospitals and data centres). Overall, BTM storage delivers cost savings, enhances energy independence, and provides backup or resiliency for end users.

2.4 Benefits for stakeholders across the value chain

Electricity storage delivers substantial value throughout the energy system, yet how that value is realized varies across stakeholder groups. Recognizing these diverse benefits is essential for crafting effective international policies, investment frameworks, innovative business models and market structures that enable the rapid and equitable scaling of storage technologies.

1. GRID OPERATORS (TRANSMISSION AND DISTRIBUTION)

For transmission and distribution system operators, electricity storage is a strategic enabler of grid stability, flexibility, and cost efficiency, particularly in systems with growing shares of renewable energy.

Grid balancing and congestion management

Storage can relieve congestion by absorbing excess energy in congested areas and discharging it during high-demand periods. In countries like the Netherlands¹⁹ and France²⁰, storage has been deployed to manage local grid bottlenecks, reducing the need for costly network reinforcements.

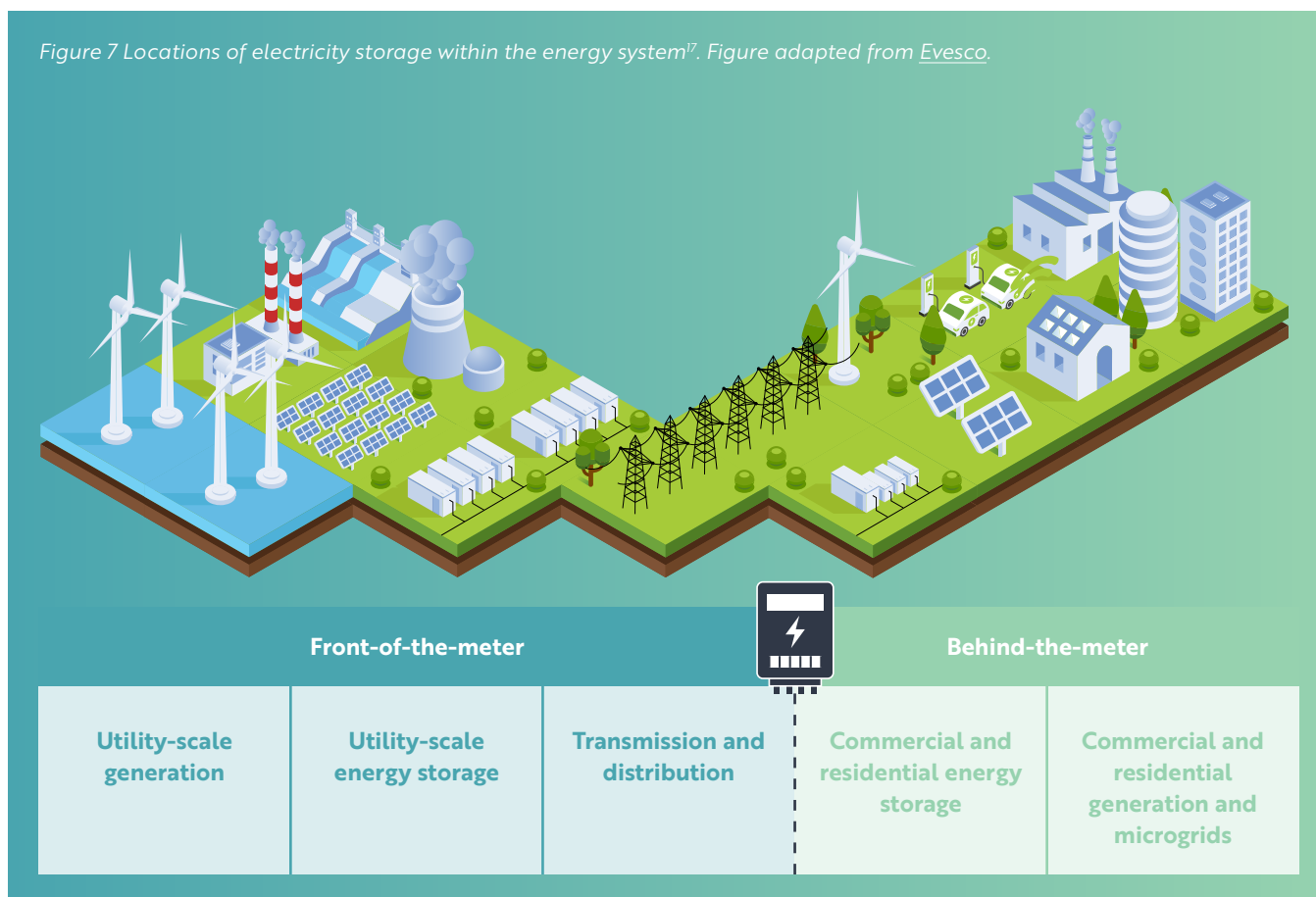
Frequency and voltage regulation

The fast response times of electricity storage technologies, often within milliseconds, allow them to deliver essential ancillary services like frequency regulation and voltage support, helping to stabilize the grid and prevent further outages²¹.

Black start and resilience

Storage can help restart the grid after outages, especially critical in disaster-prone or islanded systems. In California,

Figure 7 Locations of electricity storage within the energy system¹⁷. Figure adapted from *Evesco*.



utility-scale battery systems have been used to restore services for a black-start²².

2. PRODUCERS

For producers of renewable energy, electricity storage strengthens the business case by improving asset performance and unlocking new revenue streams. Co-locating batteries with solar and wind parks can enhance the integration of variable renewable energy into the grid.

➡ See exhibit Chile AES Andes – Pampas Hybrid Park for more information

Curtailment reduction and firming renewables

Storage allows wind and solar projects to reduce energy curtailment and provide firm, dispatchable output. In Chile, hybrid solar-plus-storage projects are being used to meet capacity requirements in a cost-effective and clean way²³. Another example of hybrid energy storage is the Netzbooster Project in Germany, which further investigates the combination of combining batteries with hydrogen to improve grid stability and avoid grid congestion²⁴.

Multi-market participation

In mature markets producers are increasingly using storage to participate in energy, capacity, and ancillary markets simultaneously (an approach called value stacking, which is further defined in Chapter 3). Zenobe's large-scale Blackhillock system showcases value stacking in mature UK energy markets²⁵. It absorbs surplus renewable (offshore wind) generation, stabilizes frequency, participates in energy arbitrage, contributes to capacity, and strongly supports grid services. Through this, simultaneous access to multiple market revenue streams is generated.

Electricity storage is a strategic enabler of grid stability, flexibility, and cost efficiency, particularly in systems with growing shares of renewable energy

Improved bankability

By stabilizing cash flows and reducing exposure to volatile energy prices, storage increases the attractiveness of renewable energy projects for investors, particularly when supported by long-term contracts or supportive regulation.

3. CONSUMERS/PROSUMERS

Consumers benefit from electricity storage through greater energy independence, cost control, and reliability, regardless of whether they are households, businesses, or community entities. Electricity storage offers significant cost-saving opportunities for consumers, particularly in industrial and commercial settings. First, storage enables peak shaving (reducing electricity drawn from the grid during periods of high demand), which can lower costly peak demand charges. Second, by temporarily supplying additional power during internal load spikes, storage systems can increase usable on-site capacity without exceeding the limits of the grid connection. This avoids or defers expensive upgrades to the grid connection or transformer, especially under capacity-based grid tariffs. Electricity storage can also help users avoid waiting times for grid reinforcements in congested areas, enabling continued electrification and business operations without additional infrastructure investment, in addition to potential fastened access to congested grids. Below are some examples of consumer benefits per sector.

Built environment sector

Battery systems in residential and commercial settings store excess solar energy generated during the day and discharge it during peak hours, boosting solar self-consumption and reducing demand charges. These are mainly behind-the-meter solutions, with benefits for consumers dealing with congestion. However, if not clearly regulated, BTM batteries that trade electricity on the markets could increase congestion; e.g. if there is high wind supply and therefore low electricity prices, but the battery is in a demand congested neighbourhood, congestion can be worsened if the battery starts charging from the grid. In countries like Germany and Japan, residential batteries allow consumers to store surplus rooftop solar energy, reduce grid reliance, and lower electricity bills. Some programs also enable consumers to earn revenue by participating in grid services through aggregated battery fleets (e.g. Germany, Netherlands, Australia, Austria).

Industry sector

Large-scale battery behind-the-meter installations help industrial users maintain operational continuity during outages, manage exposure to electricity price volatility through arbitrage, and contribute to grid stability. At NSG Group's Pilkington automotive glass plant near Toronto, a 5 MW/10 MWh behind-the-meter lithium-ion battery has been installed to manage peak electricity demand²⁶. This

peak-shaving strategy reduces both energy costs and CO₂ emissions, replacing more carbon-intensive grid power.

Mobility sector

Vehicle-to-Grid (V2G) systems enable EVs to function as mobile storage assets, with charging during low-price periods and exporting energy back to the grid for peak demand, frequency support, or emergency backup. The UK's Octopus Powerloop trial equipped 135 Nissan LEAFs with bidirectional chargers, demonstrating value in reducing peak load and contributing to grid flexibility; it is now entering the National Grid's balancing market²⁷.

Agriculture sector

In remote and rural settings, BTM battery storage integrated with renewables enables reliable access to power for essential agricultural services, such as irrigation, cold storage, and mechanized tools, reducing dependence on diesel and improving food security. The Western Downs Green Power Hub (Australia) features a 400 MW solar farm and a 540 MW/1080 MWh battery, demonstrating utility-scale storage sited on agricultural land²⁸.

Community

In Australia and Canada, targeted programs (e.g. Flinders in Victoria, Australia or CERRC in Canada) enhance energy access and stability in remote or vulnerable areas, often with Indigenous community involvement.

➞ See the exhibits:

- Australia Flinders Community Battery
- Canada Mary's Harbour Renewable Project
- Canada Lhu'àan Mân N'tsi Project for more information

4. GOVERNMENTS AND SOCIETY

Beyond direct market players, governments and society benefit from electricity storage in ways that support broader public policy goals.

Grid resilience and energy security

Storage enhances national energy security by enabling higher shares of domestic renewables, reducing reliance on imported fossil fuels, and providing backup capacity during extreme weather events or geopolitical shocks. For example, the Republic of Korea has prioritized storage in their national energy security strategies²⁹.

Decarbonization and system cost savings

By displacing fossil-fuel peaker plants, reducing curtailment, and enabling a more flexible grid, storage helps achieve climate goals while lowering long-term system costs. For example, Germany's system studies

show that large-scale deployment of storage could avoid billions in avoided grid upgrades and curtailed generation by 2045¹³.

Better air quality

By enabling clean energy in densely populated or diesel-reliant areas, storage reduces local air pollution and public health burdens, particularly in urban and remote regions where air quality is a growing concern.

In conclusion, electricity storage creates significant value for the power system by enhancing flexibility, reliability, and efficiency across multiple dimensions. It supports the integration of renewable energy sources by balancing supply and demand in real time, reducing curtailment, and deferring costly grid upgrades. Storage contributes to system resilience by providing backup power during extreme weather events, supporting black-start capabilities, and improving overall energy security by reducing dependence on imported fossil fuels. Furthermore, it offers essential ancillary services such as frequency and voltage regulation, enabling a more stable and responsive grid. Storage can also reduce system-wide costs by minimizing the need for peaker plants and optimizing the use of existing infrastructure. As these benefits often extend beyond the traditional market framework, recognizing the full system value of storage is crucial for designing effective policies and investment strategies. Moreover, when aggregated across many users, these flexible loads reduce pressure on the grid during expensive peak periods, easing wholesale market price volatility. This collective load shifting lowers the need for high-cost peaker plants and reduces system balancing costs borne by all consumers. In the long term, broad deployment of storage supports a more efficient, flexible system, contributing to lower average electricity prices across the market.

Having established how electricity storage can deliver system-wide value, the next chapter explores how developers and asset owners can capture that value through market participation, revenue stacking, and business models that align with evolving energy system needs.



The battery with a specially designed mural, painted by Bunurong artist, Glenn Shaw. Picture courtesy Mornington Peninsula Shire.



3.

VALUE CAPTURE STRATEGIES FOR DEVELOPERS AND OWNERS

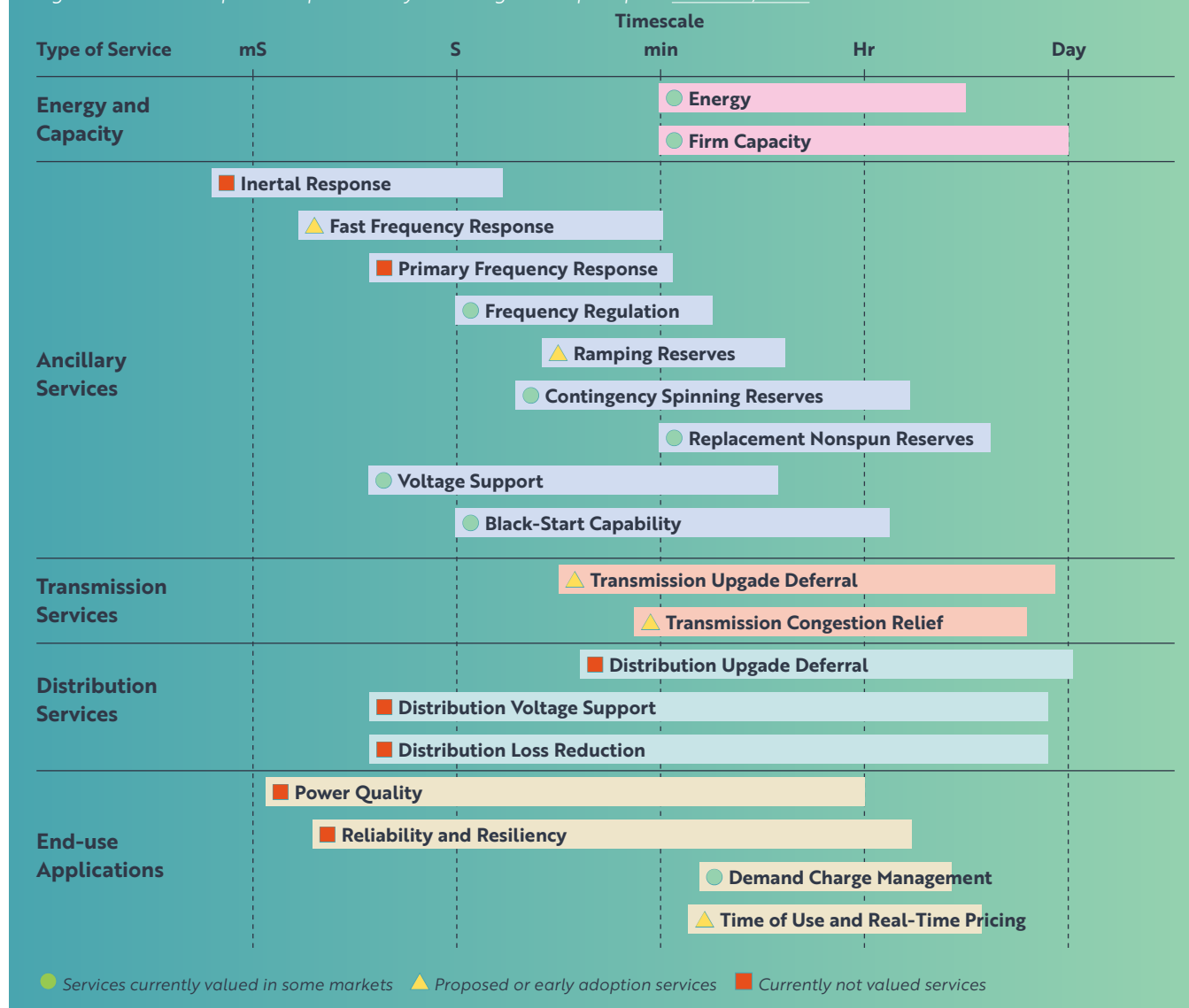
3.1 Revenue Generation

A wide range of services is already supplied by electricity storage projects and portfolios. The associated revenues for storage can be generated in different energy markets. Figure 8 shows an overview of different types of services that storage provides and the emergence of new services with lower market maturity and less well defined valuation and market conditions. The figure depicts differences between services currently valued in some markets (e.g. black-start capability), proposed or early adoption services (e.g. fast frequency response) and currently not valued services (e.g. inertial response). There are examples, however, where the services not (yet) valued are practiced in projects such as the RWE battery project in the Netherlands, providing inertial response.

Grid system services

In general, grid system services are essential to maintain power quality, grid stability and system flexibility. Especially with the transition to intermittent renewable energy sources, electricity storage can support the integration of renewable energy sources, avoiding curtailment, decreasing peak demand and dampening price fluctuations. Additionally, ancillary services, are becoming increasingly important for grid balancing, as conventional generation assets will partly be replaced by smaller scale fast-responding electricity storage solutions. One of the current services often not valued is the inertial response, a grid service supplying or absorbing power within milliseconds, usually provided by rotating masses of turbines. In the Netherlands, the first inertia-ready battery energy storage system of 7.5 MW/11 MWh

Figure 8 Timescale of services provided by BESS⁶. Figure adapted from CEM SBS, 2024.



has started commercial operation on the site of the company's power plant³⁰. Establishing revenue models for these services will become increasingly important as grids move away from synchronous fossil generation.

See the exhibits

- The Netherlands RWE's inertia battery
- Finland Kurkiaska Supercapacitor Integration for more information

Long-duration electricity storage services

The timescale of services provided by battery energy storage systems (BESS) is currently projected to range from several hours to a day. However, long-duration energy storage (LDES) is gaining traction in regions with strong seasonal variation, while short-duration systems thrive in fast-response markets. In the near future, long-duration storage, such as flow batteries (see exhibit Yadlamalka in Australia) or hydrogen-based systems, will also require bespoke valuation frameworks to reflect their contributions to seasonal balancing and firm capacity. Future services that can be fulfilled by LDES solutions might be different from current shorter term services and more research could be done for this integration. The UK has designed a policy framework (cap and floor) to enable investment in long-duration electricity storage to counter barriers as long-lead times, high upfront capital costs and uncertainty in securing revenues³¹. Next to this, the International Solar Alliance has recently created an implementation roadmap for long-duration energy storage in developing nations, guiding decision-makers towards further upscaling of LDES solutions³².

See exhibit Australia Yadlamalka Energy-Spencer Energy Project for more information

Diverse revenue streams

A study by EnTec on energy storage highlights the wide variety of business models currently in use, many of which are also illustrated by exhibits in this whitepaper³³. It shows that different storage technologies often rely on distinct primary revenue streams, depending on the specific services they provide to the energy system. The study also emphasizes the versatility of battery and other electricity storage technologies, which can deliver a broad range of services, including support for energy generation, bulk energy storage, transmission and distribution grid services, behind-the-meter energy management, ancillary services, and more. In that study (*Table 2 and Figure 9*) respondents mentioned generation support services and bulk storage services as very important and within this category arbitrage is the most mentioned service. Frequency containment reserve is the dominant service provided in the Ancillary services which was in that study the second largest group of services provided by storage projects and portfolios. For batteries it was the group of services providing the largest revenue stream. This analysis followed the definitions and descriptions of service segmentation provided by EASE³⁴.

Revenue differences throughout the year

The value of electricity storage shifts throughout the year, from adapting to seasonal market dynamics, to renewable generation patterns and evolving grid needs, strengthening its overall revenue position. In summer, storage systems can capitalize on midday solar surpluses and high evening demand peaks through energy arbitrage and fast frequency response, while in winter, they capture higher returns from capacity markets, balancing services, and resilience during grid stress. This seasonal flexibility allows storage to "stack" multiple revenue streams over time, such as self-consumption optimization in spring, grid support in summer, storm resilience in autumn, and backup power or arbitrage in winter. This enhances the year-round utility and can increase investment resilience.

Table 2 Share of revenue by service group and technology³⁷

*Mechanical and electrochemical technologies are both part of electricity storage technologies

Technology group	Generation Support Services and Bulk Storage Services	Services to Support Transmission Infrastructure	Services to Support Distribution Infrastructure	Services to Support Behind the Meter Customer Energy Management	Ancillary Services	Any other service
Chemical	59%	14%	9%	1%	3%	13%
Mechanical*	49%	12%	16%	1%	21%	0%
Electrochemical*	28%	3%	4%	10%	54%	1%
Thermal	0%	5%	13%	73%	3%	8%
Mix	35%	0%	4%	9%	35%	16%

For example, the Hornsdale Power Reserve in South Australia, a 150 MW/194 MWh battery, generated major summer revenues by delivering ultra-fast frequency control and capturing high spot prices during extreme heat events, saving the grid an estimated A\$116 million³⁵. Meanwhile, the Kilroot BESS in Northern Ireland, a 10 MW battery, increased winter earnings through co-optimized arbitrage, inertia, and balancing services, with studies showing revenue gains of over 50%³⁶. These examples demonstrate how seasonal revenue stacking not only maximizes the value of storage assets, but also strengthens their economic case across diverse applications and climates.

3.2 Value Stacking Strategies

The concept of value stacking, where multiple revenue streams are combined, is critical for the viability of many storage projects, technologies, and portfolios, as most rely on several sources of income.

By combining services across energy, capacity, and ancillary markets, developers and owners can improve both capital (CAPEX) and operational (OPEX) efficiency. Value stacking is particularly viable in mature markets where storage can offer layered services. Instead of using the asset for a single purpose, such as grid support, it is utilized for various services like peak shaving, arbitrage, and self-consumption, creating multiple income sources.

Different value stacking strategies are possible for creating the best value for electricity storage. *Figure 9* shows the results of the EnTec study, where respondents

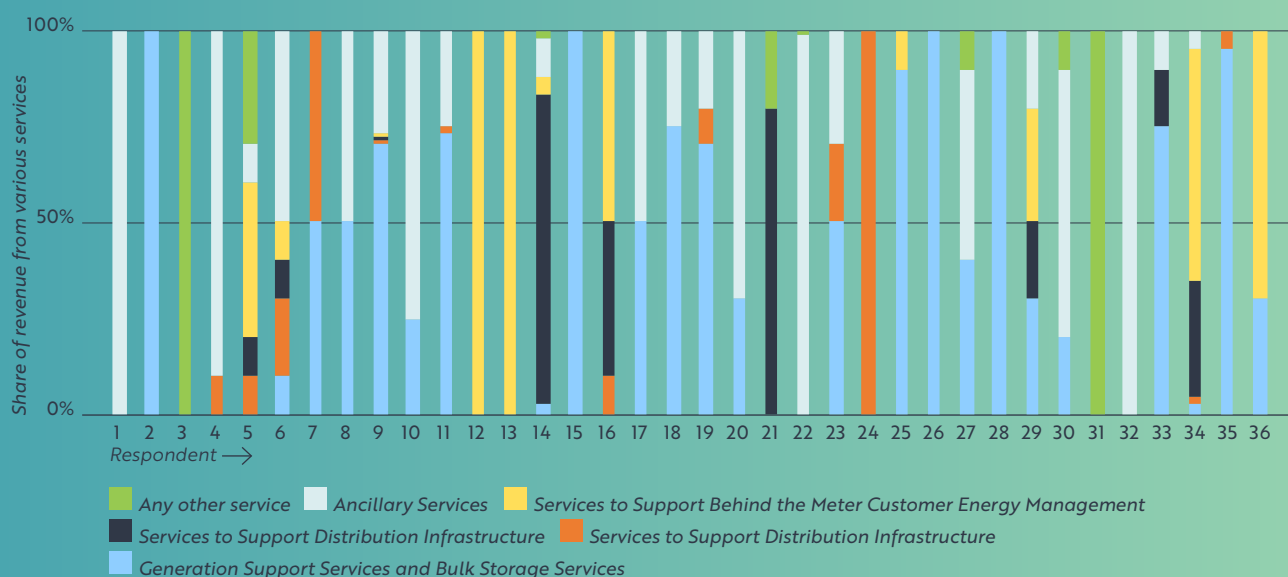
show a variety of value stacking possibilities³³. While some respondents show singular service revenue streams, most respondents show that stacking multiple value streams across the different services yields higher revenue. Evaluating the business case for each use case of electricity storage can be beneficial for building a strategy that incorporates value stacking.

World-wide examples showcase the value electricity storage can generate through multiple services. For example, the Oneida BESS project in Canada demonstrates how value stacking can include ancillary services, energy arbitrage, and capacity market participation at the same time. Another example can be seen in the United Kingdom. The National Grid ESO's Enhanced Frequency Response (EFR) program catalyzed investment in fast-response battery systems by offering a bankable revenue stream for services only batteries can deliver³⁸. These projects frequently combine EFR with capacity market contracts and balancing mechanism participation, demonstrating the technical and financial synergy of multi-service use⁴³. Furthermore, in the Republic of Korea, the Miryang ESS supports grid stability by providing fast-response services such as frequency regulation and peak shaving (see exhibit)³⁹.

➡ See the exhibits:

- Canada The Oneida Energy Storage Project
- The Republic of Korea Miryang ESS for more information

Figure 9 Different business models with various value stacking strategies for electricity storage³³



Value stacking is not merely a financial strategy but also a technical and operational challenge. Storage systems must be engineered to deliver multiple services simultaneously without degrading performance or lifespan, or adding too much complexity to the design and operation of the system. This demands advanced control software, forecasting tools, and interoperability with market access platforms. In essence, value stacking is both a systems engineering challenge and a business model innovation.

3.3 Market Conditions Enabling Value Capture

The viability of electricity storage projects is heavily influenced by regulatory design, market structure, and price dynamics. These conditions are explained in more details below. Additionally, technology enablers such as digital control platforms, forecasting software, and aggregation models also play a critical role. These tools allow distributed storage assets, such as residential batteries or electric vehicles, to be aggregated into virtual power plants (VPPs) capable of market participation. This democratizes access to value streams while enhancing system-level flexibility.

Regulatory design

Regulatory design plays a critical role in enabling electricity storage to capture its true value by defining its role in the energy system and ensuring access to sufficient revenue streams. Effective regulatory frameworks recognize storage as a distinct asset class and allow it to participate in both energy and grid service markets without facing double-charging or ownership restrictions. For example, in the United Kingdom, regulatory reforms have enabled storage assets to simultaneously provide grid balancing services and participate in the wholesale market, enhancing investment certainty and operational flexibility. Furthermore, Germany's recent revisions to the Renewable Energy Sources Act (EEG) have improved the regulatory treatment of co-located storage by reducing grid fees and clarifying tariff structures⁴⁰. This has increased the bankability of hybrid storage projects (see Eco Power One exhibit).

➡ See exhibit Germany Eco Power One for more information

Market structure

Markets that allow participation in multiple service layers and provide clear price signals and regulatory stability are better positioned to support storage deployment. Local market structures determine the accessibility of revenue streams for electricity storage, including participation in energy, capacity, and ancillary service markets. Markets with open, transparent rules and non-discriminatory access allow storage operators to stack revenues across

multiple services, which is essential for economic viability. In some areas, bilateral contracting and grid service procurement are the dominant model; in others, open market participation and aggregation are preferred. Australia offers a leading example of market alignment, where the Australian Energy Market Operator (AEMO) has developed a dynamic Frequency Control Ancillary Services (FCAS) market that supports fast-response technologies (see Bouldercombe exhibit). Time-of-use tariffs and flexible dispatch mechanisms further enable these assets to respond in real time to system needs.

➡ See exhibit Australia Bouldercombe for more information



Price dynamics

Price dynamics can create opportunities for storage assets to capture value through arbitrage and system balancing. High volatility and frequent price swings enable storage to buy electricity when prices are low (e.g., during solar peak production) and sell when prices are high (e.g., during peak demand). Yet arbitrage alone rarely sustains a viable business case. Markets must enable access to ancillary services, capacity mechanisms, and grid support programs to unlock the full potential of storage. In Canada, the proliferation of solar generation has resulted in negative midday prices and steep evening ramps, allowing storage systems to profit from price arbitrage while enhancing grid reliability (see exhibit Canada Restructured Energy Market).

➡ See exhibit Canada Restructured Energy Market for more information

In conclusion, to unlock the full potential of electricity storage, policymakers must align regulation, market access, and innovation. As Chapter 3 shows, value stacking across energy, capacity, and ancillary services is key to financial viability. Clear rules, digital infrastructure, and support for new business models, like residential aggregation and shared-use, will enable broader deployment. These measures will strengthen the business case for storage and accelerate the transition to a more flexible, resilient, and low-carbon energy system.



4.

THE ECONOMIC GAP IN ELECTRICITY STORAGE PROJECTS

4.1 Market Failure for Electricity Storage is Looming in Transitioning Markets

Current market mechanisms often fail to adequately recognize the diverse functions that electricity storage systems can provide to enable a resilient, reliable, affordable and sustainable energy system. This mismatch creates an economic gap: while the technical and market need for storage is growing rapidly, especially with increasing shares of renewable energy sources, the financial incentives remain insufficient to drive large-scale deployment, hindering further market integration.

A clear example of a market in transition is the increasing grid congestion, high curtailment of power and occurrence of negative electricity prices, where Australia, California and several European countries exceeded 5% of the hours in 2024⁴¹. This trend has been steadily growing throughout the past years, indicating the need for flexibility in a system where supply and demand cannot be continuously matched. Electricity storage systems can effectively reduce curtailment by absorbing electricity during the middle of the day (with peak PV production) and releasing at a later stage, creating a more stable market for electricity prices. However, adequate revenue generating market mechanisms should be put in place to achieve this.

Some countries have begun to close the economic gap by addressing the market failures quickly. Germany has recognized storage as an essential part of grid stability,

incentivizing BTM storage, and recently allowed storage to participate in the frequency response market⁴². The UK has adopted a Smart Systems & Flexibility Plan, implementing several market mechanisms for incentivizing flexibility solutions⁴³. Lastly, the province of Alberta in Canada has adopted a restructured energy market package that recognizes the flexibility services electricity storage can provide.

➔ See exhibit [Canada Restructured Energy Market](#) for more information

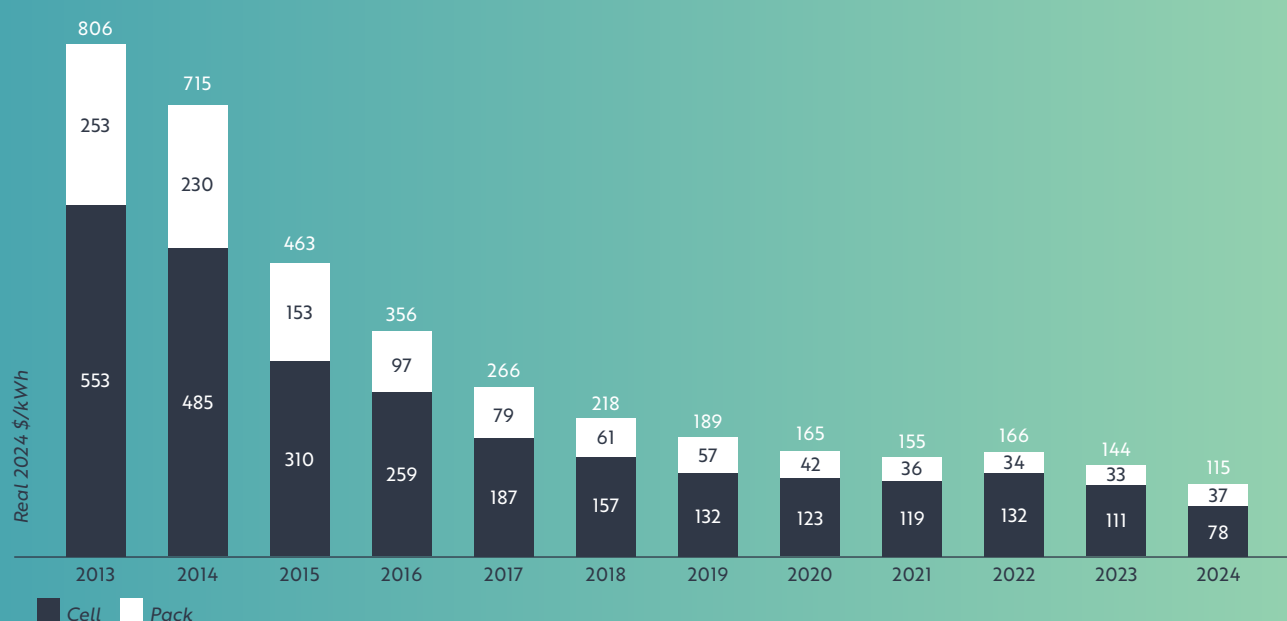
4.2 Project Costs Hinder a Viable Business Case

Despite the urgent need for electricity storage, the existing gap between project revenues and costs results in a reluctant attitude of electricity storage project developers. This project gap is partly due to high project costs, and partly due to large uncertainty in revenue streams.

Investment costs dynamics in electricity storage projects

Project costs very often hinder widespread deployment of both mature and maturing storage technologies. Capital expenditures alone typically account for more than 50% of total project costs (as visualized in Figure 6). Over the past decade, these costs have dropped significantly for lithium-ion batteries, with a 90% cost

Figure 8 Global cost developments in the past decade of volume-weighted average lithium-ion batteries, with a split between packs and cells⁴⁶. Figure adapted from [BloombergNEF](#).



reduction since 2010⁴⁴. *Figure 8* depicts this exponential decay, showing the extremely fast learning rate and cost decrease. It is expected that further innovation could drive an additional 40% cost reduction towards 2030¹⁰. Other storage technologies could experience similar cost declines if the same trend as lithium-ion batteries is followed. This cost decline is expected to not only arise from economies of scale and numbers (including improved supply chains), but also increased R&D investments (learning-by-researching), customer feedback (learning-by-using), and spill-over effects (learning-by-interacting)⁴⁵. Technology standardization and modularity are typically important factors that rapidly drive down costs. This underscores the need for fast innovation cycles, cooperation and market scaling to achieve the prospected 2030 cost decline.



Current market mechanisms often fail to adequately recognize the diverse values that electricity storage systems can provide to enable a resilient, reliable, affordable and sustainable energy system.

Supply chain disruptions and the demand for scarce materials significantly affect investment costs as well. Especially when there is large dependence on one export country or region, supplier diversification might be difficult to achieve. The further upscaling of the electricity storage markets requires diversification of technologies and global supply chains to counteract large price fluctuations. For this, properly managed international collaboration is required. Together, these measures could drive down CAPEX for electricity storage solutions.

Market and regulatory frameworks driving operational costs

Next to the technology investment cost, developers face significant operational expenditures, part of which are highly influenced by market mechanisms and regulations. These OPEX, as visualized in *Figure 6*, consist of, amongst others, O&M expenditures, grid connection fees and taxations. In many countries, as long as electricity storage is both considered a generator and consumer, electricity storage systems are charged both for charging and delivering to the grid, also referred to as double taxation⁴⁷. This is generally considered as one of the key regulatory barriers for electricity storage.

Furthermore, grid connection fees highly affect, arguably disproportionately, electricity storage projects and often do not follow the principle of cost-reflectiveness, since storage can alleviate grid congestion and system grid costs⁴⁸. Lastly, increased interest rates and financing risks due to project immaturities significantly increase the OPEX and hinder the bankability of projects⁴⁹. As loan costs increase, the overall project costs increase as well, resulting in reduced investor returns and a more reluctant investor attitude. This creates the so-called interest rate feedback loop, which can be broken by adequate policy measures to derisk the technology and project financing.

4.3 Uncertainty in Revenue Streams Hinder Long-Term Project Viability

As highlighted in Chapter 3, electricity storage projects typically rely on value stacking to build a viable business case. However, these markets are often still immature or lack long-term price signals, making it difficult for project developers to forecast long-term project returns.

Energy arbitrage and its forecasting challenges

With increased renewable energy penetration, forecasting reliable revenue streams for electricity storage systems becomes increasingly difficult. Energy arbitrage, relating to charging the storage device when electricity prices are low, and selling when prices are high, is typically exposed to market volatility⁷. Forecasting this aspect is becoming increasingly difficult due to the uncertainty in RES penetration, electricity price fluctuations, and specifically the aspect of negative electricity prices⁵⁰. As more storage

assets enter the market, the cannibalization effect (where increased competition decreases the available incomes) increases, undermining the profitability of electricity storage services.

The undervaluation of ancillary services

Ancillary services provided by electricity storage systems are vital to a reliable operation of the grid, yet cease to be adequately recognized and translated into viable revenue streams. These revenue streams can either relate to the capacity procured, the electricity produced, or a combination of both⁵³. The ancillary market was originally designed for large-scale conventional generators, where the market is often only opened for large-scale operators, hindering the participation of smaller scale electricity storage solutions⁵¹. Without reforms to open and standardize these markets, electricity storage will continue to face structural barriers to revenue certainty. A study of the European Association on Energy Storage has investigated the current market accesses for various European countries, highlighting the current trend towards the capacity markets in the first countries⁵².

4.4 System Cost Benefit Gaps that Hinder a Viable Business Case

As discussed in Chapter 2, there is a wide range of services that electricity storage services provide to the

power system. As visualized in *Figure 6*, the system cost-benefit of electricity storage can significantly exceed the revenues generated by a project. Despite the growing attention towards the added value of electricity storage services, there is a discrepancy between this value and the revenues that are captured by the market. This is commonly referred to as the 'system gap', or project cost-benefit gap. This subchapter discusses the most important undervalued system services.

Security of supply and energy system resilience

The combination of electricity storage with renewable energy sources enhances the integration of a diverse energy supply mix, while also alleviating the pressure on the electricity grid. Especially in countries with high congestion, tackling this issue is extremely relevant in the coming years with further integration of renewable energy sources. When this is combined with increased international interconnectors with neighboring countries, an even more stable and flexible energy system is created. Avoided grid strengthening costs can be a key aspect of added system value by electricity storage solutions. Grid positive (i.e. not negatively impacting congestion) electricity storage is already identified as a key mitigation solution, and examples of markets that value congestion relief are rising, however, this is often not translated into monetary revenues yet⁵³.

Improved grid quality

With the transition to renewable energy systems, the rotating inertia by large generators will partly phase out. To maintain grid stability, this will have to be replaced by synthetic inertia, which is a fast, digitally controlled response that imitates the stabilizing effect of spinning turbines⁵⁴. Electricity storage systems, particularly batteries, could respond within milliseconds, helping to prevent grid failures and outages. However, despite this crucial functionality, synthetic inertia is often not recognized or compensated for in current market structures, leaving a gap between system needs and project revenues⁵⁵.

Reduced import dependency

Through the implementation of electricity storage solutions, a higher integration of renewable energy sources can be achieved. As electricity storage tackles intermittency issues, the business case of renewable energy can improve, which not only results in CO₂-emission savings, but also in increasing energy independence. Countries, regions and remote areas can increase their self-sufficiency and reduce the dependence on other countries, thereby reducing exposure to threats⁵⁶. This requires long-duration electricity storage to be implemented. However, valuing LDES in market frameworks is emerging but not yet commonly translated into market value or project revenues in regions and countries across the world.



4.5 Key Market Design Limitations

Fast market deployment for electricity storage solutions is highly region and country specific. The absence of pricing mechanisms for various services can discourage investment and slow down the deployment of storage technologies that could otherwise enhance system reliability. This misalignment is mainly due to following aspects (see Figure 9):

- **Electricity storage asset class is not clearly defined or is not defined as a separate asset:** electricity storage should not be solely considered a generation or consumption asset in order to fully make use of its potential. This currently hinders the potential business case of energy supply and demand as one asset and results often in double taxation and not a level playing field in comparison to other flexibility solutions.
- **Low level of technology maturity results in high investment and financing costs:** the CAPEX of various electricity storage technologies is often still too high for a viable business case. Technology development is needed with fast innovation cycles that support economies of scale. Derisking technologies with proof of concept projects to allow bankable and insurable storage projects is very important to keep overall

project costs manageable and create a sustainable business case.

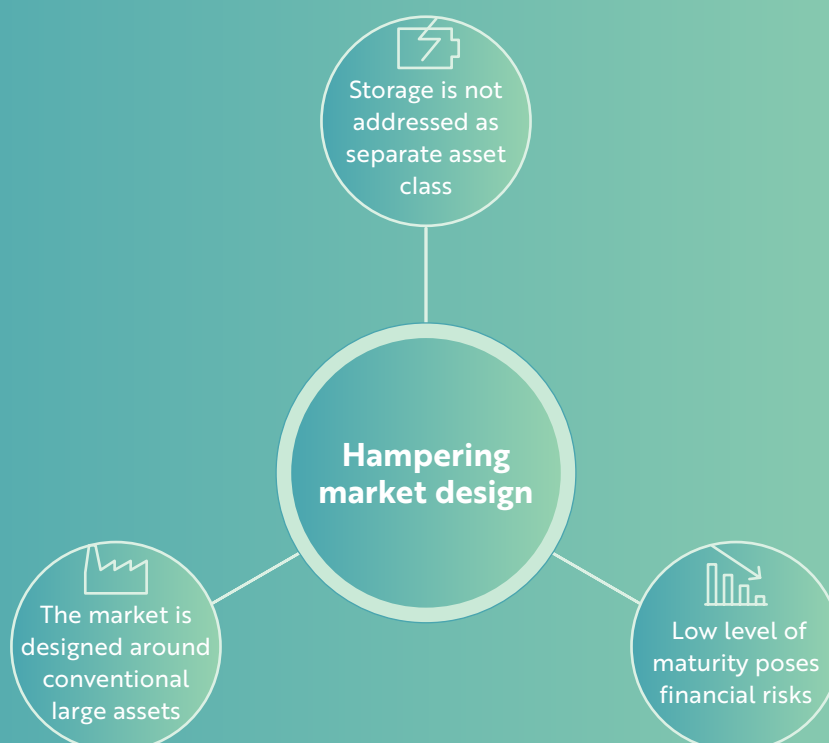
- **The current market is designed around conventional assets:** current market mechanisms still focus on conventional large-scale assets, blocking the integration of small-scale electricity storage solutions. This hinders access to various markets and inhibits value-stacking. Unvalued system benefits hinder the emergence of long-term price signals for storage projects and secure (stacked) revenue streams.

The next chapter proposes ways to address these market limitations and provides key examples of international exhibits to show strategies for successful replication.

Republic of Korea Samsung SDI Ulsan Solid-State Battery Line.
Image credit: Samsung



Figure 9 Key market design limitations for electricity storage integration in the energy system



5.

ACTIONS TO BRIDGE THE ECONOMIC GAP



Netherlands FlevoBESS. Image credit: Alfen and FlevoBESS.

To close the economic gap for electricity storage projects, multiple actions are needed. Support mechanisms that increase the business viability can focus on two aspects; decreasing the project gap, focusing on decreasing the difference between project cost and revenue streams, or decreasing the system gap, focusing on monetizing currently undervalued system aspects. This chapter addresses which actions are needed to close these gaps, where the answer lies on one hand on providing financial incentives to invest in electricity storage projects, and on the other hand on how to monetize system benefits.

5.1 Actions to Close the Project Gap: Decrease Project Costs

This part of the support strategy focuses on extending governmental financial support mechanisms to derisk electricity storage solutions, changing regulations to decrease operational expenditures, and increasing supply chain control to avoid material price fluctuations.

Extend support mechanisms

Extended support mechanisms are required to decrease the gap between project costs and revenues, ensuring that technologies are derisked and investments are increased. Decreasing the CAPEX of electricity storage projects is essential to accelerate the further deployment and improve the financial viability. One of the most direct mechanisms is the use of grants or subsidies, where part of the upfront investment costs are born by the government, often coupled to a certain percentage of total investment cost. One such example is the Clean Energy Investment Credit in the United States, accounting for up to 30% of the electricity storage investment costs⁵⁷. Boosting more investments can eventually facilitate economies of scale and drive down overall technology costs. Another example is the announcement of the Australian Renewable Energy Agency (ARENA) for funding support for a total of 2 GW/4.2 GWh grid-scale storage capacity, equipped with grid-forming inverter technologies⁵⁸.

Another significant part of the project costs relates to the network costs and grid tariffs levied when connecting an electricity storage asset to the grid. Lowering project costs could be achieved by reforming market regulations, for example avoiding double taxation, or creating exemptions from grid fees for BTM systems.

Flexible connection agreements between grid operators and project owners exemplify an approach that accommodates variable grid capacity without imposing penalties, or even result in lower connection costs. Non-firm grid access contracts, which allow storage assets to connect without guaranteed capacity, are being implemented in the Netherlands to reduce connection costs⁵⁹. Next to this, the Eco Power One project in

Germany is a great example of flexible connection contracts between the storage owner and grid operator.

➡ See exhibit Germany Eco Power One for more information

Cable pooling, where storage assets share grid infrastructure with co-located renewable generation, can significantly lower lifetime project costs, reduce grid congestion and reduce spatial needs. Countries like Germany and Canada have implemented such measures to encourage co-location and reduce grid congestion, by changing grid operator regulations.

Increase control on supply chain and strengthen international partnerships

Beyond direct financial incentives, supply chain resilience is becoming increasingly important. This is specifically relevant with high market concentrations in a low number of supplier countries, increasing vulnerability to supply shocks and disruptions for key components and materials⁶⁰. As electricity storage markets expand, additional control can be exercised on which materials are imported from which countries. Diversifying suppliers and securing access to critical materials and components can help mitigate risks and avoid unforeseen price fluctuations.

International cooperation and innovation are crucial to efficiently harvest technological potential on where it is developed best. Strategic partnerships on supply chains can broaden technology portfolios, together with increasing the sustainability of raw material production and recycling. A broad perspective should be taken on the full value chain for electricity storage technologies requiring scarce materials⁶¹. A good example of this is the recently announced strategy of the UK on critical minerals to further “explore collaboration with key partners such as the EU, US, and the Republic of Korea, whilst building on our existing critical mineral partnerships including with Australia, Canada, Japan, and Saudi Arabia”⁶². Fostering cross-border cooperation in technology development and material exchange can help mitigate risks and reduce costs. An example of the

geographical spread of current giga-industry factories for battery production is visualized in *Figure 10*.

5.2 Actions to Close the Project Gap: Increase Project Revenues through Market Risk Mitigation

Project viabilities can be increased by providing certainty on future revenue streams, enabling project developers to better assess the profitability of their project. Achieving this requires the clear establishment of electricity storage contracts and the development of new market mechanisms to recognize and compensate for the currently undervalued electricity storage services.

Extend financial guarantee and secured revenue structures

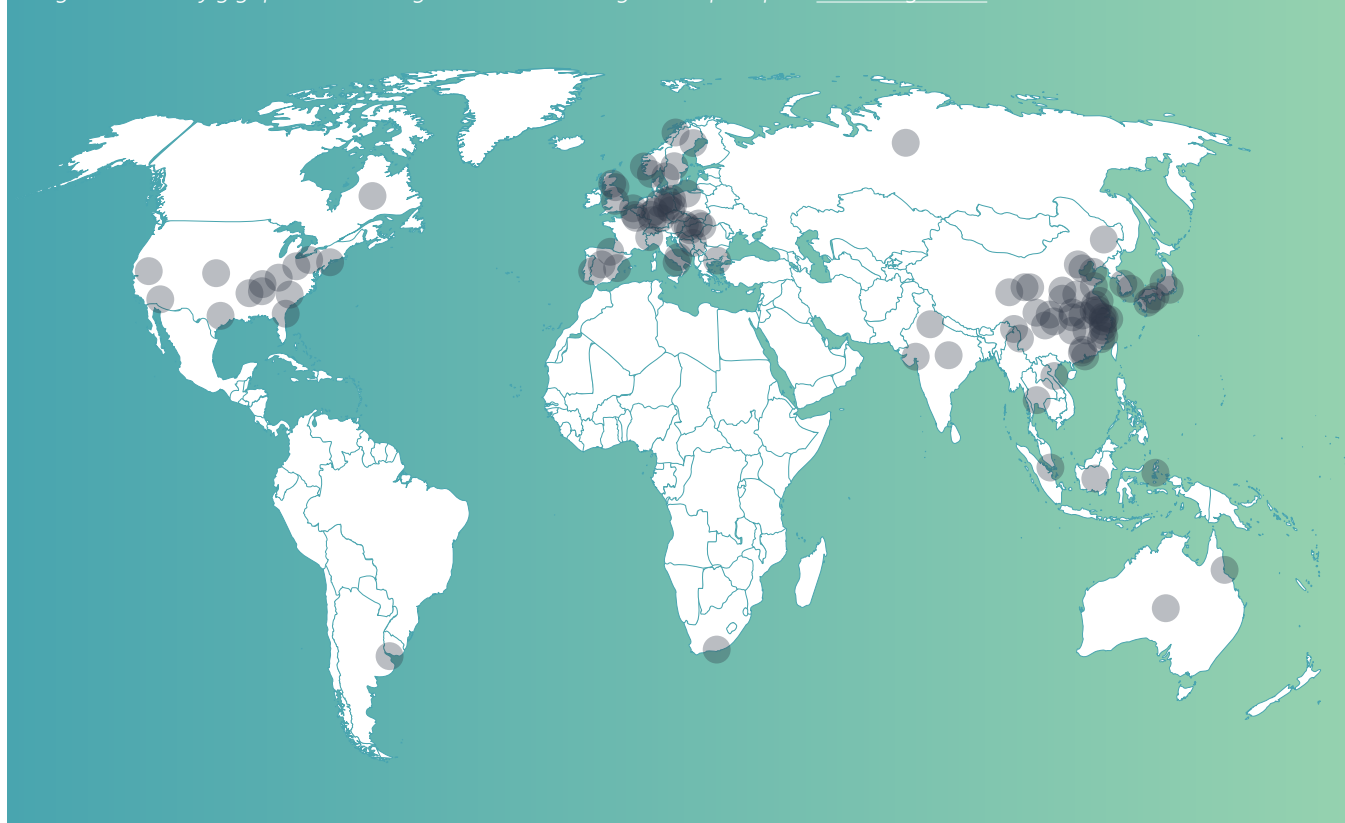
Mitigating market risks for future revenue streams is crucial for providing long-term clarity. Financing and guarantee structures, such as feed-in premiums or (two-way, cap and floor) contracts for difference (CFD), can help derisk market conditions by providing predictable revenue streams. A clear example is feed-in tariffs, where a set price per kWh is paid by the government, independent of the current market price. Another example is a cap and floor CFD where the storage

operator is paid the difference when market revenues fall below a fixed strike price and must pay back the difference when revenues exceed it. In this way, the added role of electricity storage next to renewable energy generation is valued as a service. When these types of support mechanisms are coupled to long-term contracts, risks are even mitigated further. The IEA has pledged that the most attractive electricity storage markets exist in countries with strong governmental support mechanisms for long-term contracts⁵. For example, in Canada, the Mary's Harbour Renewable Project in a highly remote area couples battery storage to a Power Purchase Agreements (PPA) to ensure grid reliability. Another example is the UK government implementing a cap and floor scheme to boost investments in LDES projects. The goal is to provide revenue certainty for investors by guaranteeing a minimum return (floor) and limiting potential maximum returns (cap)⁶⁴.

➡ See exhibits:

- Canada Mary's Harbour Renewable Project
- Canada Summerland Solar and Storage Project for more information

Figure 10 Battery gigafactories throughout the world⁶³. Figure adapted from *CIC energiGUNE*.



Incentivize peak reduction mechanisms

Another way to enhance electricity storage revenues is by to incentivize peak reduction mechanisms⁷. Storage systems can be actively used to alleviate the pressure on the grid in times of high load, where the project developer is paid when the asset reduces the system load. Very often, these storage systems are directly coupled to renewable energy sources. A clear example is the Summerland project in Canada, where homeowner's batteries are coupled to a PV system to lower electricity bills and charge during high load times.

5.3 Actions to Close the System Gap: Implement Market Reform Strategies

The formation of new markets for undervalued electricity storage services is essential to increase the revenue streams, as traditional electricity markets often fail to capture the added values of electricity storage. Value stacking and innovative business models will have to be increasingly enabled, where electricity storage solutions can simultaneously participate in several markets.

Enable storage assets to operate in various markets

To generate multiple revenue streams simultaneously, regulatory frameworks must allow storage assets to participate in multiple energy markets. When an asset can operate on the day-ahead and intraday market, revenue can be generated for the asset owner, while averaging out electricity prices.

Electricity storage can be valued not only for its role in energy arbitrage, but also for its ability to provide capacity during peak demand hours. In order for this to be incorporated in market design, capacity markets must evolve to reflect the fast-response and short-duration characteristics of storage, which differ from traditional generation assets. In Japan, a new capacity market has been designed that allows electricity storage systems to compete for three-hour blocks of 10 MW, with winners receiving 20-year subsidies that cover fixed costs⁶⁵. Integrating this in future market design will ensure that electricity storage solutions will be fairly compensated for their contribution to grid reliability.

➡ See exhibits:

- [Canada Expanded Ancillary Services in Alberta](#)
- [Canada's Targeted Programs Supporting Energy Storage Deployment](#)
- [Canada Alberta eReserve4 and eReserve6 for more information](#)

When electricity storage assets can also participate in ancillary markets, an even wider scope of revenue streams becomes available. These ancillary services relate to frequency regulation and voltage support to provide grid stability. However, these services are often undervalued or inaccessible to storage assets because of hindering regulations. A good example of where participating in multiple services is possible is Australia's Bouldercombe BESS, operated in partnership with Tesla. The BESS participates in all eight Frequency Control Ancillary Services (FCAS) markets while also engaging in energy arbitrage.

➡ [See the exhibit Australia Bouldercombe for more information](#)

Extend governmental support options towards electricity storage

Governments play a pivotal role in accelerating electricity storage deployment through target setting, incorporating storage in tendering processes, and formulating mandates. Through the explicit valuation in governmental requirements, project developers will be incentivized to incorporate electricity storage in their project design. One clear example is the coupling of renewable energy production with electricity storage in tenders, helping on one hand the further integration of renewables, and on the other hand stabilizing the grid frequency. The Tomakomai PV project in Japan is such an example, which solely uses its battery to stabilize grid frequencies⁶⁶. This ensures that new renewable energy capacity contributes to system stability as well.

One of the key enablers for kickstarting new markets is setting clear targets. National and regional storage targets can provide long-term market signals and reduce investor uncertainty. This has also been addressed as an example for emerging economies where electricity storage has been implemented only on a somewhat smaller scale yet⁶. For example, in 2022, India released its draft National Electricity Plan, setting out ambitious targets for the development of battery storage, with an estimated installed capacity of 51-84 GW by 2031-2032⁶⁷. Next to this, specific requirements can be designed for the incorporation of electricity storage in new projects, such as the mandatory installation of energy storage systems in public buildings in the Republic of Korea⁶⁸.

Monetize societal system values

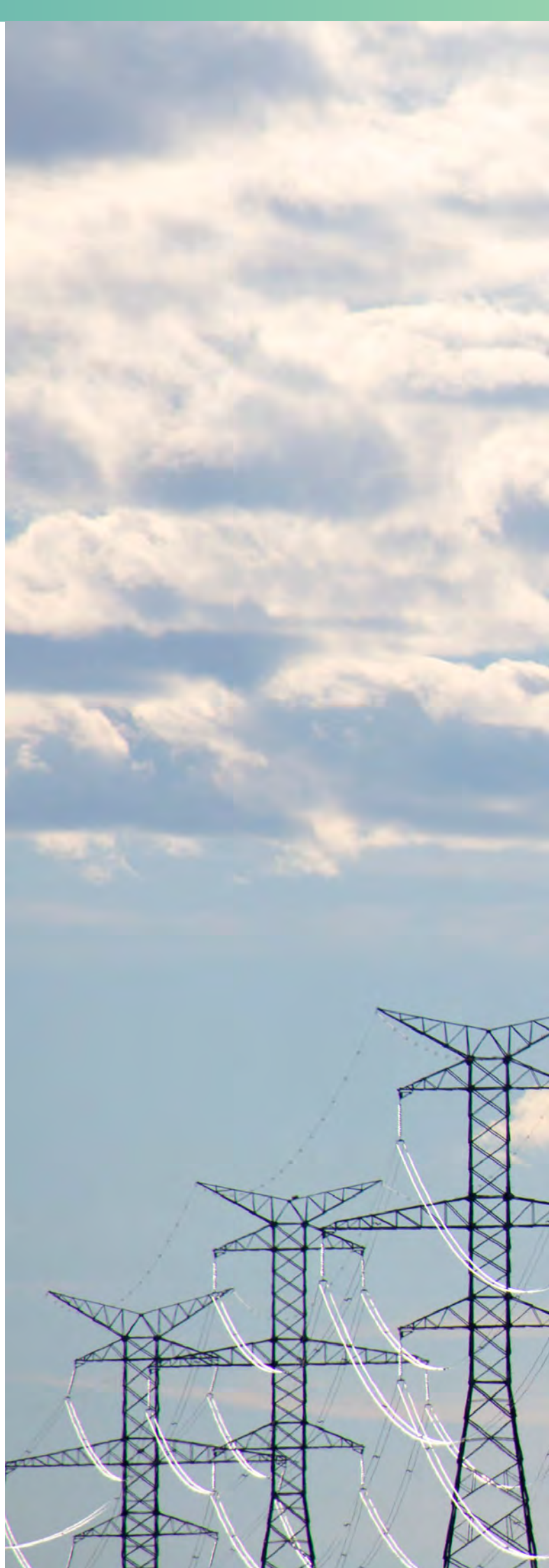
Beyond direct energy market participation electricity storage delivers significant system values that are often not monetized, such as alleviating grid congestion and avoiding CO₂ emissions and other environmental impacts. Moving towards lowest monetized and non-monetized societal cost of the energy system would require policymakers implementing mechanisms that

reward these contributions, with for example advanced carbon pricing schemes that recognize avoided emissions. Electricity storage also enhances energy independence by reducing reliance on imported fuels and increasing the energy system resilience. Capturing these broader values is essential for aligning market incentives with the societal benefits of storage but is also challenging⁶⁹.

Innovative business models

Supporting innovative business models for electricity storage is essential to unlock its full potential. This includes revisiting standard roles and collaboration across the value chain—engaging developers, producers, consumers, grid operators, financiers, local community and technology providers—to allow for more effective value creation and risk sharing. Such models not only enhance system flexibility but also improve the bankability and scalability of storage projects. For instance, the FlevoBESS project in the Netherlands has strong community involvement and wide risk and value sharing through an ownership structure with more than 400 local shareholders. The project supports local wind farms and has a revenue base through a long-term arrangement with a large national electricity producer that manages supply and demand in energy markets with the battery. Through this, revenue can be generated for all involved partners and risks can be shared and reduced to enhance the bankability of storage projects.

➞ [See exhibit The Netherlands FlevoBESS for more information](#)





6.

CONCLUSION & WAY FORWARD

Electricity storage holds significant value for modern energy systems, offering both economic and non-economic benefits. By understanding value capture strategies, addressing the economic gap, and involving key stakeholders, a profitable future for electricity storage projects is created at the benefit of reaching a more reliable, affordable and clean energy system for society. International collaboration, such as through the Clean Energy Ministerial (CEM), is crucial for sharing best practices and accelerating the deployment of effective storage solutions throughout the world. Achieving the ambitious global target of 1500 GW of energy storage in the power sector by 2030 will require such coordinated and collaborative action. Continued efforts and innovations are needed to further drive down costs for a broad and diversified portfolio of electricity storage technologies. To help bridge the remaining economic gap and accelerate progress, several key actions are formulated (see Figure 11):



Figure 11 Action table for increasing the value of electricity storage, organized according to the CEM pillars

1. Policy & Regulation	2. Supply Chain & Manufacturing	3. Financing
• Enable value capturing and stacking through equal market access • Establish market designs that value new and diverse electricity storage services • Integrate storage in long-term infrastructure strategies	• Establish a broad portfolio of energy storage solutions • Diversify supply chains of electricity storage technologies • Increase energy independence through local projects	• Increase support mechanisms to kick-start electricity storage investments • Ensure bankable and insurable storage technology projects to unlock private capital

Policy actions

Successful electricity storage projects have to rely on **equal market access** and a long-term perspective on revenues. **Value stacking** is a crucial strategy, leveraging multiple revenue streams from energy, capacity, and ancillary markets to ensure financial viability. To fully harness the system value of electricity storage, policies must evolve to **recognize and compensate for the diverse services** that storage technologies can provide. This means that market design should enable the participation of storage assets in various energy and ancillary service markets. Next to this, **long-term strategies should integrate storage** as a core component of energy infrastructure development. Lastly, **the broader system and societal values** should be recognized, relating to avoided CO₂-emissions, improved air quality and reduced electricity prices for consumers.



Supply chain actions

A **resilient portfolio** of electricity storage technologies and their supply chains is critical for maintaining grid stability, and ensuring a secure and cost-effective energy system. The **diversification of supply chains** decreases the risk for supply chain disruptions and eventually **increases energy independence** of both rural areas as well as nations as a whole. Next to this, a broad portfolio of electricity storage technologies increases the overall resilience of the energy system, by offering a wide range of services, ranging from short-term fast-response to long-term storage for energy security.



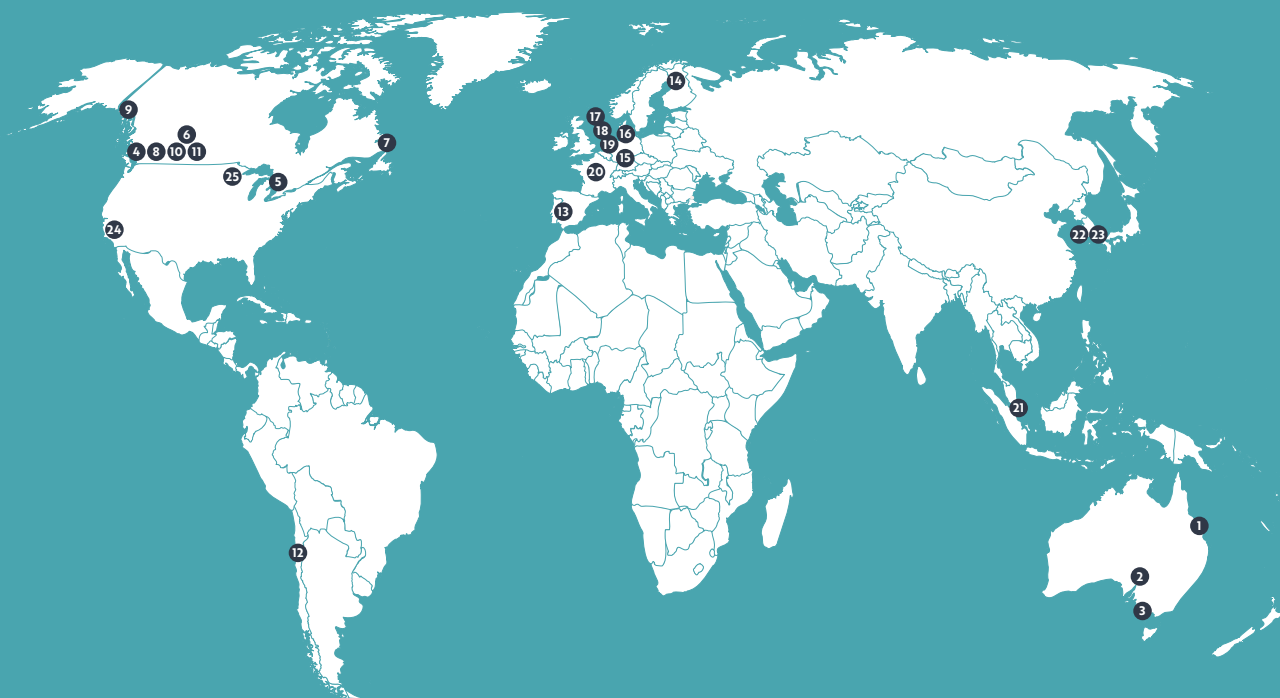
Financing actions

To close the economic gap and avoid market failures, **support mechanisms** are needed to decrease project costs and monetize undervalued system benefits, ensuring a viable business case for electricity storage projects. Additionally, having **bankable and insurable projects** is vital for attracting investment and mitigating risks, ensuring long-term project success. Lastly, excessive OPEX should be avoided, for example related to **double-taxation** and grid tariffs.



7.

INTERNATIONAL EXHIBITS ON ELECTRICITY STORAGE



#	Country	Title	Page
1	Australia	Bouldercombe BESS	47
2	Australia	Yadlamalka Energy-Spencer Energy project	37
3	Australia	Flinders Community Battery	43
4	Canada	Canada's targeted programs supporting energy storage projects	52
5	Canada	Oneida Energy storage	48
6	Canada	Alberta eReserve	54
7	Canada	Mary's Harbour Renewable Project	44
8	Canada	Summerland Solar and Storage Project	49
9	Canada	Lhu'ààn Mân N'tsi Project	45
10	Canada	Alberta Restructured Energy Markets	53
11	Canada	Ancillary Services in Alberta	55
12	Chile*	AES Andes - Pampas hybrid park	45
13	Spain*	Alcántara reversible pumped hydro storage	41
14	Finland*	Kurkiaska Supercapacitor Integration	49
15	Germany*	Study on the value of large battery storage	40

#	Country	Title	Page
16	Germany	Eco Power One	50
17	The Netherlands*	FlevoBESS	46
18	The Netherlands*	RWE inertia battery	51
19	The Netherlands*	Value of electricity storage	39
20	EU*	EnTEC study on energy storage	38
21	Singapore*	Seatrium Floating Living Lab	40
22	Republic of Korea*	Miryang ESS	50
23	Republic of Korea*	Samsung solid-state battery line	41
24	USA*	Willow Rock Compressed Air Storage	42
25	USA*	Form Energy's Iron Air battery	42

*literature based exhibit

EXHIBITS CHAPTER 1: INTRODUCTION INTO THE ENERGY STORAGE PORTFOLIO AND FUNCTIONS

AUSTRALIA YADLAMALKA ENERGY-SPENCER ENERGY PROJECT: co-located Vanadium Flow Battery Storage and Solar project helps meet Australia's energy needs



HIGHLIGHTS

- The Spencer Energy Project co-locates a Vanadium Flow battery (8MWh AC) and a solar photovoltaic farm (6MWp DC).
- The project demonstrated that Vanadium Flow batteries (VFBs) and PV Direct Current (DC) coupled systems can be successfully integrated.
- VFBs present significant advantages over lithium batteries, going further (medium duration of 4 hours storage, 100% discharge for longer, heavy cycling and 25-year lifetime) while thriving in hot conditions.
- It has helped to resolve grid stability problems in South Australia.

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The project is a world-first, successfully connecting VFB (41 units) to a PV plant through a DC coupled Power Conversion System. The longer duration storage capabilities of VFB enables consumers to time shift power from midday to peak periods in the mornings and evenings, unlocking significant price advantages for South Australia. Unlike lithium batteries, VFB helps to meet the need for medium duration storage prescribed by the Australian Energy Market Operator's Integrated Systems Plan 2024 in geographies where

pumped hydro isn't viable. Importantly, the water-based chemistry, longer lifetime, and cycling and discharge efficiencies of VFBs, make them a safer and more robust alternative suited to Australia's extreme climates.

SPECIAL INSIGHT

The project highlighted the importance of prioritising early planning to identify the main sources of revenue, address equipment limitations and capacity constraints effectively. This helps determine which trading activities to pursue with regulators and design the equipment and control systems around the limitations of the trading environment. The Project team identified several trading scenarios that required independent control of power imports, exports, and Frequency Control Ancillary Services. For most of these scenarios, the team developed workarounds that allow the system to participate in profitable market activities without the need for costly upgrades or redesigns. This process also provided valuable insights into the system's technical boundaries, helping identify areas where future advancements in inverter technology will unlock even greater flexibility and market participation.



Image credit: ARENA



EU ENTEC STUDY ON ENERGY STORAGE: Unlocking Flexibility for a Renewable Future³³

HIGHLIGHTS

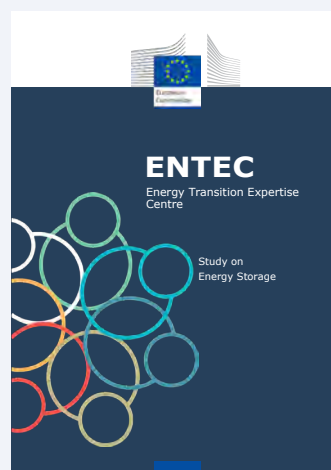
- Energy storage can significantly reduce system costs by optimizing electricity generation, reducing curtailment of renewables, and minimizing the need for fossil fuel-based backup
- By enabling higher shares of renewable energy, storage plays a crucial role in reducing CO₂ emissions and achieving climate targets
- Storage technologies enhance the reliability of the electricity system by providing essential services such as frequency regulation, voltage control, and backup during outages

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

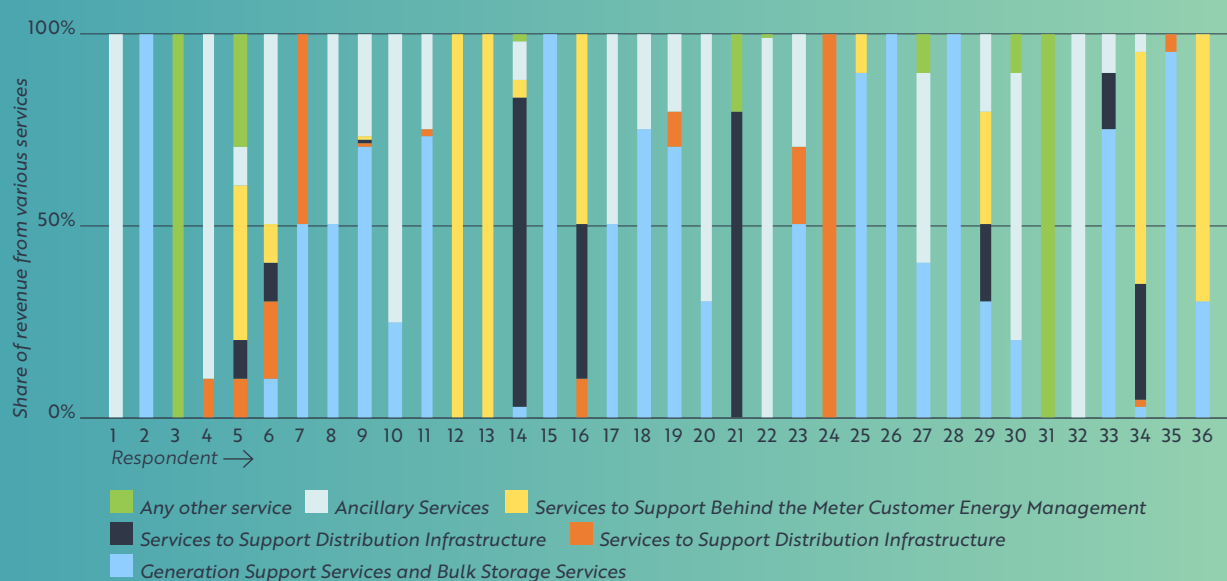
Energy storage is emerging as a cornerstone of the EU's future energy system. It allows for the efficient use of renewable energy by storing excess electricity during periods of low demand and releasing it when demand is high. This flexibility reduces the need for fossil fuel-based peaking plants and helps avoid costly investments in grid infrastructure. From a business perspective, storage systems can participate in multiple markets, energy, capacity, and ancillary services, creating diverse revenue streams. The economic value is further amplified by the reduction in fuel and CO₂ emissions, as well as the stabilization of electricity prices, which benefits both producers and consumers.

SPECIAL INSIGHT

The deployment of energy storage in the EU is expected to grow rapidly, with a diverse mix of technologies including lithium-ion batteries, pumped hydro, and thermal storage. By 2050, storage systems could provide a substantial share of the flexibility needed to balance a greatly intermittent grid. This growth will be accompanied by an increase in storage duration, enabling not just hourly balancing but also daily and even seasonal shifts in energy use. However, realizing this potential will require supportive policies, clear market signals, and investment incentives to ensure that storage can compete on a level playing field with other flexibility options.



Different business models with various value stacking strategies for electricity storage³³





THE NETHERLANDS STUDY ON THE VALUE OF ENERGY STORAGE: the costs and benefits of batteries in the power system¹⁵

HIGHLIGHTS

- Batteries in the power system can yield a net benefit of **€315 million per year**
- Next to this, batteries can reduce the climate impact and enhance system reliability with essential services

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Energy storage is emerging as a cornerstone of the Netherlands' future energy system. The flexibility reduces the need for fossil fuel-based peaking plants and helps avoid costly investments in grid infrastructure. From a business perspective, it would be beneficial if storage systems can participate in multiple markets, including energy, capacity, and ancillary services, creating diverse revenue streams. The economic value is further amplified by the reduction in fuel and CO₂ costs, as well as the stabilization of electricity prices, which benefits both producers and consumers. This study, conducted by Kalavasta in the Netherlands, has investigated these total system benefits and compared them with the total costs, showing a highly positive result towards 2030 (see image below)

SPECIAL INSIGHT

The deployment of energy storage in the Netherlands is expected to grow rapidly. By 2035, a 6 GW/24 GWh system could yield a net benefit of €315 million per year, as visualized in the figure below. This number arises when you add up all the system benefits and costs from both a consumer and producer perspective. On one hand, revenues are generated by the wholesale market and imbalance markets, whereas the costs are associated with operating the battery. On the other hand, savings are generated for electricity consumers from lower grid fees and lower electricity prices. For the producers, this results in a loss in margin. From a system perspective (depicted under 'various stakeholders') batteries result in imbalance costs savings and decrease the need for back-up capacity. Overall, this results in a total system benefit of €315M for one of the scenarios studied. But it is apparent that system values and benefits are not equally distributed across the value chain.

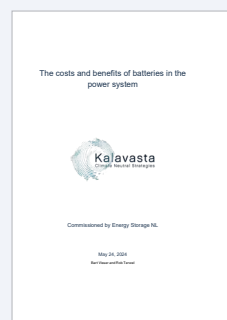


Figure adapted from Kalavasta¹⁵.



GERMANY VALUE OF LARGE BATTERY STORAGE:

evaluating the potential and benefits of large battery storage systems in Germany's future electricity system¹³



HIGHLIGHTS

- Expected 50x capacity growth towards 2050 and storage duration increase from ~1 hour to >4 hours
- Economic Benefit: Large battery storage systems can generate an economic benefit of approximately €12 billion by 2050
- CO₂ Reduction: storage can avoid 6.2 million tons of CO₂ emissions by 2030, increasing to 7.9 million tons by 2040
- Investment Pressure Reduction: energy storage reduces the need for additional gas power plants, potentially avoiding 9 GW of new gas power plants by 2030.
- Price Reduction: energy storage can decrease wholesale electricity prices by an average of €1/MWh between 2030 and 2050.

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Large battery storage systems can generate an economic benefit of approximately €12 billion by 2050. This can be achieved through reduced fuel and CO₂ costs, as well as lower electricity generation costs. The economic benefit indicated here results solely from the day-ahead wholesale market, whereas BESS can also generate further economic benefits. The storage systems can lower wholesale electricity prices by an average of €1/MWh between 2030 and 2050, benefiting consumers with a larger reduction of €1.1/MWh.

Large scale battery storage reduces the need for additional gas power plants, potentially avoiding 9 GW of new gas power plants by 2030. If there is no possibility of replacing large-scale battery storage and requiring the additional installation of gas-fired power plants, the wholesale price would be expected to be €4/MWh higher on average between 2030 and 2050.

SPECIAL INSIGHT

Battery storage is expected to increase from 1.2 GW/1.4 GWh in 2023, to 15 GW/57 GWh (average ~4 hours storage) by 2030 and 60 GW/271 GWh by 2050. This will go hand in hand with a storage duration increase from approximately 1 hour in 2023, towards 4 hours in 2050.

SINGAPORE SEATRIUM FLOATING LIVING LAB:

Southeast Asia's first floating and stacked battery storage system⁷⁰



HIGHLIGHTS

- First floating and stacked energy storage system (ESS) in Southeast Asia
- 7.5 MWh of battery storage capacity deployed on a floating platform
- Developed by Seatrium in partnership with EMA and Univers
- Operational since Q1 2024, located at Pioneer Yard, Singapore

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Singapore's Floating Living Lab addresses the country's land constraints by deploying a vertically stacked energy storage system on water. The system supports grid stability by storing solar energy during off-peak periods and discharging it during high demand. It also serves as a testbed for marine electrification, including charging infrastructure for electric harbor craft and LNG bunkering.

SPECIAL INSIGHT

The ESS is mounted on a modular floating platform designed to withstand marine conditions, including tidal variations and wave action. This innovative design not only conserves valuable land but also opens up possibilities for scalable offshore energy hubs. The vertical stacking of battery racks further optimizes space usage, achieving up to 40% land savings compared to traditional ground-based systems. A key feature of the project is its Smart Energy Management System (SEMS), developed in collaboration with Univers (formerly Envision Digital). This AI-driven platform continuously monitors energy demand, battery health, and grid signals to optimize charging and discharging cycles. It also integrates predictive analytics to anticipate peak loads and renewable generation patterns, enhancing both economic returns and grid reliability.

REPUBLIC OF KOREA SAMSUNG SDI ULSAN SOLID-STATE BATTERY LINE: Advancing Next-Gen Storage Manufacturing in the Republic of Korea⁷¹

HIGHLIGHTS

- Construction of a solid-state battery line will be developed at Samsung SDI's Ulsan plant
- Energy density can be 40% higher than current prismatic batteries
- Planned to be operational in 2027



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Samsung SDI's new facility in Ulsan marks a major step toward the commercialization of solid-state batteries, offering higher energy density, improved safety, and longer lifecycles compared to conventional lithium-ion batteries. The batteries will have an energy density of 900Wh/L. The pilot line will serve as a blueprint for future gigafactories, enabling the scale-up of solid-state production for electric vehicles and stationary storage. This initiative aligns with the Republic of Korea's broader industrial policy to secure battery supply chains and maintain global competitiveness in advanced energy technologies.

SPECIAL INSIGHT

The Ulsan line builds on Samsung SDI's pilot operations in Suwon and integrates cutting-edge materials and manufacturing processes. It also serves as a platform for collaboration with local universities and research institutes, fostering innovation and workforce development in the solid-state battery sector.

Image credit: Samsung



SPAIN ALCÁNTARA II REVERSIBLE HYDROELECTRIC POWER PLANT: powering renewable integration in Spain⁷²

HIGHLIGHTS

- Existing pumped hydro project will be upgraded to enable reversible energy storage of 16 GWh
- Project will optimize management of water resources
- Grid connected with installed capacity of 440 MW



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Alcántara project leverages the existing hydroelectric complex on the Tagus River. Instead of only releasing power through the pumped hydro facility, it also operates as a reversible pumped-storage system. Two reservoirs operate as a closed-loop system, where the upper reservoir acts as a 'giant battery'. Using surplus renewable electricity, especially from solar and wind, water can be pumped to the upper reservoir. During peak demand, the water is released to generate electricity, providing up to 16 GWh of dispatchable energy.

SPECIAL INSIGHT

By using natural land formations and a closed-loop seawater system, the project minimizes the environmental impact and avoids the need for river diversion. Its integration with a nearby solar project creates a fully renewable, dispatchable energy system, demonstrating how geography and innovation can converge to deliver sustainable energy solutions at scale.

USA WILLOW ROCK ENERGY STORAGE CENTER: Long-Duration Compressed Air Storage for California's Clean Energy Future⁷³

HIGHLIGHTS

- 500 MW/4000 MWh Advanced Compressed Air Energy Storage (A-CAES) facility
- Designed to deliver 8+ hours of dispatchable power
- Developed by Hydrostor USA Holdings, with a conditional \$1.76 billion loan guarantee from the U.S. Department of Energy



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Willow Rock Energy Storage Center will store excess renewable energy as compressed air in underground caverns and release it during peak demand, providing reliable, on-demand electricity to the California grid. With a 50+ year operational life and minimal performance degradation, the project offers a cost-effective, long-duration alternative to lithium-ion batteries. It supports grid reliability, reduces curtailment of solar and wind, and optimizes transmission infrastructure by shifting energy delivery to when it is most needed. Its use of standard components and underground storage makes it scalable and less dependent on critical minerals, positioning it as a strategic asset in the U.S. long-duration energy storage portfolio.

SPECIAL INSIGHT

Willow Rock demonstrates how compressed air storage can complement California's clean energy goals by providing technology diversity and geographic flexibility. The project is expected to create up to 700 construction jobs and 40 FTE jobs during operation, many of which align with skills from the region's oil and gas workforce.



Image credit: Hydrostor

USA IRON-AIR BATTERY DEPLOYMENT: Pioneering Multi-Day Storage in Minnesota⁷⁴

HIGHLIGHTS

- 100-hour duration iron-air battery system
- First commercial project planned to be deployed by the end of 2025
- Project capacity: 1.5 MW/150 MWh



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Form Energy's iron-air battery system stores and discharges energy by reversibly rusting and un-rusting iron, using oxygen from the air. This low-cost, earth-abundant chemistry enables multi-day storage at a fraction of the cost of lithium-ion batteries. The Minnesota project, developed in partnership with Great River Energy Xcel Energy, will help enable a clean and reliable electric grid year-round. With a 100-hour discharge duration, the system is designed to provide resilience during extreme weather events, and prolonged periods of low wind or solar generation, and other periods of grid stress. The project is expected to be deployed by the end of 2025, marking a major milestone in the commercialization of long-duration storage.

SPECIAL INSIGHT

This deployment is the first utility-scale demonstration of iron-air technology and a key step in continuing to validate its performance under real-world grid conditions. It also supports U.S. energy security by using domestically sourced materials and avoiding critical mineral supply chains. The project aligns with the U.S. Department of Energy's efforts to advance Long Duration Energy Storage (LDES) technologies towards widespread commercial deployment.

Form Energy iron-air battery modules built at the company's first high-volume manufacturing facility, Form Factory 1, in Weirton, West Virginia. Image credit Form Energy.



EXHIBITS CHAPTER 2: THE VALUE OF ELECTRICITY STORAGE IN DIFFERENT SYSTEMS AND CONFIGURATIONS

AUSTRALIA FLINDERS COMMUNITY BATTERY:

Mornington Peninsula Shire Council launches Flinders community battery, first non-network owned battery backed by the Australian Government



HIGHLIGHTS

- In 2024, the Mornington Peninsula Shire Council launched its first fully owned 120kW/360kWh battery.
- It absorbs excess solar energy, reducing solar waste and emissions while powering over 100 households.
- Profits from the battery will be directed to a Community Benefit Fund, to assist vulnerable and low-income households partake in the renewables transformation.
- It has created new capacity for more local rooftop solar and increased solar uptake in the area.

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

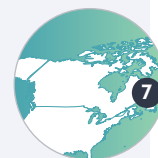
The Flinders Community Battery is a 120kW/360kWh battery, supplied by the Norwegian company Pixii, that plays a key part in the locality's ambition towards net zero carbon emissions from energy by 2030. The battery supports over 100 households in storing excess locally generated solar energy in the daytime for evening use. As part of a national initiative to provide shared storage for households and communities participating in the renewables transformation, the Australian Government awarded \$AUD 500,000 through the Community Batteries for Household Solar Initiative to fund this project.

SPECIAL INSIGHT

The Flinders Community Battery was an Australian first to be fully owned by a local council instead of a network service provider. The project was initiated as a campaign led by the local Flinders Zero Carbon Community Inc. Profits from the battery are directed into a Community Benefit Fund to promote energy equity through subsidizing solar installations for vulnerable and low-income households in the community. In addition to stabilizing the local grid and creating new capacity for more rooftop solar, the battery will help reduce network costs by deferring the need for new or expanded transmission. Community batteries provide a canvas to pay homage to First Nations peoples, Country and Traditional Owners, while enriching the community with street art. The Flinders Community Battery features artwork by Glenn Shaw, a Bunurong (Victoria) and Plangermairreenner (Tasmania) man. This artwork is titled 'Bush Currant' and depicts a native plant which grows in coastal Australia and two waterholes and springs, which represent the Bunurong's connection to water.

The battery with a specially designed mural, painted by Bunurong artist, Glenn Shaw. Picture courtesy Mornington Peninsula Shire.





CANADA MARY'S HARBOUR RENEWABLE PROJECT: renewable energy and storage project successfully operating and reducing diesel fuel use in a remote community

HIGHLIGHTS

- The first hydro/PV renewable generation with battery storage and microgrid controller connected to a remote diesel microgrid in a remote community in Canada
- Successful completion of this project has led to a 30% reduction in the community's diesel consumption with a corresponding reduction in greenhouse gas emissions
- Employment and revenue generation for the community of Mary's Harbour in the Province of Newfoundland and Labrador

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Mary's Harbour Renewables Project included the refurbishment of a decommissioned run-of-river hydro system (240kW), the installation of a solar photovoltaic array (189 kW) and Battery Energy Storage System (335kW / 669 kWh), and the integration of these

technologies with existing diesel generators using an innovative microgrid controller. The new system targets a penetration level over 30%, reducing 400,000L of diesel fuel each year. A power purchase agreement was successfully negotiated between the St. Mary's River Energy Limited Partnership and Newfoundland and Labrador Hydro, the first of its kind to generate revenue from the sale of renewable power for a remote community in Atlantic Canada.

SPECIAL INSIGHT

The success of the Mary's Harbour Renewables Project, especially in the shadow of challenges brought about by the Covid-19 pandemic, underscores the importance of strong community support. This project demonstrates that hybrid renewable energy and an energy storage micro-grid can reduce diesel use within a remote community while maintaining utility customer service standards.



Image Credit: Natural Forces

CANADA LHU'ÀÀN MÂN N'TSI PROJECT:

brings clean and quiet power to Kluane First Nation

HIGHLIGHTS

- Diesel generators shut off for 8 consecutive days within the first month of commissioning in spring 2025
- Supports Kluane First Nation's energy sovereignty
- Replicable model for other communities and Nations with diesel-powered microgrids



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Lhu'ààn Mân N'tsi Project is an Indigenous-led demonstration of wind generation on a remote diesel-powered microgrid in Yukon Territory, Canada. The 900 kW wind turbine and 500 kW/713 kWh battery leverage energy storage to best use the approximately 1.14 GWh of forecasted annual wind power generation and displace over 300 thousand liters of diesel annually (~52% of the diesel power plant's prior fuel use). In addition to reduced fossil fuel use, the project generates economic benefits for local residents and supports local energy sovereignty.

SPECIAL INSIGHT

In reducing local diesel reliance, the Lhu'ààn Mân N'tsi Project allows Kluane First Nation to strengthen their energy self-determination while simultaneously achieving their goals of respecting and protecting the land, water and air. The project is an innovative demonstration of how a high-penetration wind energy and battery storage system can reduce environmentally and economically costly diesel reliance for many other remote communities and Nations. In addition, with having such a high share of wind power generation in a remote microgrid, as well as the ability to shut off the diesel generators when sufficient wind power is available, the project will help better inform utilities, regulators and policy-makers in advancing the further deployment of such systems.

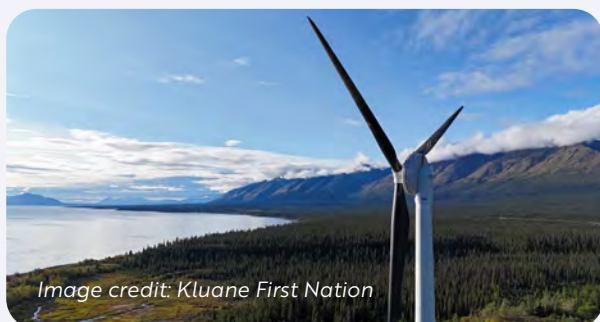


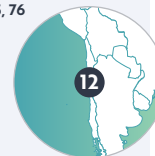
Image credit: Kluane First Nation

CHILE AES ANDES – PAMPAS HYBRID PARK:

Large-Scale Hybrid Storage Project Unlocks Renewable Potential in Northern Chile^{75, 76}

HIGHLIGHTS

- One of Chile's largest hybrid renewable energy projects: 392 MW of combined wind and solar capacity
- Integrated Battery Energy Storage System (BESS) with 624 MW of power capacity and 5-hour duration
- Located in Taltal, Antofagasta Region, leveraging high solar irradiance and strong wind resources



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Pampas Hybrid Park combines 140 MW of wind and 252 MW of solar PV with a large-scale BESS to provide flexible and dispatchable renewable energy. Through this, grid reliability is enhanced and the system reduces curtailment in a region with high renewable penetration. The project is expected to begin construction in 2025 and enter operation by 2027. The project aims to showcase how hybrid systems can accelerate the transition to 100% renewable energy in Latin America.

SPECIAL INSIGHT

The project includes two separate lithium-ion battery systems, one each for the wind and solar components, allowing for tailored optimization of each resource. This modular approach improves operational flexibility and supports grid services such as frequency regulation.

THE NETHERLANDS FLEVOBESS: energy storage project provides value to local energy system and has more than 400 local shareholders⁷⁷

HIGHLIGHTS

- The largest battery in Netherlands and one of the first 4hr duration systems (31.6MW/126.4MWh)
- Services local windfarms in closed distribution system
- More than 400 local shareholders including community participation



VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The FlevoBESS energy storage project will deploy the one of the largest battery in the Netherlands with a capacity of 31.6 MW/126.4 MWh. The FlevoBESS battery is part of the Dronter Energy Storage battery park, where a total of three batteries of 31.6 MW each will be realized. The project supports local wind farms by storing excess electricity and using it when production is low. This increases the operational hours of the turbines and makes efficient use of renewable energy. The project has more than 400 local shareholders, including local residents.

SPECIAL INSIGHT

The FlevoBESS project is unique due to its scale and technology, being one of the first large-scale 4-hour duration systems in the Netherlands. It offers a new service by stabilizing the grid and enabling renewable integration. The ownership structure with more than 400 local shareholders emphasizes strong community involvement and participation. FlevoBESS is a fully independent enterprise in both legal and economic terms. Additionally, the project earns revenue through a long-term arrangement with Eneco (a renewable energy company with balancing responsibilities), where Eneco uses the battery to manage differences in demand and supply in the energy markets.



Image credit: Alfen and FlevoBESS.

EXHIBITS CHAPTER 3: VALUE CAPTURE STRATEGIES FOR DEVELOPERS AND OWNERS

AUSTRALIA BOULDERCOMBE BATTERY ENERGY STORAGE SYSTEM: one of the first standalone Battery Energy Storage Systems in Queensland



HIGHLIGHTS:

- The 2-hours, 50 MW/100 MWh battery helps manage supply and demand during peak times.
- Supplies power to over 4000 homes.
- Operates under a combined arbitrage and Frequency Control Ancillary Services (FCAS) revenue model.

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Developed by Genex Power Limited, the Bouldercombe BESS in Rockhampton is a 50 MW/100 MWh large-scale, stand-alone battery system. It can power over 4,000 homes and plays a key role in reshaping energy management during periods of peak demand. The battery soaks up the region's renewable energy to put downward pressure on prices by mitigating investments in traditional transmission, while providing ancillary services to support network stability and reliability. The system is expected to offset 22,655t of CO₂/yr. The battery is located next to the 275kV/132kV Bouldercombe substation, owned by

transmission network operator Powerlink. The location was strategically chosen as a midpoint between the renewables rich areas (rooftop solar, wind & solar farms) within Queensland and centres of high demand for electricity. This is a critical part of the Queensland electricity grid with high network strength and Marginal Loss Factors.

SPECIAL INSIGHT

Genex and Powerlink have a Connection Agreement to connect the BESS to the Queensland grid via the Bouldercombe substation. Genex also have a revenue sharing agreement with Tesla to operate the BESS under a combined arbitrage and Frequency Control Ancillary Services (FCAS) revenue model with the ability to bid into all eight existing FCAS markets. This allows the project to generate and optimize revenue from both buying and selling energy in the market (arbitrage) and providing services to maintain grid frequency (FCAS). The project is working on abilities to participate in future markets for inertia and fast frequency response.



Image credit: Genex Power



CANADA THE ONEIDA ENERGY STORAGE PROJECT: enables renewable energy deployment, adds critical storage capacity to the grid and generates energy cost savings

HIGHLIGHTS

- Largest battery facility in Canada, and amongst the largest in the world
- Creates revenue source and opportunities for employment, internships and education for Indigenous communities
- Reduces natural gas use, facilitates additional renewable energy generation, increases grid reliability, and provides ancillary services

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Oneida Energy Storage project is a 250 MW/1000 MWh energy storage facility in Haldimand County, Province of Ontario. It is the largest battery facility in Canada, and amongst the largest in the world. The Project is intended to optimize the use of existing generation and transmission assets by balancing supply and demand in real-time and will play a crucial role in enhancing grid reliability and supporting the clean energy transition.

The Oneida Energy Storage Project demonstrated a collaborative funding approach, having received support and backing from Natural Resources Canada, the Government of Ontario, and the Canada Infrastructure Bank.

SPECIAL INSIGHT

The Project results in a reduced use of natural gas power plants, which in turn contributes to the reduction of greenhouse gas (GHG) emissions. The energy storage facility's operation allows for reduced curtailment of renewables, increased grid reliability, and storage capacity to facilitate additional renewable energy generation.

As a first-of-a-kind battery energy storage system at this scale installed in Canada, the Project plays a significant role in the provision of grid services, optimizing the Ontario energy system and lowering costs for ratepayers. The Project will also reduce waste and inefficiencies in the electricity system, and distribute the stored power when Ontario needs it most, in a cost competitive and efficient way.

The project is a good example to validate the use of energy markets set by the system operator. These include real-time energy markets that enable energy arbitrage to help support overall grid stability by smoothing out electricity demand spikes and operating reserves that provide readily available power to tackle sudden surges in demand or generation losses. The project also provides ancillary services such as frequency regulation and voltage control necessary to support grid stability and reliability. The project's participation in capacity auctions will also incentivize dispatchable resources, such as energy storage, to meet future peak demand and ensure long-term grid reliability.

The Project creates a new revenue source for the Six Nations of the Grand River Development Corporation (SNGRDC) and the Mississaugas of the Credit Business Corporation (MCBC). It features contracting opportunities with various Six Nations-based organizations, and facilitates employment, internships, and educational opportunities for the community during construction and operations, and capacity building to pursue future energy projects.

The Project strongly aligns with Indigenous investment values of peace, future generations, and respect for the natural world.

Image Credit: Northland Power.



CANADA SUMMERLAND SOLAR AND STORAGE PROJECT:

Introduces Benefits of Utility-Scale Energy Storage in Canada



HIGHLIGHTS

- The project consists of a 0.4 MW solar array as well as four EVLO 1000 battery energy storage units paired with the EVLOGIX energy management system that will provide 1 MW/4 MWh of storage capacity.
- The Summerland project is a combined solar and battery facility located in the District of Summerland, Province of British Columbia, Canada. The solar installation has been geoballasted, meaning no ground anchors or concrete were needed during construction, helping minimize the carbon intensity of the project. In addition, 80% of the construction team was based locally.

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

In addition to extending the output of the solar array to provide more clean energy to the local grid, the Summerland project enables peak shaving to eliminate short-term demand spikes and lower peak loads, reducing demand charges and the overall cost of energy for the district's residents.

This Hybrid solar and battery facility in Summerland is crucial for a reliable and sustainable energy future due to its ability to provide uninterrupted power, reduce reliance on fossil fuels, and lower energy costs. The facility achieves this by combining solar power generation with battery storage, allowing for continuous power even when solar panels aren't producing electricity.

SPECIAL INSIGHT

Hybrid systems ensure a constant power supply by using batteries to store excess solar energy, which can then be used during periods of low solar irradiance or outages.

Hybrid systems can lower electricity bills by utilizing solar power and reducing the need to purchase electricity from the grid, especially during peak demand periods.

FINLAND KURKIASKA SUPER-CAPACITOR INTEGRATION:

Fast-Response Grid Support from Hydropower in Finland^{78, 79}



HIGHLIGHTS

- First-of-its-kind integration of super-capacitor energy storage with a hydropower plant
- Located at the Kurkiaska Hydropower Plant in Finland
- Designed to deliver 2 MW of ultra-fast frequency response for grid stability

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Kurkiaska project demonstrates how supercapacitors can enhance the flexibility of traditional hydropower by providing instantaneous power injection during frequency deviations. Unlike batteries, supercapacitors can respond in milliseconds and endure millions of cycles with minimal degradation, making them ideal for Fast Frequency Reserve services. By combining the long-duration capacity of hydropower with the high-power density of supercapacitors, the system supports grid reliability in a region with increasing renewable penetration.

SPECIAL INSIGHT

This hybrid approach showcases how existing infrastructure can be upgraded with next-generation storage technologies to meet modern grid demands. The Kurkiaska installation serves as a blueprint for similar retrofits across Europe, particularly in regions with hydropower assets and growing needs for ancillary services.



Image credit: VEO

GERMANY ECO POWER ONE: battery storage project applies innovative approach to partnerships maximizing its value for the energy system⁸⁰



HIGHLIGHTS

- Currently biggest battery storage project for renewable energy in Germany (103 MW/238 MWh)
- Innovative approach to increase value for energy system by partnering of storage technology provider (ECO STOR), flexibility marketing provider (Entelios) and provider of AI-driven optimization for participating in short-term and balancing reserve markets (enspired)
- Collaboration with grid operator allows for further optimizing algorithms to improve operational planning of the project

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Eco Power One project is currently the largest battery storage project in Germany with 103 MW power capacity and 238 MWh energy capacity. The project is located in northern Germany having a high share of renewables particularly from wind farms. Surplus energy from wind and PV provided via the high-voltage grid of Schleswig-Holstein Netz AG is stored twice a day and used to be fed back into the public electricity grid during the morning and evening peaks in electricity demand. This means that around 170,000 households can be supplied with renewable electricity for two hours in the morning and two hours in the evening thus contributing to grid stability and energy security.

SPECIAL INSIGHT

Eco Power One maximizes the value of battery storage solutions by establishing partnerships of the storage operator (Eco Stor) with aggregators (Entelios and enspired). Because grid connection capacity is limited, Eco Stor has concluded a flexible connection agreement with the grid operator. In certain situations, the storage operator proactively limits storage operation to prevent grid congestion.



Eco Power One facility. Image credit: Entelios AG

THE REPUBLIC OF KOREA MIRYANG ESS:

Asia's largest grid stabilizing battery system^{82, 83}



HIGHLIGHTS

- 978 MW/889 MWh lithium-ion battery system
- Largest battery energy storage system in Asia

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

The Miryang ESS has started operation in 2024 and is considered the largest BESS for grid stabilization purposes in Asia. By delivering fast-response ancillary services such as frequency regulation, voltage control, and peak shaving, the system helps balance supply and demand in real time. Co-located with an existing 154 kV substation, the project minimizes land use and infrastructure costs, making it a highly efficient and scalable model for future deployments.

SPECIAL INSIGHT

The system demonstrates how modular lithium-ion storage can be deployed within existing grid assets to deliver high-value ancillary services. It also serves as a testbed for advanced control systems that optimize battery dispatch in real time, contributing to the Republic of Korea's transition toward a smarter, more resilient energy system. A total of 14 companies participated in the project.

THE NETHERLANDS RWE'S INERTIA BATTERY: the first battery in central Europe to deliver grid-forming inertia services⁸¹



HIGHLIGHTS

- Capable of delivering grid-forming inertia services (7.5MW/11MWh)
- Part of the OranjeWind offshore wind project on system integration
- Serves as a pilot to define future standards for inertia-capable battery systems

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

This inertia battery represents a significant milestone in the evolution of grid infrastructure in the Netherlands. With a capacity of 7.5MW and 11MWh, the system is designed not only to store and dispatch electricity, but also to deliver synthetic inertia, which is an advanced grid service that mimics the stabilizing effect of traditional spinning turbines. With fluctuating energy demand and supply, it is crucial to ensure grid stabilization by supplying resistance to sudden changes in frequency. This ultra-fast battery storage system is able to respond to frequency deviations within milliseconds.

The project helps defining the technical and regulatory frameworks for future inertia-capable battery systems. The project is in close collaboration with TenneT, the Dutch transmission system operator, as part of a two-year pilot aimed at establishing performance benchmarks and compliance standards for grid-forming technologies. serves as a commercial pilot to explore new revenue streams from ancillary services, such as inertia provision. As such, it can be considered a blueprint to expand BESS capacities throughout the world.

SPECIAL INSIGHT

The battery storage system is powered by lithium iron phosphate batteries with highly reactive grid-forming inverters. These inverters are the innovate concept of the project, capable of setting their own voltage waveform and frequency, and thereby not following the fluctuating grid. The battery has recently been installed and has an installed capacity of 7.5 MW and is capable of delivering a total storage capacity of 11 MWh.

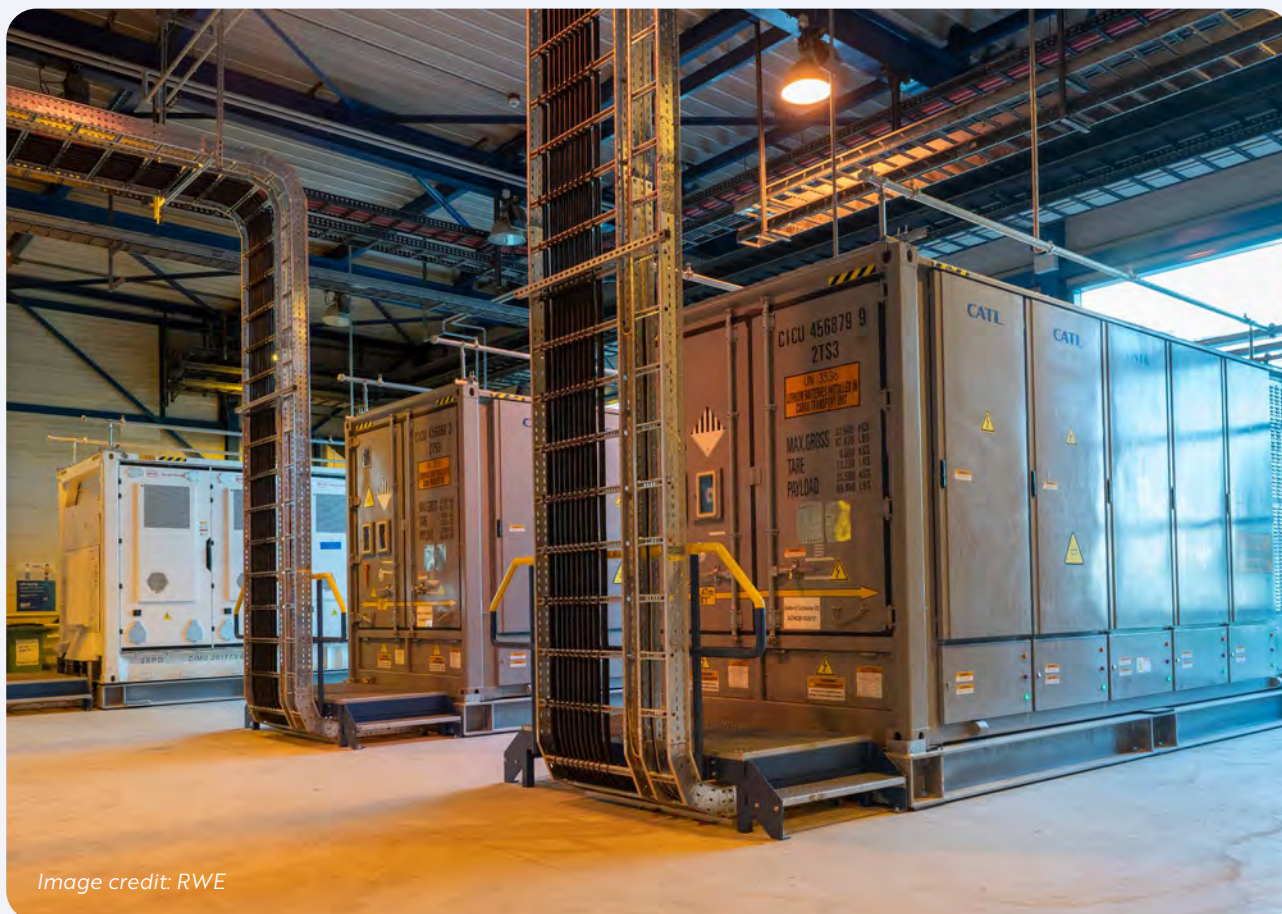


Image credit: RWE

EXHIBITS CHAPTER 5: ACTIONS TO BRIDGE THE ECONOMIC GAP

CANADA'S TARGETED PROGRAMS SUPPORTING ENERGY STORAGE DEPLOYMENT:

Decarbonizing Energy Systems and Strengthening Energy Security in Remote, Rural, and Indigenous Communities



HIGHLIGHTS

- The Government of Canada has invested over \$60 billion CAD in its electricity sector to support its 2050 net-zero emissions target, with targeted programs like the Clean Energy for Rural and Remote Communities (CERRC) and the Smart Renewables and Electrification Pathways Program (SREPs) programs.
- The CERRC program has funded 229 projects since 2018, aiming to reduce diesel use and related GHG emissions in remote, mostly Indigenous communities through capacity building and the demonstration and deployment of renewable energy and battery storage. These projects further enhance energy security, reduce local air pollution, and support Indigenous reconciliation.
- The \$4.5 billion CAD SREPs program has allocated \$1.6 billion CAD to date, funding 72 renewable energy deployment projects between 2021 and 2023 (including 13 with energy storage) and promoting Indigenous participation to modernize Canada's grid and accelerate energy system decarbonization.

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Through the Canadian Net-Zero Emissions Accountability Act, which became law in 2021, Canada committed to achieving net-zero emissions by 2050. To help achieve this goal, the Government of Canada has established targeted programs to enable greenhouse gas emissions reductions across all sectors of the economy, including tailored funding for Indigenous communities.

About 85% of Canada's electricity is already non-emitting, coming mainly from hydro, nuclear and other renewables such as solar and wind. However, the electricity mix differs amongst provinces and territories, with some using more fossil fuels than others. To support the provinces and territories in their energy transition, and to help reduce the costs of the transition for ratepayers, the Government of Canada has invested more than \$60 billion CAD in the electricity sector, including tailored funding for Indigenous communities. Programs include:

- Clean Economy Investment Tax Credits
- Smart Grid Program
- Smart Renewables and Electrification Pathways Program
- Canada Growth Fund

- Canada Infrastructure Bank
- Low Carbon Economy Fund
- Clean Energy for Indigenous, Rural and Remote Communities
- Indigenous Off Diesel Initiative
- Northern REACHE program

SPECIAL INSIGHT

The Clean Energy for Rural and Remote Communities (CERRC) Program

Across Canada, over 200 remote communities, most of which are Indigenous communities, use diesel for power and heat. Using diesel fuel has disadvantages such as greenhouse gas emissions, localized air pollution, and risks of fuel spills during transportation and storage. In addition, diesel power generation capacity is limited, which constrains economic growth and community development. Finally, it is expensive to transport fuel to remote areas, resulting in high costs to communities, governments, and ratepayers to operate and maintain the diesel generating systems. The Government of Canada has committed to supporting communities transition to cleaner energy as part of the larger federal mandate to achieve a net-zero economy by 2050.

Launched in 2018, the \$453 million CAD Clean Energy for Rural and Remote Communities program (CERRC) aims to reduce diesel use for heat and power through clean energy demonstration, deployment, and capacity building initiatives in Indigenous, rural and remote communities.

In addition to reducing greenhouse gas emissions, community-driven clean energy projects support local economic development and reduce costs and risks related to diesel use. Investing in clean energy solutions in Indigenous communities also supports energy security, reconciliation, and self-determination of Indigenous Peoples.

In addition to storing energy, battery energy storage systems (BESS) facilitate the integration of renewables into local isolated grids. For example, the CERRC program provided funding to Kivalliq Alternative Energy to install a 1 MW solar system and a 1 MWh battery storage system in Naujaat, Nunavut. The project, named Ikayuut, will integrate into Naujaat's existing microgrid and will provide up to 30% of the community's current energy demand, displacing an

estimated 465,000 liters of diesel annually, or 13.8 million liters over the project's lifetime.

Since 2018, CERRC has supported 229 renewable energy and capacity building projects in remote off-grid and Indigenous communities across Canada, about 96% of which have Indigenous involvement.

The Smart Renewables and Electrification Pathways Program

Launched in 2021, the Smart Renewables and Electrification Pathways Program (SREPs) has allocated \$1.6 billion CAD to accelerate the deployment of renewable energy across Canada. The program supports the deployment of grid modernization, energy storage and renewable energy technologies, including electricity transmission and distribution infrastructure, as well as Indigenous participation in the

sector. Between 2021 and 2023, the program funded 72 deployment projects, 13 of which included energy storage. The program has also seen strong Indigenous participation, with seven of these energy storage projects having Indigenous involvement.

Building on the success of the program, in 2023 the Government of Canada announced an additional \$2.9 billion CAD to further enable the decarbonization of Canada's energy system between 2024 and 2036. SREPs funding is complementary to other federal measures, including Investment Tax Credits and Canada Infrastructure Bank financing, which all contribute directly to achieving Canada's net-zero economy by 2050. The Oneida Battery Storage project, which was supported by the SREPs program, is further detailed in a separate exhibit.

CANADA RESTRUCTURED ENERGY MARKET:

to provide more granular signals for flexible energy storage to respond to in Alberta

HIGHLIGHTS

- Energy storage is a highly flexible resource, both in operation and ability to site
- Decarbonizing electricity systems need to have clear economic signals to provide capacity and flexibility
- The Province of Alberta, Canada, is reforming its electricity market to have stronger signals for both capacity and flexibility

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Alberta's unique-to-Canada "energy-only" market has largely remained unchanged for over two decades. While the market has been a boon for investment in clean electricity, namely from wind and solar via renewable Power Purchasing Agreements (PPAs), the market design is increasingly poorly suited to facilitating the dispatch and investment required for a more heavily clean electricity system. The current design has a relatively weak signal for capacity and flexibility, including from energy storage. The new "Restructured Energy Market" will update Alberta's market design to include a shorter settlement, higher offer and price caps, a negative price floor, locational marginal pricing, and a new ramping and uncertainty reserve ancillary service. Together, these changes will provide a much stronger signal for resources which can provide firm and flexible capacity, creating a reliable

and affordable electricity system which can accommodate high penetrations of renewables.

SPECIAL INSIGHT

Alberta has historically had a simple electricity market, with a single nodal price across the entire system, a transmission planning policy that eliminated all congestion in the long term, a minimal suite of ancillary services, and no direct price on capacity. This simplicity has been both a strength and weakness of the Alberta electricity system. The simplicity creates a straightforward investment environment relative to other liberalized electricity markets, but it is also ill-suited to address a lot of the operational needs present in a more complex electricity system, such as ramping and uncertainty management, firming capacity, and ancillary needs like frequency support and inertia. In addition to signaling electrical energy storage to charge, negative pricing could also incentivize electric thermal energy storage (ETES) in Alberta, enabling surplus electricity to be used as clean heat. Alberta's market redesign will provide a big step towards signaling for the reliability needs of a modern grid, which energy storage is poised to meet, and set the stage for an evolution of Alberta's electricity market.





CANADA ALBERTA ERESERVE4 AND ERESERVE6: Essential to Regional Grid Reliability

HIGHLIGHTS

- eReserve4 & eReserve6 are collocated Battery Energy Storage Facilities (BESF) with the combined capacity of 40 MW located near the town of Hardisty, in the Municipal district of Provost No. 52, Province of Alberta, Canada
- These facilities, operated by Enfinite, support the reliability of the Alberta Interconnected Electric System (AIES).

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

This type of Battery Energy Storage System (BESS) deployed in the Province of Alberta plays a crucial role in enhancing the reliability and security of electric grids by providing grid-scale energy storage. They can store excess energy when generation is high and release it when demand is high or during outages, improving grid stability and the integration of intermittent renewable energy sources like solar and wind. Additionally, batteries can provide stability services like frequency and voltage regulation, essential for maintaining grid stability, especially during emergencies.

SPECIAL INSIGHT

In addition to providing backup power to get through emergencies, battery storage also offers strategic flexibility. Power grids must find a way to store excess energy when demand is below supply and release it quickly and cheaply when supply is low. BESS provides a buffer between generation and consumption of energy, storing it from all sources in periods of low demand and releasing it when demand is high, whether during peak usage hours or during unplanned outages. However, implementing BESS is not a silver bullet; there are challenges in its high upfront costs and the complexity of integrating it into grid infrastructure, its limited lifespans, and inconsistent regulatory support that would enable widespread adoption. On March 6, 2024, the Government of Alberta proclaimed the Electricity Statutes (Modernizing Alberta's Electricity Grid) Amendment Act which provides clear definitions for "energy storage facility" and "energy storage resources" and expanded the definition of "Distributed Generation" to encompass energy storage resources, providing clarity and certainty to the energy storage industry on the regulatory requirements for building energy storage facilities in the province.

CANADA EXPANDED ANCILLARY SERVICES IN ALBERTA: enabling energy storage to provide clean reliability and affordability



HIGHLIGHTS

- Energy storage is a capacity and flexibility rich energy resource
- In electricity systems, capacity and flexibility need to have clear economic signals
- The Province of Alberta, Canada, has introduced multiple new ancillary services to provide signals for flexibility and resulting reliability

VALUE FOR ENERGY SYSTEM AND BUSINESS CASE SPECIFICS

Alberta has an “energy-only” deregulated electricity market that is unique to Canada and which compensates generators based on the electricity they actively supply to the grid rather than for the capacity they maintain. As a capacity-rich flexible resource, energy storage provides value to the electricity system through availability. In an energy-only market, this is signaled in two ways: high energy prices in times of relative scarcity and ancillary services. Batteries are especially well suited to provide ancillary services as they are exceptionally flexible and can change output in seconds. As the reliability needs of the grid change with decarbonization, especially from inflexible technologies like wind, solar, nuclear, gas with Carbon Capture and Storage (CCS), and cogeneration, flexible capacity is increasingly needed to balance the electricity system. To meet system needs, Alberta has expanded its ancillary services with new services such as Fast Frequency Response (FFR), Fast Regulating Reserves (FRR), Fast Net Demand Response (FNDR), and a 30-minute Ramping Reserves (R30). Together, these products will build on existing Operating Reserves (including spinning and regulating) to signal and direct more value out of existing and future energy storage projects.

SPECIAL INSIGHT

Energy storage is a commonly misunderstood technology, often thought only to be about shifting energy from times excess supply, such as midday solar production peak, or nighttime off-peak, to times of scarce supply. While energy arbitrage, or energy time-shifting, is a definite use of energy storage with a large market, it is also risky, especially in markets with a relatively high amount of flexible generation, such as legacy gas generation. Ancillary services markets (as well as direct capacity auctions) have been the primary driver of energy storage investment thus far, as seen in US markets like Texas (ERCOT), California (CAISO). Energy storage and inflexible clean power enable each other, with inflexible clean power increasing the need for ancillary services, which further enable deeper penetrations of clean power. With more inflexible power on the system, supply-demand imbalances become more common, enabling a less risky market for energy arbitrage, potentially enabling a market state that is investible for longer duration storage technologies. For example, with higher volumes of renewable energy in Alberta’s electricity mix, forecast uncertainty becomes a more important reliability risk to manage. The new Ramping Reserves product will procure a volume or flexible supply to cover risk of forecast inaccuracy as well as system ramping needs. With energy storage poised to affordably meet ramping reserve needs, more renewable energy can be reliably added to Alberta’s mix. A modern ancillary service suite is a vital step to scaling up the reliable development of energy storage and clean power in Alberta, with Alberta’s competitive market ensuring that competition to meet system needs maintains affordability.

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The Netherlands RWE's inertia battery. Image credit: RWE.



