Scaling-up Energy Storage: Technology and Policy

E3 Analytics

Acknowledgements

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This report is based on a recent analysis supported by the European Climate Foundation, and conducted in partnership with the **Centre for the Study of Democracy (CSD)** in Sofia, Bulgaria. The focus has been broadened beyond just the South East Europe region to be relevant to a broader range of utilities, policy-makers, and regulators in other regions of the world.

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January 2023

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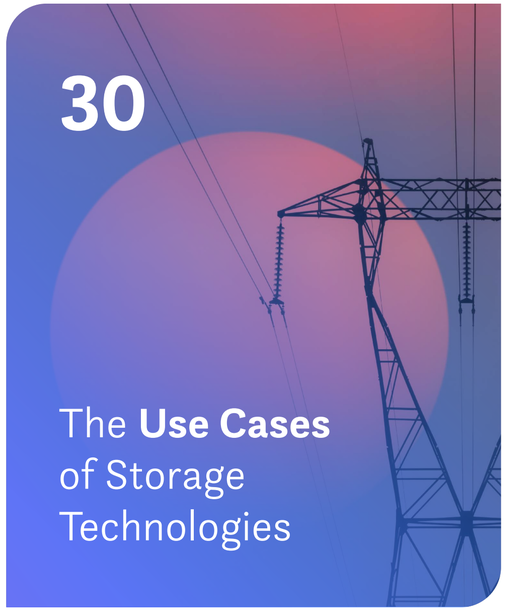
Overview of Storage Technologies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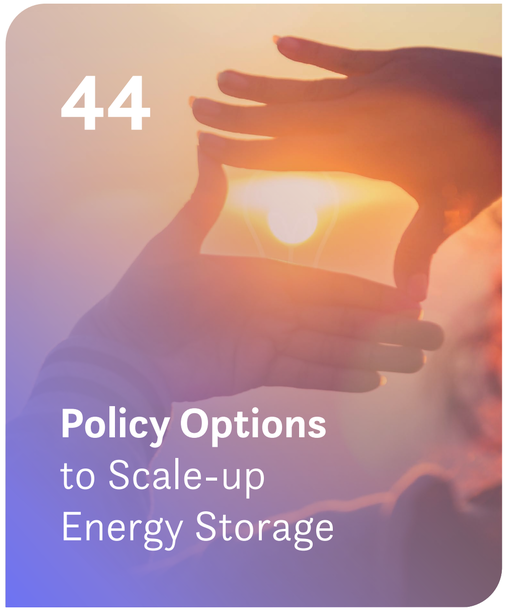
Main **Barriers** to Storage Technologies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Policy Options to Scale-up Energy Storage

Goal of the Report

The aim of this analysis is to lay out policy options to help catalyze the deployment of energy storage technologies worldwide. Storage technologies can help improve local energy security, smooth the path to decarbonization, and give utilities greater confidence when adopting variable renewable energy technologies like wind and solar power.

While this report covers a wide range of storage technologies like pumped hydro and Power-to-X, the focus is primarily on the role of battery storage.

Introduction

Several factors now make a rapid scale-up of storage technologies likely

High electricity & gas prices, combined with rapidly declining storage costs

Although electricity prices have come down from their peak earlier in 2022, high prices remain a major concern. At the same time, battery storage costs have declined rapidly over the last 10 years, making them economic in a growing number of applications and regions.

Growing concerns over energy security

Energy security has re-emerged as an over-riding geo-political issue, rising back to the top of the global political agenda. Storage can support with energy security and resilience, helping protect countries, companies, and customers from both energy price volatility, as well as from energy supply disruption.

Rise of variable renewables like solar and wind

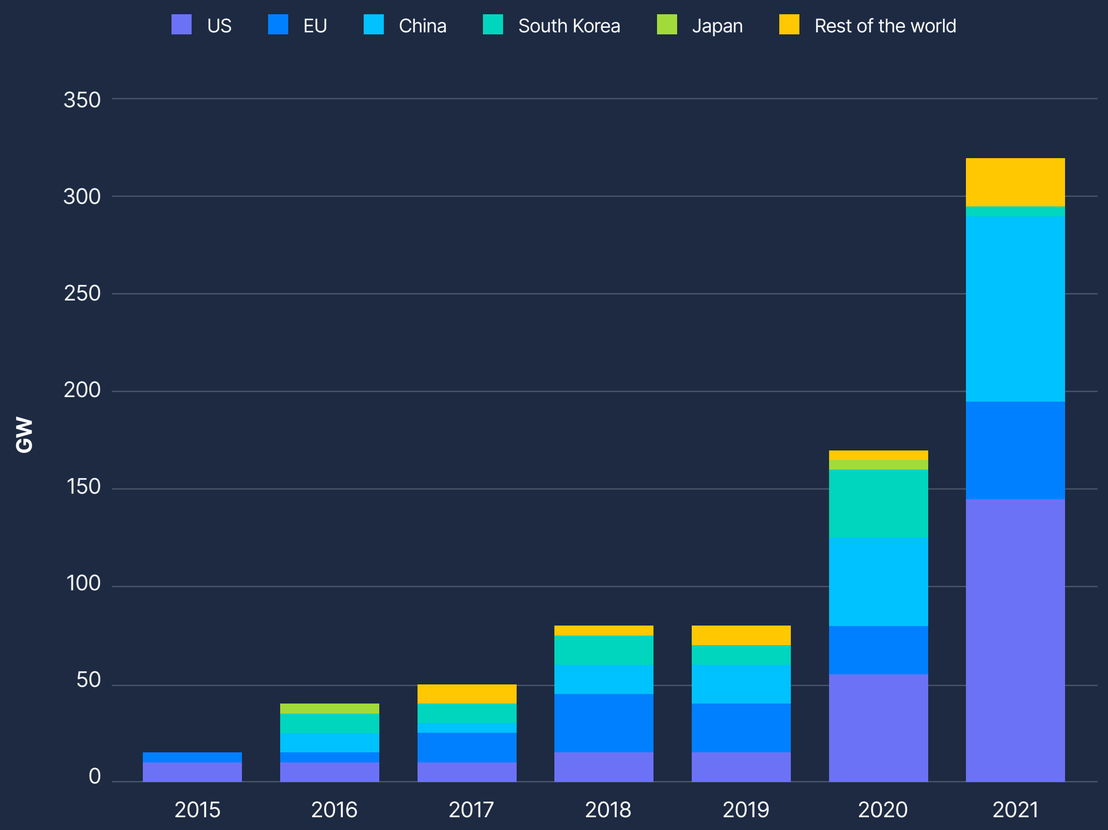
Rising shares of wind and solar are making storage more important than ever before: storage can help smooth out the fluctuations of variable renewables, extend solar output into the evening hours, support with balancing, and provide a range of other services vital to the stability of the power system.

Adoption of utility-scale storage is growing rapidly

- With significant new deployments in the U.S., India, China, and the new impetus generated by the EU's REPowerEU Plan, growth in grid-connected storage expected to surge.
- Growth of between 15–20%/year expected.

Annual Utility-scale Battery Storage Additions

(2015–2021, in GW)



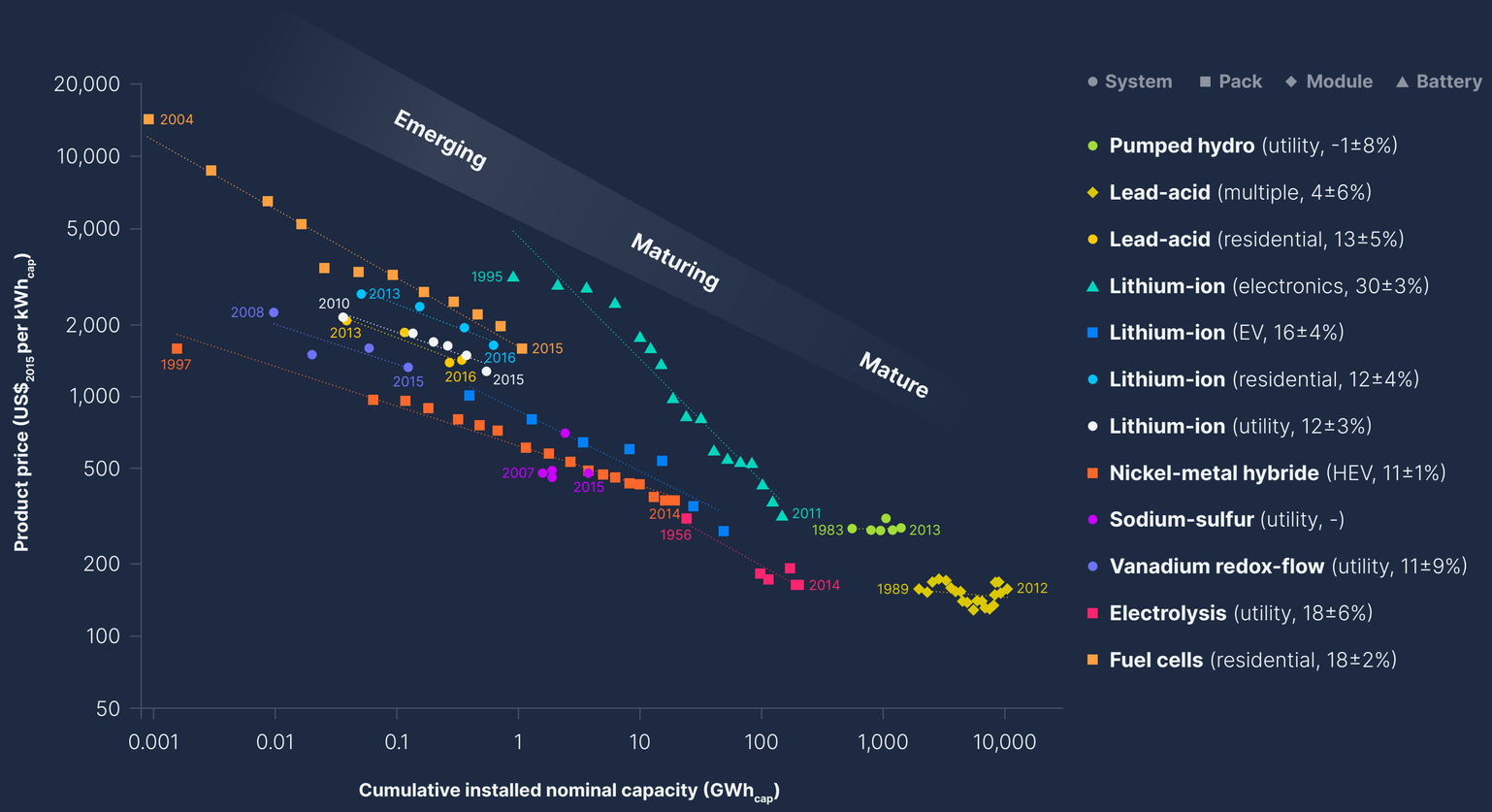
Source: IEA (2021). https://www.iea.org/reports/grid-scale-storage

The Economics of Storage

Storage costs declining across all technology categories

- While lead-acid costs remain low, other battery storage technologies are rapidly catching up.
- Most rapid pace of decline (steepest experience curve) is currently found among Li-Ion batteries, which are improving at an annual rate of over 15%.
- Up to 95% of battery metals, including rare earths, can be recycled.

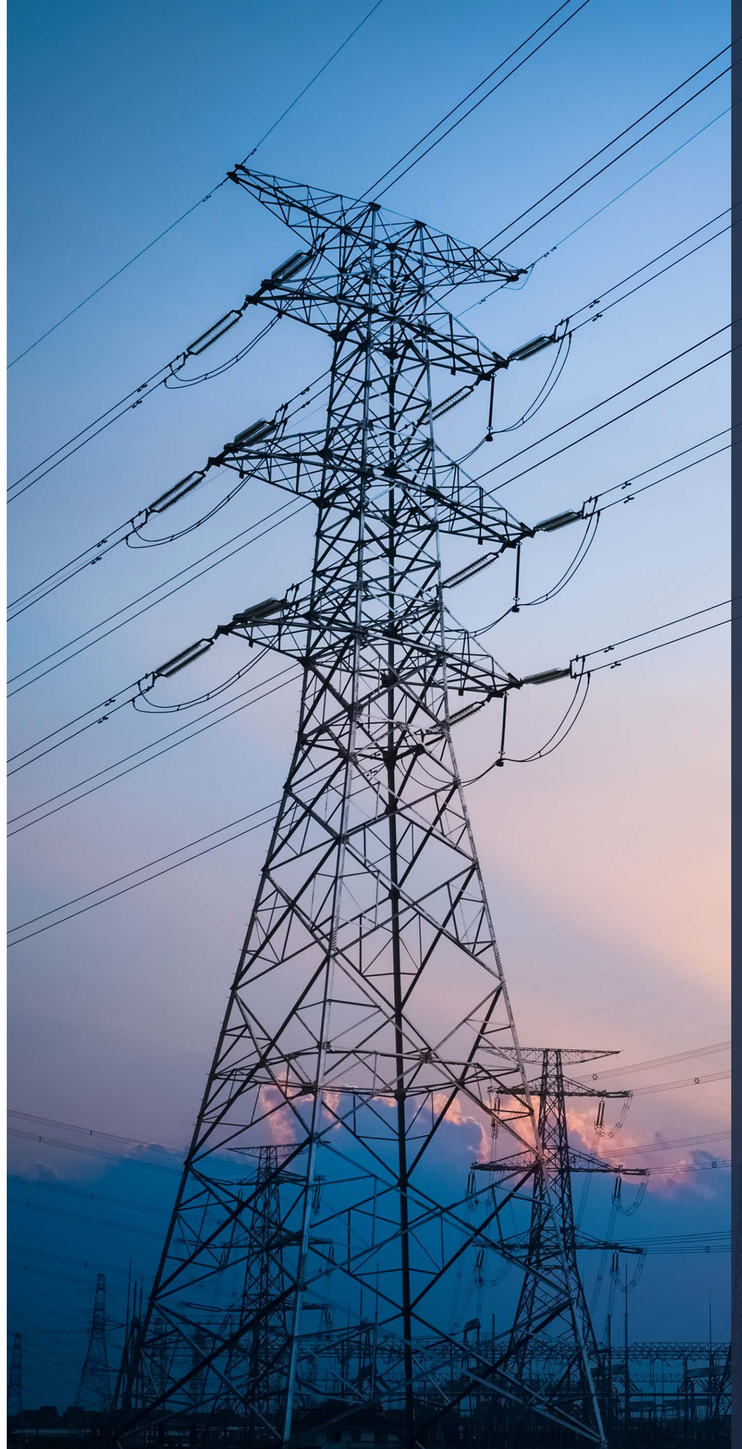
Overview of cost declines across various battery chemistries



Source: based on Schmidt, O., Hawkes, A., Gambhir, A. et al. The future cost of electrical energy storage based on experience rates. Nat Energy 2, 17110 (2017). https://doi.org/10.1038/nenergy.2017.110

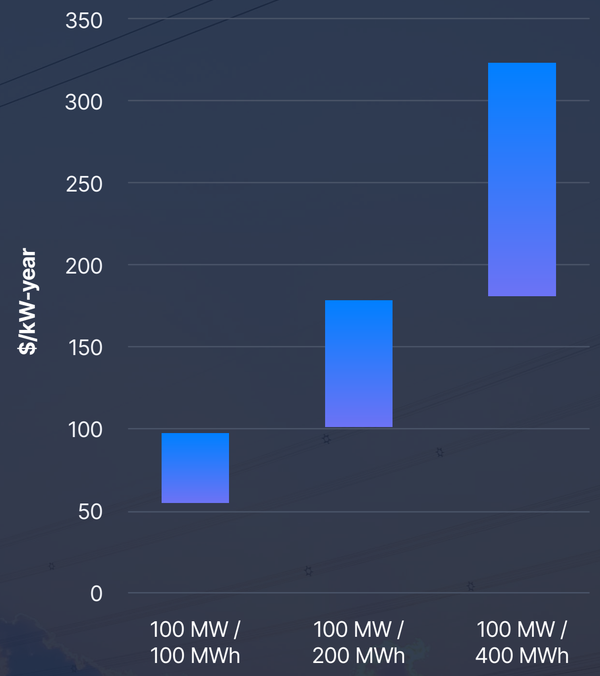
The Economics of Storage

- For utility-scale applications, the levelized cost of storage depends significantly on the storage duration.
- A battery with a power rating of 10MW/20MWh can discharge at full power (10MW) for two hours.
- As shown in the graph here, the longer the discharge, the higher the cost.



Unsubsidized Levelized Cost of Utility-scale Battery Storage

(in $/kW-year) (2021)



Source: based on Lazard (2021). LCOE of Storage, v.7. https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf

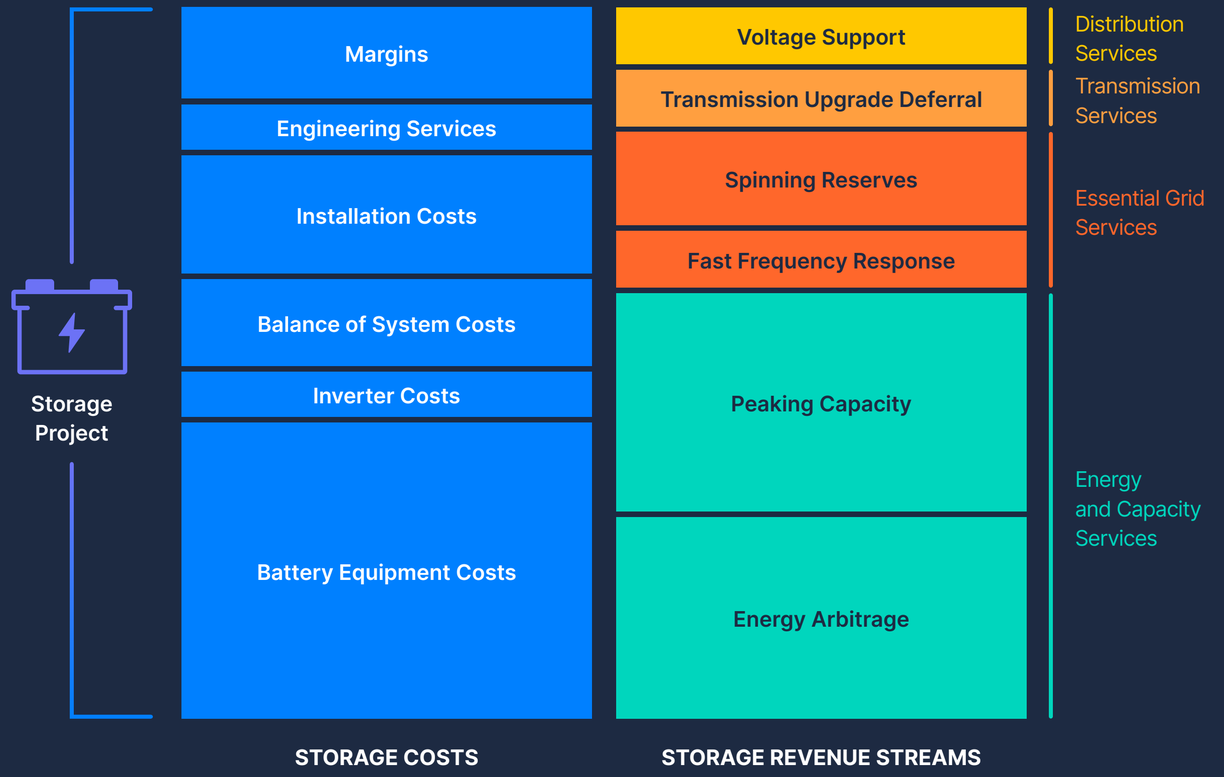
Understanding Storage

- A key distinction is whether battery storage technologies are installed **“behind-the-meter”** (i.e. on the customer’s premises) or whether they are installed **“in-front-of-the-meter”** (i.e. connected directly to the grid).
- Where batteries are installed influences what kinds of services they can provide.

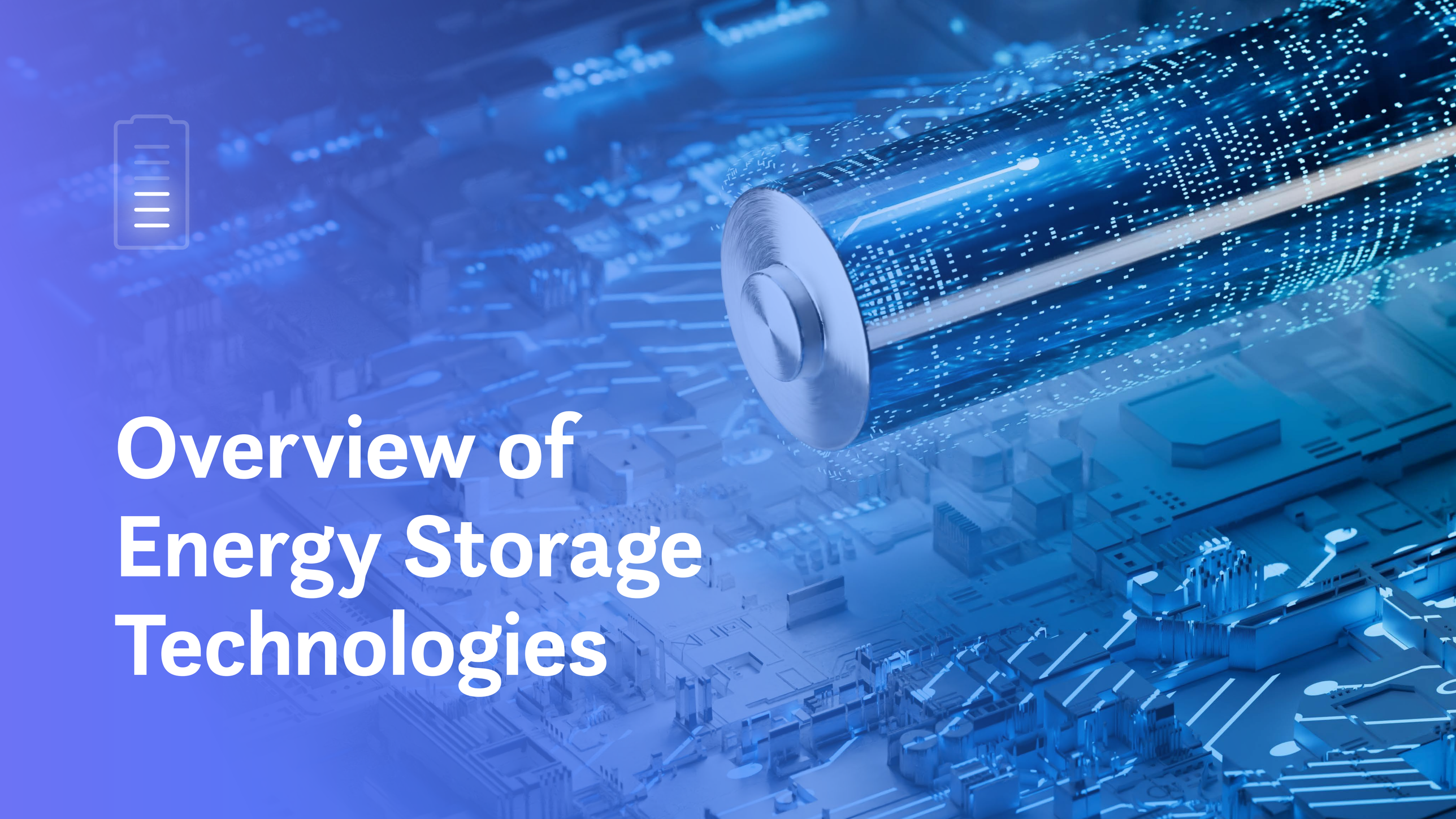
The Storage Value Stack

- This figure shows how battery costs (left) compare against the hypothetical battery storage project revenues (right) in a developed electricity market.
- One of the challenges for storage is that few electricity markets remunerate the full range of services that batteries provide.
- Over the course of a single battery storage project's life, the value generated by each of these services can change dynamically as markets and prices evolve.
- There is currently a disconnect between the value that storage technologies bring to the system (and to power system resilience and decarbonisation efforts) and the revenues they can earn.

Breakdown of storage costs (left) compared to hypothetical project revenues (right): Illustrative



Source: based on USAID (2021), Energy Storage Decision Guide for Policymakers, https://www.nrel.gov/docs/fy21osti/78815.pdf



Overview of Energy Storage Technologies

There are five main categories of energy storage

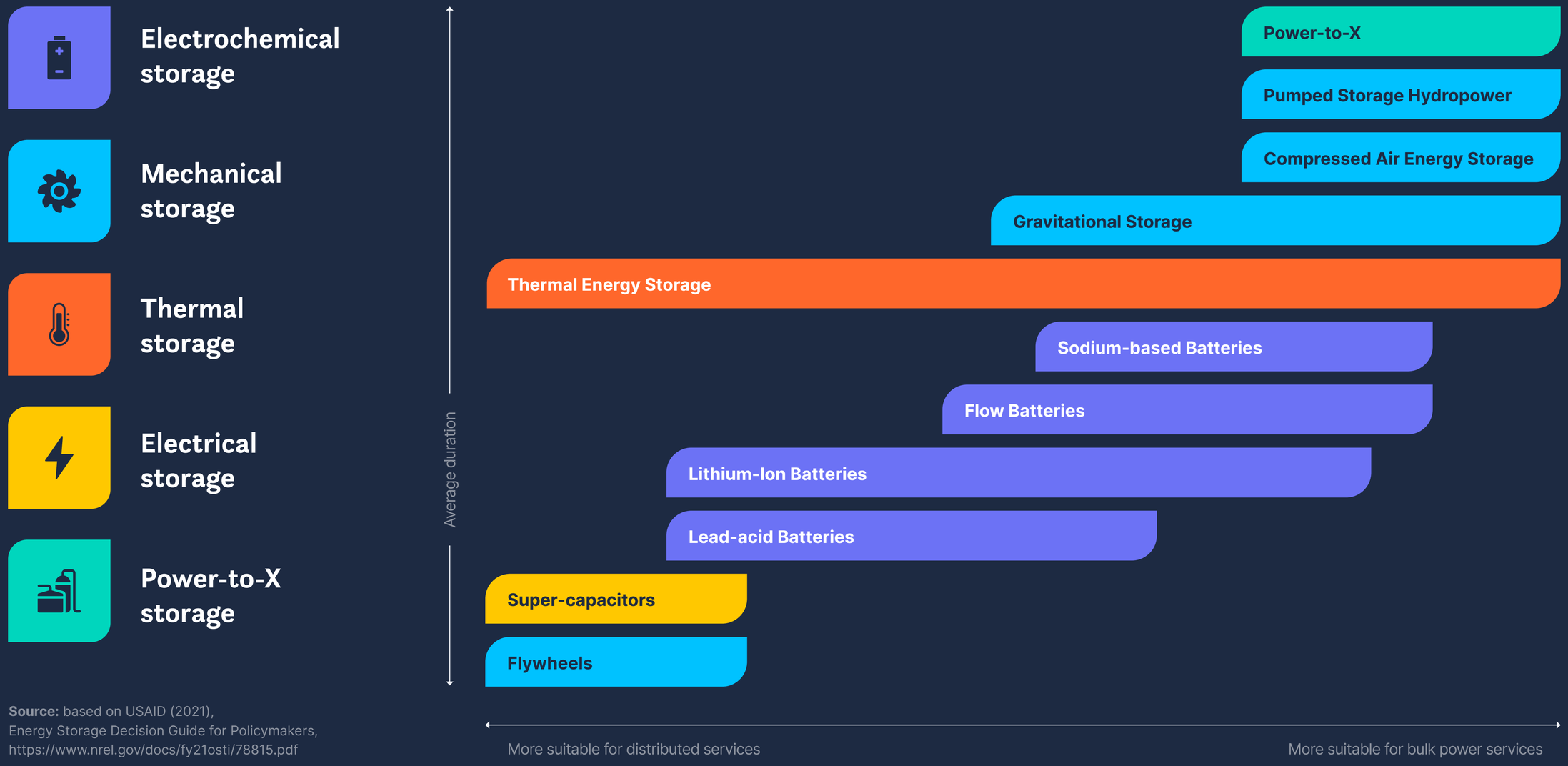
Electrochemical storage

Mechanical storage

Thermal storage

Electrical storage

Power-to-X storage



Source: based on USAID (2021),
Energy Storage Decision Guide for Policymakers,
https://www.nrel.gov/docs/fy21osti/78815.pdf

Electrochemical Storage

LFP Batteries

There are two main Lithium-based battery chemistries:

- **Lithium-Ion*** (Li-Ion)
- **Lithium Iron Phosphate** (Li-FE-PO_4)

Although Lithium-Ion remains dominant, Li-FE-PO_4 technologies have several advantages:

- **Longer life:** better suited for long duration applications such as stationary, grid-connected battery storage systems
- **More tolerant of higher operating temperatures**
- **More chemically stable**

However, Li-FE-PO_4 batteries are heavier than Li-Ion, making them less well-suited for portable applications.

* The dominant Li-Ion technology makes use of Lithium-Nickel-Cobalt-Manganese, abbreviated here to Li-Ion.

Electrochemical Storage

Lithium-Ion Batteries

At a glance:

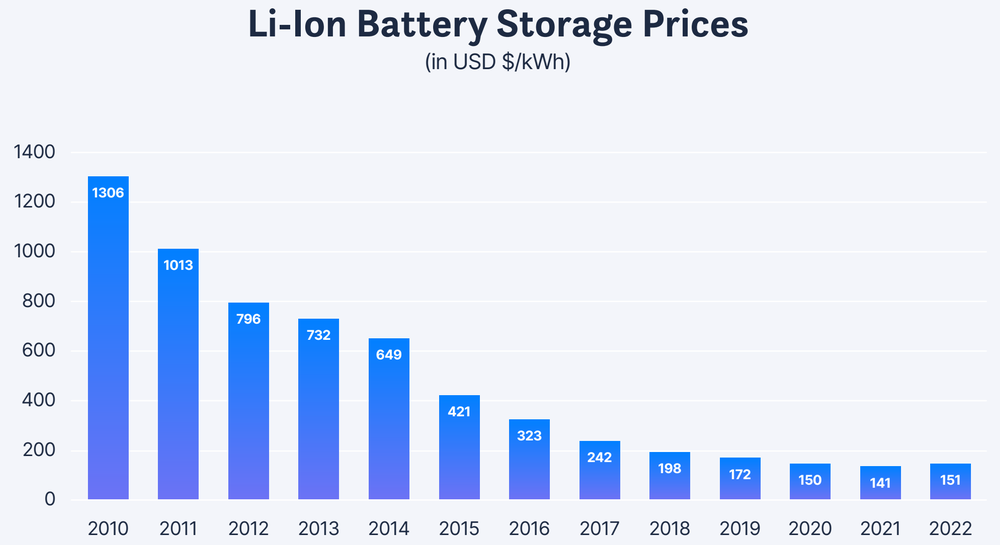
- Lithium-ion makes up 90% of the global battery storage market
- 3GW/4.2GWh of cumulative global installations by 2021
- Costs have been declining 16%/year on average since 2010
- Current Li-Ion battery costs in the range of $120 – 160/kWh

Lithium-ion batteries are largely considered the industry standard for battery energy storage systems and technological improvement has been further accelerated by the rise of electric vehicles (EVs).

They can be deployed across a range of applications in both end-use appliances and at grid-scales.

In power grids, they have been used mainly for short-duration services such as frequency regulation but are starting to be used for peaking capacity and energy arbitrage.

The largest projects around the world reach into the hundreds of megawatts.



Source: Evelina Stoikou (2022). BloombergNEF, https://twitter.com/EvelinaStoikou/status/1600120701637120000

Case Study – Moss Landing

In Moss Landing, California the world's largest lithium-ion battery storage facility at 400 MW/1,600MWh was built to meet peak demand and reliability needs and facilitate the transition from gas to renewables.

Electrochemical Storage

Lead Acid Batteries

At a glance:

- Mature battery technology, common in the automotive industry
- Makes up about 2% of the grid-connected battery capacity worldwide
- Typical storage duration ranges from about 1 - 5 hours
- 174MW/183.5MWh of grid-connected installations, with stable growth

Lead-acid batteries currently cost around $65/kWh making them slightly cheaper than lithium-ion batteries. However, they have a few disadvantages:

- Lower energy density
- Shorter operating life
- Not as scalable (i.e. to multi-MW and GW-scale)

The main benefit of lead-acid batteries is their lower cost.

Case Study – Shetland Islands

In Lerwick in the Scottish Shetland Islands, a1MW/3MWh lead acid BESS is being used to increase the level of local wind power that can be used and to reduce the reliance on a local 66MW diesel generating plant.

Electrochemical Storage

Sodium-based Batteries

At a glance:

- Makes up 17% of grid-connected storage capacity worldwide
- Typical storage duration ranges from 1 - 6 hours
- 217MW/1.35 GWh of cumulative global installations by 2021

Sodium-based batteries are considered mature and have been deployed at grid-scale in several jurisdictions in recent years.

They are currently competitive at a cost of about $120/kWh.

However, sodium-based batteries have a few disadvantages:

- Lower energy density
- Shorter operating life
- Higher self-discharge rate

Case Study – Abu Dhabi

The Abu Dhabi sodium-sulfur battery system that totals 108MW/648MWh spread across 10 locations in the city make up what has been called the “world’s largest virtual battery plant.” The project provides up to 6 hours of storage, balances the networks, provides frequency and voltage control, operating reserves and assists with peak shaving.

Electrochemical Storage

Flow Batteries

At a glance:

- Flow batteries are large, rechargeable batteries with massive external liquid electrolyte tanks which hold the charges
- Makes up ~16% of the global battery storage installed capacity
- 319 MW/1.24 GWh of cumulative global installations by 2021
- Typical storage duration ranges from 2–12 hours

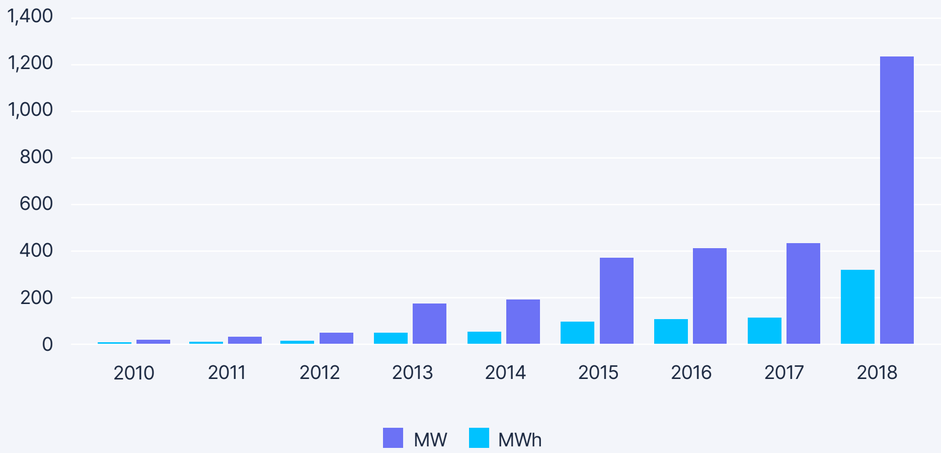
Flow batteries typically have a lifespan of 20–25 years and system costs range from $255/kWh to $439/kWh. They have several advantages, including:

- Can provide nearly unlimited cycles
- Rely on cheaper and more abundant materials, such as iron, salt and water
- Can be deployed in a range of sizes and locations to provide grid services

Main challenges relate to the use of expensive fluids that are can be corrosive or toxic, as well as the onsite electricity demand associated with operating the pumps.

Global Cumulative Flow Battery Installations

(in MW and MWh, 2010–2018)



Source: Sandia National Laboratories (2022). Statistics, https://sandia.gov/ess-ssl/gesdb/public/statistics.html

Case Study – San Bernardino

The largest utility-scale flow battery project to date is a 500kW/2MWh facility in San Bernardino, California which is sited at a bioenergy facility and is used to help shave peak demand and maximize the efficiency of the area's microgrid.

Electrochemical Storage Technologies Technical Parameters

Technology	Round-trip efficiency	Reaction time	Power Density (W/kg)	Operating Life (Number of Cycles)
Lithium-Ion Batteries	86% – 88%	Sub-second to seconds	4.000 – 6.500	1.000 – 4.000
Lead Acid Batteries	79% – 85%	Seconds	30 – 50	500 – 1.000
Sodium Batteries	77% – 83%	Sub-second	120 – 600	4.000 to 5.000
Flow Batteries	65% – 70%	Sub-second	0,5 – 2,0	12.000 – 14.000 (and above)

Source: based on USAID (2021). Grid-Scale Energy Storage Technologies Primer: https://www.nrel.gov/docs/fy21osti/78815.pdf

Mechanical Storage

Pumped Hydro

At a glance:

- Pumped hydro currently makes up approximately 95% of the global grid-connected storage capacity
- Storage duration ranges from multiple hours to years
- 181 GW/602 GWh of cumulative global installations as of 2021

Pumped hydro involves pumping water to an upper reservoir where it can be stored and released later to generate hydroelectric power. It is a mature technology, highly efficient and can provide large-scale, long-term storage capacity.

However, it has a few drawbacks:

- Limited to suitable locations and geologies
- Long lead times (projects can take 8–10 years to plan and build)
- Siting and building new projects can be costly
- Vulnerable to droughts
- Can have a significant environmental impact

Mechanical Storage

Compressed Air Energy Storage

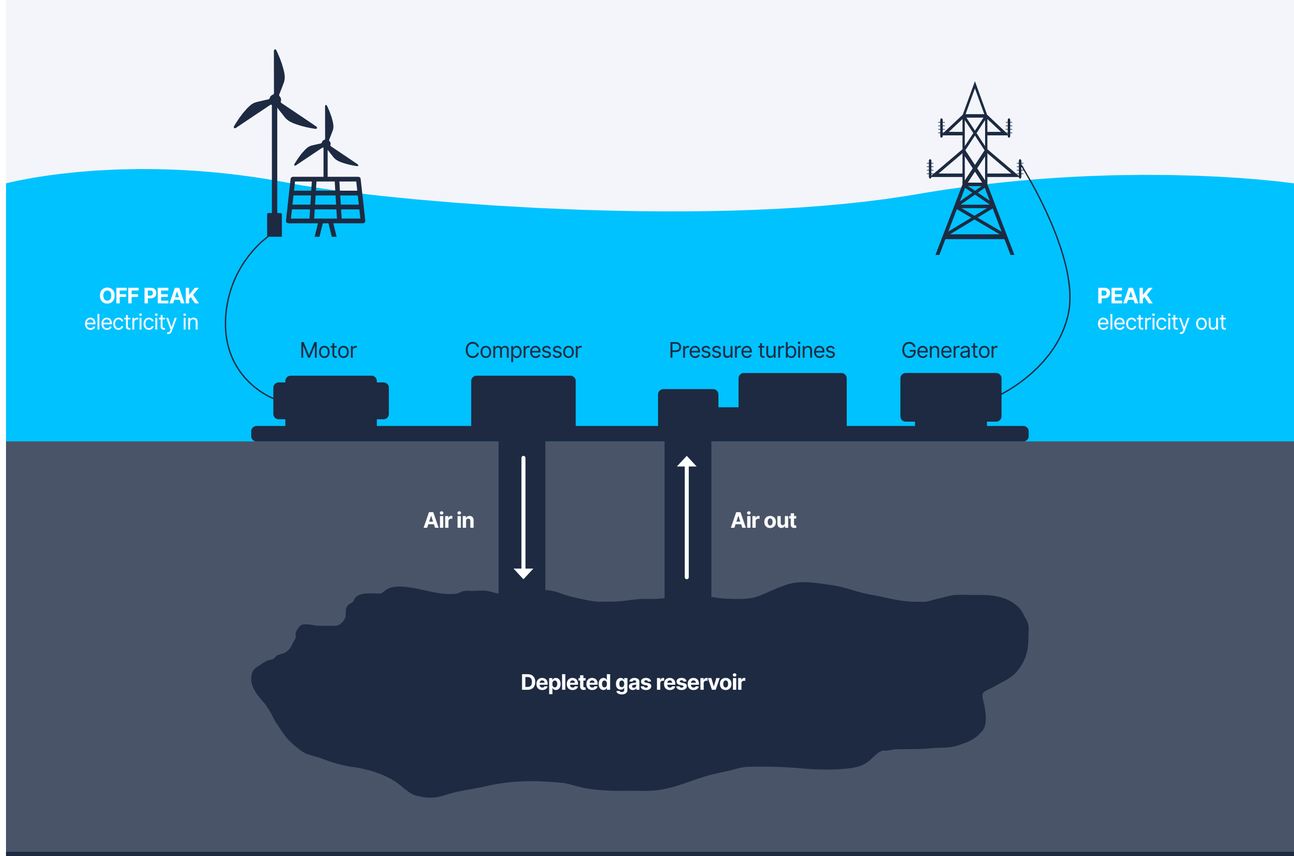
At a glance:

- Makes up 6% of the installed mechanical storage capacity
- Storage duration ranges from hours to days
- 1.6 GW/40.1 GWh of cumulative global installations as of 2021

Compressed air energy storage (CAES) involves storing generated energy by converting electricity into compressed air so it can be discharged later to turn a turbine.

In most cases, air is compressed and stored in an underground cavern, though new approaches with purpose-built caverns are starting to emerge, enabling projects to be built in any geographic location, including near load centres.

Cost estimates for CAES range from $94-$229/kWh, which make it competitive with other commercially available energy storage technologies.



Case Study – Willow Rock Energy Storage Centre

An example of a CAES system that is underway is the 500 MW/4 GWh Willow Rock project in Rosamond, California. This project will support the grid with enough energy to power 400,000 homes over 8-hour durations, provide capacity services and support renewable energy integration and time shifting.

Mechanical Storage
Flywheels

At a glance:

- 972 MW/97 MWh of cumulative global installations by 2020
- Consist of a magnetically-levitated rotor/generator that spins in a vacuum
- Storage duration is in the minutes, but with high charge/discharge cycle rate

A flywheel converts electrical energy to kinetic energy in a rotating mechanical device and can reconvert it back to electrical energy for instantaneous ramping.

They are commercially available and are particularly useful as a short duration storage technology in contexts where fast ramping response and high numbers of daily cycles are needed.

Over their lifetime, flywheels can cycle between at least 100,000 to 175,000 times. Main disadvantages relate to their small scale and relatively high costs, with costs currently ranging from $1,500/kWh to $6,000/kWh.

Case Study – Azores

The 500kW Flores PowerStore flywheel project in the Portuguese Azores has been in operation since 2005. The flywheel helps stabilize the electric system against frequency and voltage fluctuations and smooth out renewable power fluctuations to support more wind and solar PV.

Mechanical Storage

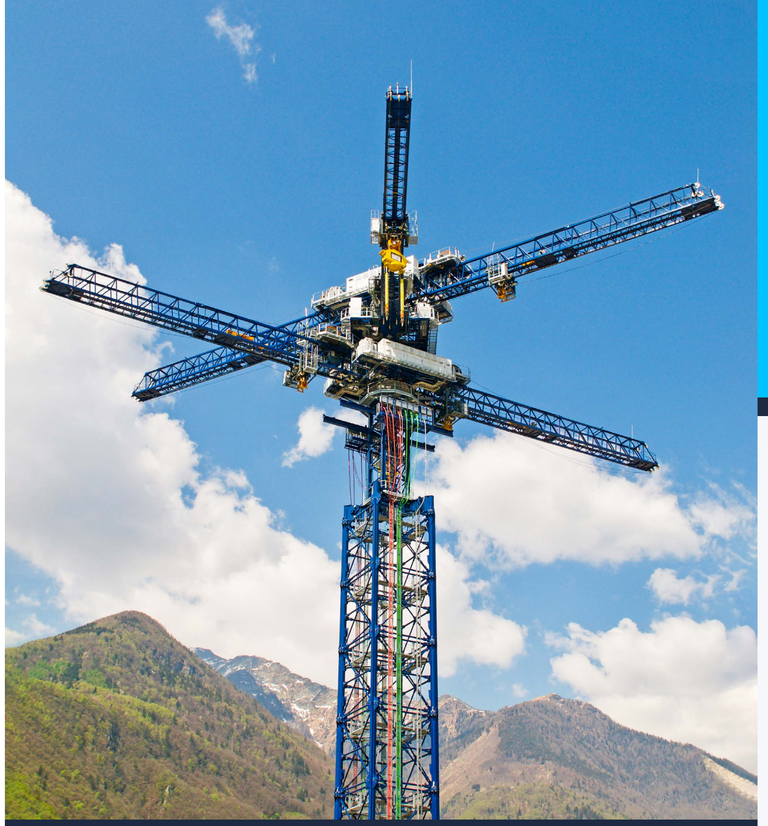
Gravitational Storage

At a glance:

- Systems rely on gravitational potential energy from raised objects that can be released to generate electricity
- Offers long duration storage ranging from multiple hours to weeks
- Relatively high round-trip efficiency ranges from 65% to 90%
- No degradation over time, and fewer supply chain issues

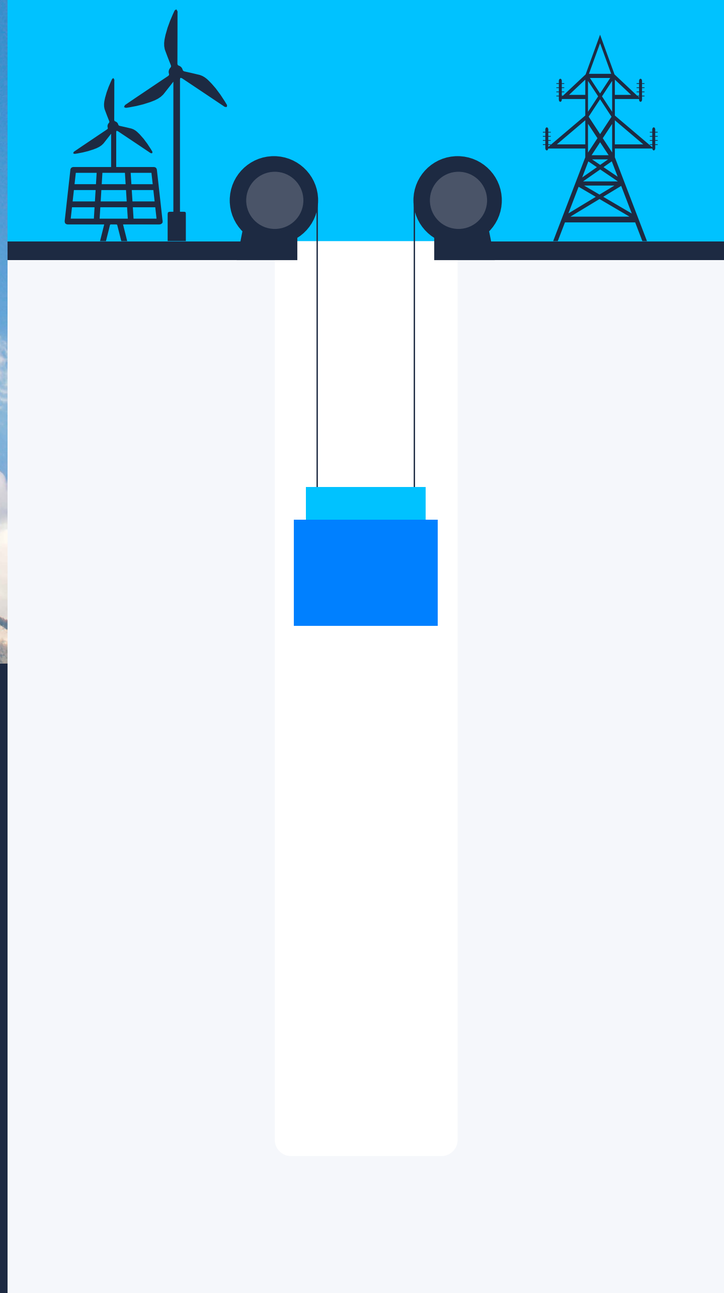
Gravitational storage systems operate by converting electrical energy into gravitational potential energy that can be converted back to electricity. In most cases this involves raising blocks with a crane, lowering weights underground, or transporting rail cars up a slope.

If successful, gravitational storage may be cost-competitive with other leading storage technologies, potentially even cheaper. A few demonstration projects have been tested and commercial deployments are now underway.



Case Study – Energy Vault EVx

Commercial demonstration unit (20MWh – 80MWh) already operational in Switzerland since 2020. In 2022, company began construction on two gravity storage systems in the U.S. and in China.



Thermal Storage

Molten Salt Storage

At a glance:

- Concentrating solar power (CSP) plants in operation around the world frequently rely on molten salt to store thermal energy
- Thermal energy can be released in a controlled way to drive a steam turbine
- Molten salt typically offers longer storage durations than batteries at 10–12 hours or longer
- At least 3 GW/20 GWh of cumulative global installations to date

Molten salt CSP facilities are best suited for large areas that have high direct normal irradiance and limited cloud coverage, such as in deserts.

Case Study – Granada

The Andasol molten salt CSP is a 150 MW facility that consists of three parts that make up one of the largest combined solar and storage facilities in Spain. It offers 7.5 hours of storage and supplies solar energy to 450,000 residents in Spain. The molten salt storage firms and shapes the solar output and helps meet evening demand peaks.

Thermal Storage

Ice / Hot Rock Storage

Ice thermal storage:

- Involves freezing water or another fluid during off-peak hours and releasing the stored energy in the form of cool air during peak hours
- Mainly used to serve air conditioning loads. Such stored cooling energy represents a flexible source of demand, one that help improve the integration of variable renewables like solar and wind.

Hot rock based thermal storage:

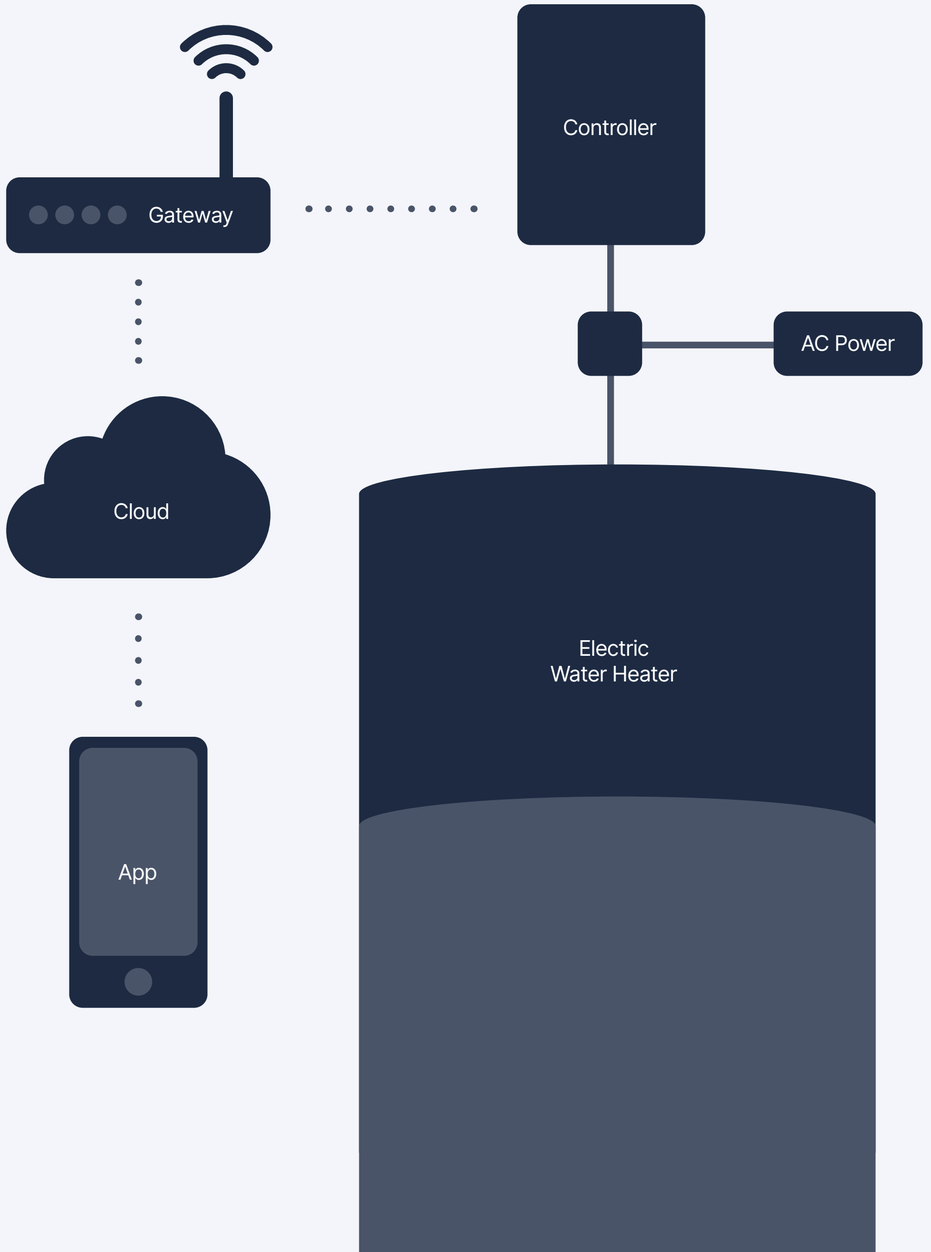
- Relies on using high-pressure steam to heat crushed rocks during the charging phase.
- During the discharge phase, the storage unit releases the accumulated heat by adding hot water.
- When the hot water strikes the heated rocks, the steam generated can be used to drive a turbine.

Case Study – TES Santa Barbara Power Plant

Companies Enel and Brenmiller Energy are piloting a 24 MWh rock-based thermal energy storage (TES) system at an existing power plant in Tuscany, Italy. The project has 5 hours of storage duration, supports renewable energy integration, increases the ramp rate for the power plant and provide heat directly to industrial customers.

Distributed Thermal Storage Solutions

- Thermal energy can be stored directly within homes and businesses in hot water tanks or other fluids, as well as in bricks or other materials like sandy loam.
- Such distributed thermal storage technologies have significant potential to reduce reliance on fossil fuels used for heating, such as gas.
- By providing on-site thermal storage that can be controlled remotely, such technologies can also help make electricity demand more flexible, enabling utilities to shift and manage demand peaks.



Electrical Storage

Super-capacitors

At a glance:

- Super-capacitors are an early-stage electrical storage technology that shows significant potential
- Technology relies on the use of graphene, a one molecule thick material that is extremely strong and highly conductive
- At least 34 MW/21.6 MWh of cumulative global installations to date

Although at a relatively early stage, super capacitors have a few advantages:

- Can be charged extremely rapidly (in seconds)
- Long lasting
- Have the potential to be rapidly scalable
- Highly efficient and scalable

The main challenges relate to scaling up production and keeping costs low; production requires manipulating materials at the nano-scale, which is currently cost-intensive. Also, super-capacitors mainly operate at smaller sizes, and are best suited to distributed rather than grid-scale applications.

Power-to-X

At a glance:

- Electricity and chemical inputs are used to produce energy carriers such as hydrogen or ammonia
- Power-to-X has the potential to offer a long-duration energy storage solution
- Such long-duration energy storage can potentially be valuable to meet longer-term seasonal fluctuations in energy demand

Based on the power-to-X facilities that have been planned to date, the cost of green hydrogen production ranges from 3 – 7 EUR/kg.

Challenges persist, however:

- Transport and delivery costs are high
- High energy and conversion losses
- Large capital investment required, including in associated infrastructure (ports, pipelines, electrolysers, etc.)
- Long project lead times (several years)
- Ranks among the higher cost energy storage options

Case Study – Grapzow, Germany

A 1MW/2.7MWh P2G system installed at the 140 MW Grapzow, Germany wind park in 2013 uses excess wind power to produce hydrogen gas. This gas is either injected directly into the local gas grid or used to fuel an internal combustion engine to minimize wind energy curtailment.

The Use Cases of Storage Technologies

There are five main categories of services that storage technologies can provide

Energy and capacity services

Transmission grid services

Distribution grid services

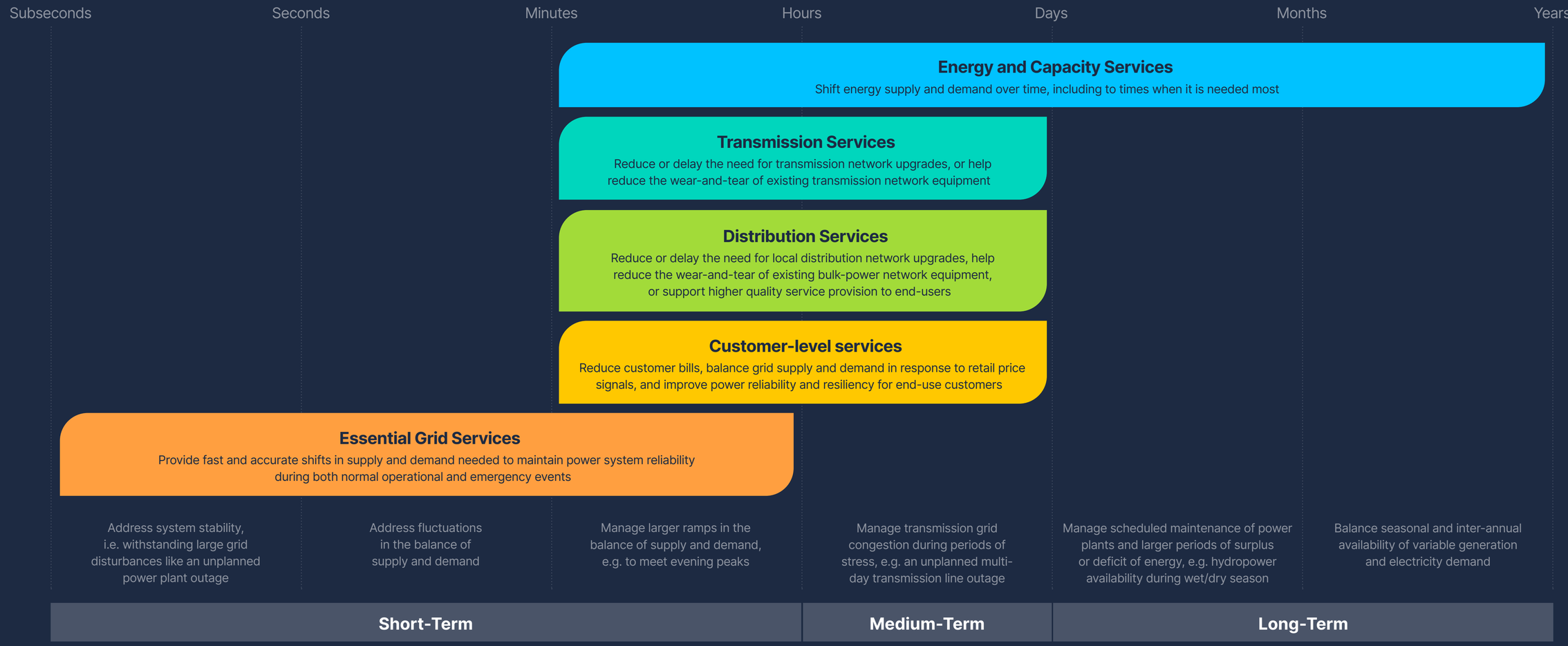
Customer-related services

Essential grid services

(i.e. ancillary services)

Use Cases of Storage

The uses of storage can be better understood by looking at the timescales over which different services are provided.



Source: Based on USAID (2021), Energy Storage Decision Guide: For Policymakers, https://www.nrel.gov/docs/fy21osti/78815.pdf

Use Cases of Storage

To gain a higher-resolution picture of how these various use cases apply in real power systems, it is possible to break the various categories down further.

This chart provides an overview of the main services that battery storage systems can provide, broken down by the application, or type of service provided.

Source: Based on USAID (2021), Energy Storage Decision Guide: For Policymakers, https://www.nrel.gov/docs/fy21osti/78815.pdf

Energy and Capacity Services

Energy storage systems can provide multiple services to support generation and the bulk energy system. The main services include:

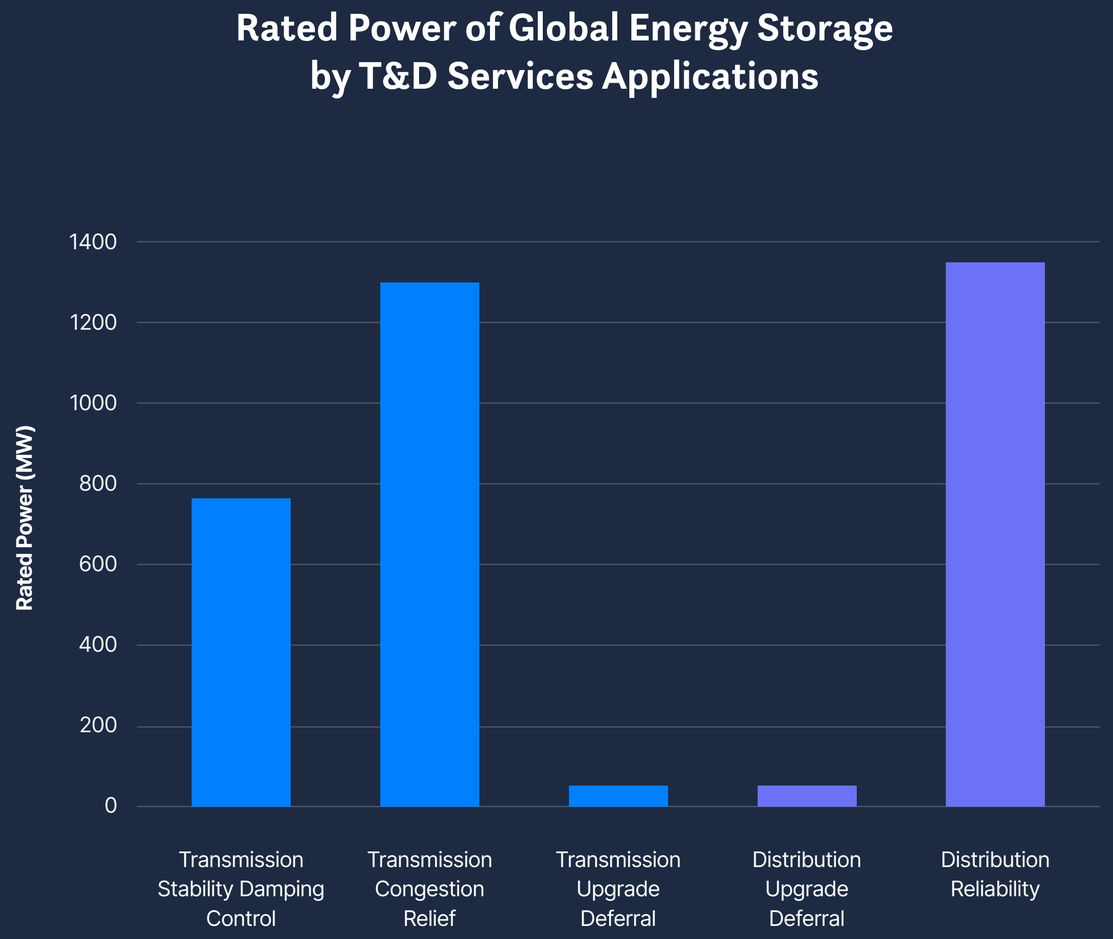
- **Capacity support:** Storage can provide additional energy capacity needed to meet peak demand or generation outages and can reduce the need for high-cost peaking plants.
- **Energy services:** Battery storage can provide electricity to the grid to support reliability and meet power needs, such as during peak demand hours
- **Firming wind and solar output:** Storage can help make renewable energy output more constant by discharging power to supplement renewable generation when output drops.
- **Mitigating curtailment:** Storage systems can reduce the amount of power lost during curtailment events by absorbing excess electricity and discharging it later.

Transmission and Distribution-related Services

Deployment of batteries across grid domains can relieve stress on the existing transmission and distribution infrastructure and defer or avoid the need for additional investments.

Additionally, batteries can help extend the life of existing infrastructure in part by reducing the amount of load served.

Experience in the U.S. suggests that a storage facility with a rated power output of 4% to 5% of a particular transmission grid infrastructure's load carrying capacity could help defer an upgrade of that piece of equipment by 1–2 years.



Source: Sandia National Laboratories (2022), Statistics, https://sandia.gov/ess-ssl/gesdb/public/statistics.html

Customer-level Energy Services

In addition to supporting the grid and wholesale electricity market, energy storage systems can provide services to customers to manage their electricity use. These include:

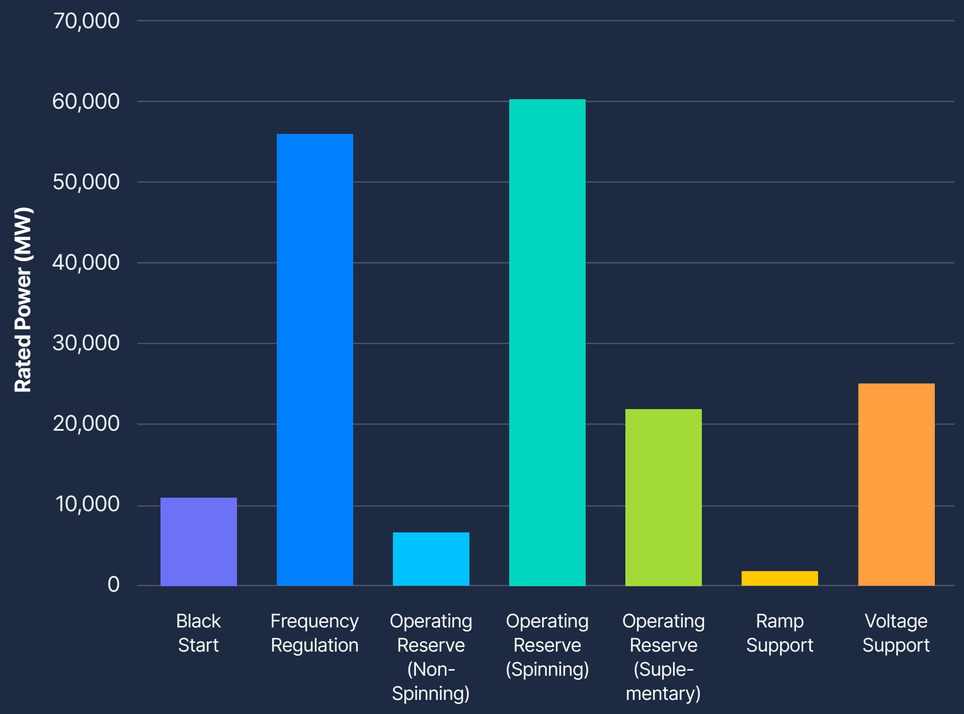
- **Reducing demand charges** - many customers have to pay demand charges (mainly commercial and industrial customers). Storage can help avoid high demand charges by keeping imports from the grid below certain thresholds.
- **Time-of-Use (TOU) management –** Customers can charge their storage systems during the lowest-cost hours and discharge during the highest-cost hours.
- **Maximizing consumption of self-generation –** By pairing a storage system with solar PV or other customer-sited generation, the storage system can be used to reduce exports to the grid and increase cost savings.
- **Continuity of energy supply –** storage can provide valuable reliability and continuity of power supply for end-users in the event of a service interruption or power outage.

Essential Grid Services

Energy storage systems can provide multiple ancillary services:

- **Voltage and frequency control** – By rapidly charging and discharging, storage systems can manage voltage fluctuations on the system and make sure that frequency is maintained within the required range.
- **Black start capability** – Storage that is located on-site at generation facilities can provide an external source of electricity to help restart large generators following a grid failure or an outage.
- **Operating Reserve** – Electricity supplies that can quickly be made available in case of an unexpected loss of generation. Storage can serve as both primary (power received within 10 minutes) and supplemental (power that can be received within 30 minutes) reserves.

Rated Power of Global Energy Storage by Ancillary Services Applications



Source: Sandia National Laboratories, https://sandia.gov/ess-ssl/gesdb/public/statistics.html

Main Barriers to Storage Technologies

Storage technologies are capital intensive (high upfront CAPEX)

- As with most power generation projects, most of the total lifetime investment in battery storage systems occurs upfront.
- This front-loaded cost structure applies across storage technologies.
- Some storage technologies (such as Power-to-X, or pumped hydro storage) also require complex additional investments, making them even more capital intensive.
- This high upfront capital investment poses a particular barrier in contexts where future revenue streams remain uncertain.

Policy and Market Design Issues

- Under many countries' legal frameworks, **electrical storage continues to lack a clear legal and regulatory framework**. This lack of legal clarity increases investment risk.
- **Lack of long-term contractual frameworks** for services offered by storage increases revenue uncertainty, and pushes up the cost of capital.
- **Minimum technical requirements** often prevent some storage technologies from participating in certain parts of the electricity market.
- Most jurisdictions do not have clear **policies for storage procurement**.
- Possibility of **double taxation** still exists in certain jurisdictions (e.g. taxation applies to both charging and discharging).
- While ancillary and grid management services can be important revenue streams for storage operators, **ancillary services markets are typically less developed** than energy markets.
- In addition, the **procurement of ancillary services** is frequently not market-based; this makes it difficult for storage projects to compete on a level playing field.
- **Incentives for grid operators** frequently favour large capital investments in transmission infrastructure over cheaper, distributed solutions such as storage.
- Storage technologies are not yet adequately captured in **national strategy or technological roadmaps**.

Grid Connection, Permitting and Regulatory Issues

In many regions, storage currently operates in a regulatory vacuum:

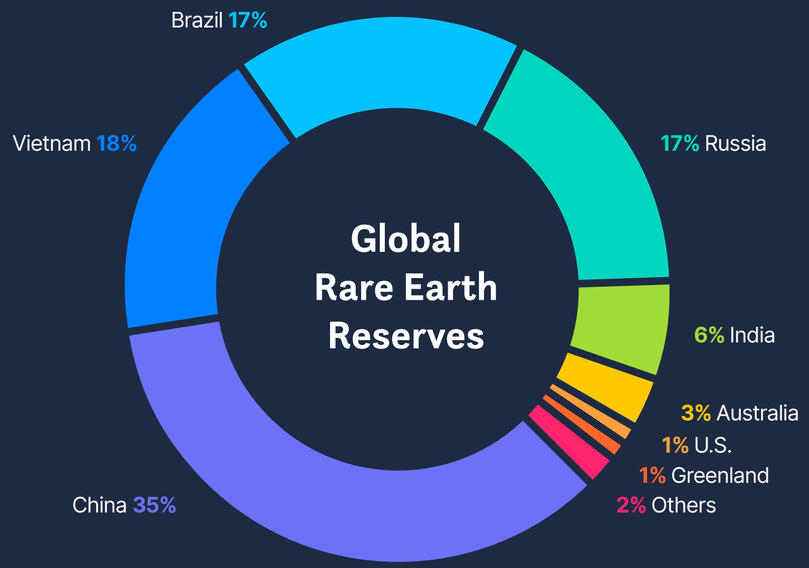
- Grid codes for storage technologies are still not implemented in most countries.
- There are hundreds of GW of storage capacity in the interconnection queue around the world, awaiting regulatory clarity.
- Projects are frequently cancelled or delayed due to uncertainty over market access, grid access, and market rules.
- This lack of clear environmental regulations continues to hinder investment in certain storage projects and technologies.

Inability to Participate in Balancing Markets

- Battery storage systems can provide many services to the power system with fast response, frequency restoration, voltage support, congestion management, as well as balancing services.
- However, rules in many countries make it difficult for operators to monetize the full range of services.
- While the balancing market can provide additional revenues for storage providers, many countries still do not have fully functioning balancing markets.
- Also, in some cases, certain services such as “Frequency Containment Reserves” are a regulatory requirement, and are not compensated separately.

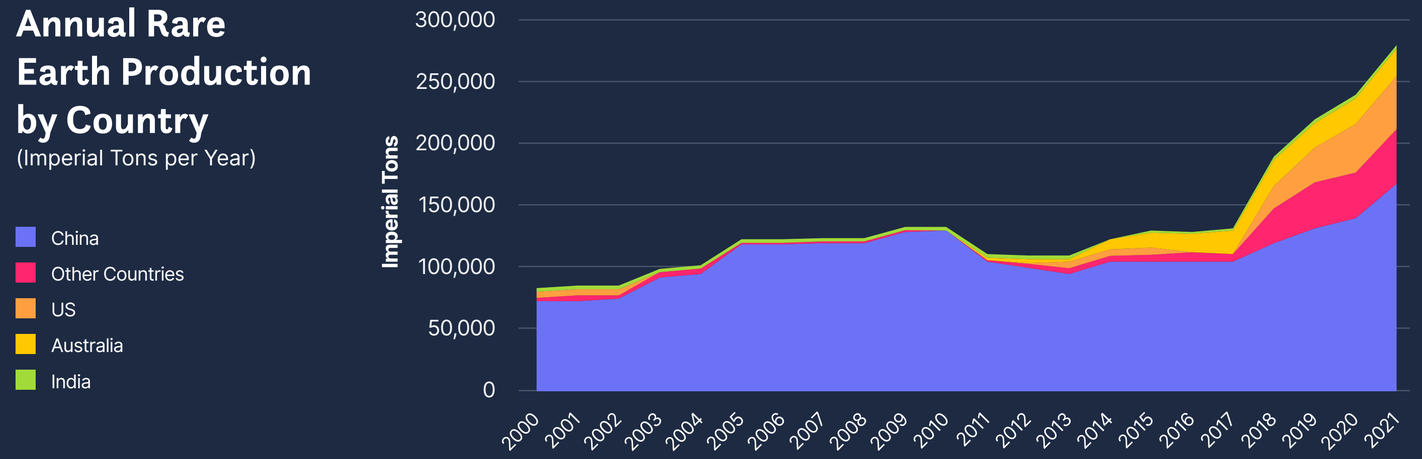
Constrained Materials Supply

- The supply of critical materials for producing batteries and green energy technologies, including lithium, cobalt and certain rare earth elements, is constrained.
- China dominates 60% of rare earth mining and 80% of rare earth processing and refining. China also controls 51% of chemical lithium, 65% of global lithium refining and 60% of global battery component manufacturing.
- In addition, there is a risk that demand growth starts to outpace production: some analysts expect possible shortages of lithium and cobalt already by the mid-2020s.



Annual Rare Earth Production by Country

(Imperial Tons per Year)



Source: USGS (2022), https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information

Policy Options to Scale-Up Energy Storage

High-level Findings
for Policymakers and Regulators

Storage is key to low-carbon power system

Storage can play a critical role in the transition to a more flexible, reliable, and decarbonized power system.

Storage can respond quickly, and flexibly

Energy storage is a highly flexible asset, one that can respond more quickly to power system needs than traditional assets like peaking power plants.

Markets need to value storage services

Key to unlocking more investments in storage is to create market conditions that enable storage projects to monetize the various services they provide (energy, capacity, spinning reserves, frequency response, etc.).

Familiarity with storage needs to grow

Increasing the familiarity of utilities and system operators with storage technologies is critical.

Battery storage has several advantages over other flexibility options

Storage can be deployed rapidly

Battery storage can be built rapidly (e.g., within 6 - 12 months) and can therefore be deployed much faster than other flexibility options like grid expansion or retrofitting fossil fuel-based power plants.

Storage is more geo-politically secure

Conventional fossil-fuel power plants are more vulnerable to fuel supply disruptions.

Storage provides valuable flexibility

Battery storage can ramp up and down much more quickly than fossil fuel-based power plants (such as gas, lignite, or coal).

Storage is increasingly cost-effective

With costs falling rapidly, battery storage already ranks among the cheapest options for increasing power system flexibility.

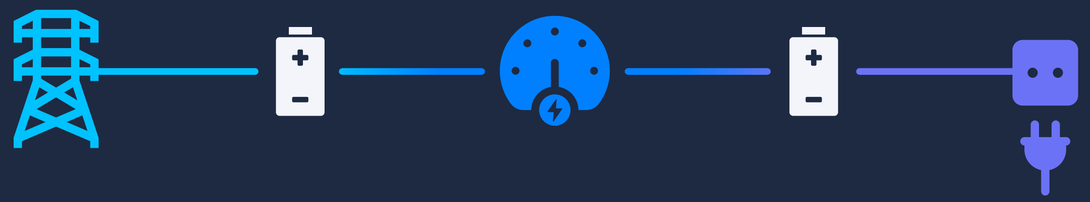
Key Question for Policymakers and Regulators:

Will storage adoption be mainly...

in-front-of-the-meter
developed by companies specializing on storage technologies

OR

behind-the-meter
bought and deployed by customers?



The answer to this question has a direct influence on the appropriate policy mix.

Key Considerations for In-Front-of-the-Meter Storage

- **Require utilities and system operators to include storage in their future planning and modelling.** Adding in-front-of-the-meter storage can reduce investment needs, such as in T&D infrastructure and bring a range of other benefits. In order for these gains to be realized, storage needs to be better integrated into power system planning.
- **Avoid sudden, erratic changes to policy, regulatory, and electricity market structures.** Uncertainty increases investment risk. One recent example is the sudden introduction of electricity price caps in the EU: such price caps arguably discourage investments in the very technologies (such as energy storage) that can help sustainably and durably mitigate price spikes in the future.

Key Considerations for Behind-the-Meter Storage

- **Provide special fiscal and financial incentives** to encourage customer-sited storage adoption: this can encourage wider adoption and spur innovations in new business models, such as vehicle-to-grid, smart home charging, and the development of aggregators.
- **Improve the attractiveness of storage by ensuring that there is no double taxation** (on charging and discharging) of customer-sited battery assets.
- **Explore the introduction of special, time-varying electricity rates** to encourage smarter energy management.
- **Adopt frameworks to facilitate the emergence of aggregators** that can group small-scale battery storage systems together to provide more value to the power system as a whole.
- **Introduce targeted measures for thermal storage:** there is enormous potential for thermal storage, and it remains largely untapped. Thermal storage can further improve household-level and regional energy security, and reduce imports of fossil gas.

Policy Options to Scale-up Storage

1

Update policies and wholesale **market rules** to allow storage to receive compensation for a wider range of services.

2

Establish **financial incentives** to support the deployment of storage technologies.

3

Introduce **binding targets** for storage adoption in order to accelerate market growth.

4

Explore the introduction of **auctions** for storage (or hybrid VRE + storage projects).

5

If direct financial incentives are to be deployed, they should prioritize customer-sited, **behind-the-meter** installations.

Policy Options to Scale-up Storage

6

Remove unnecessary technical and licensing **requirements** that hinder the adoption and integration of storage technologies.

7

Move electricity markets closer to **real-time** with shorter settlement times: this can create clearer opportunities for rapid response technologies like storage.

8

Implement policies and incentives to spur the adoption of supportive **smart grid** technologies, such as advanced metering infrastructure and demand response.

9

Encourage a **diverse ecosystem** of battery chemistries to increase resilience and reduce reliance on individual resources and minerals.

10

Accelerate the shift toward a **circular economy**, including by investing in local facilities for battery recycling and the adoption of second-life applications.

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