Framework Convention on Climate Change

TEC/2026/33/4

Technology Executive Committee

25 August 2026

Thirty-third meeting

15–18 September 2026 (18 September 2026 TEC-CTCN Advisory Board Joint Session)

Draft policy brief on accelerating the deployment of energy storage to advance clean energy transitions

Cover note

A. Background

1. As per activity A.2.1 of its rolling workplan, building on the work on collaborative research, development and demonstration (RD&D), the TEC is to analyse the needs for RD&D for high-impact emission-reduction technologies to help countries implement their NDCs and other mitigation strategies and ensure long-term environmentally sustainable energy supply.

2. At TEC 32, the TEC considered a draft outline of the policy brief on accelerating the deployment of energy storage to advance clean energy transitions and requested the open-ended activity group to develop a draft policy brief for consideration at TEC 33.

B. Scope of the note

3. The annex to this note contains a draft policy brief on accelerating the deployment of energy storage to advance clean energy transitions.

C. Possible actions by the Technology Executive Committee

4. The TEC will be invited to consider and provide guidance to the open-ended activity group on the draft policy brief on accelerating the deployment of energy storage to advance clean energy transitions.

Annex

Draft policy brief on accelerating the deployment of energy storage to advance clean energy transitions

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Foreword

To be developed

Abbreviations and acronyms

To be developed

Acknowledgements

To be developed

WHAT IS THE ISSUE

1. Why this brief

THE CONTEXT OF THIS BRIEF

Energy storage is one of several critical flexibility tools (see Fig. 1) for the energy transitions. It enables the integration of large shares of renewable energy (mostly wind and solar) into power systems by storing clean energy when available and supplying it when needed - balancing supply and demand, reducing congestion and curtailment, providing grid stability, and improving energy security during times of low supply.

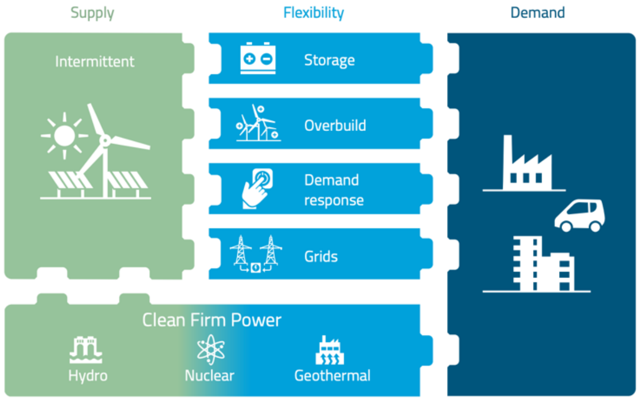


Figure 1: Energy storage as one of the flexibility tools working together to bridge the gap between supply and demand. Source: FCA (2026).

HOW THE POLICY ADRESSES IT

THE PROBLEM THIS BRIEF ADDRESSES

Yet despite the value it offers, storage remains under-recognised in the planning and policy frameworks that shape investment. Current transmission and distribution planning often neglects the multiple benefits storage brings to markets and the power system as a whole, and should be updated to reflect them. The result is a persistent gap between what the technology can already and could in future deliver and what current policy allows it to deliver.

THE CONTRIBUTION OF THIS BRIEF

This brief exists to help close that gap by providing decision-makers a clear, evidence-based account of the role of energy storage, the state of the available technologies, and the policy steps needed to accelerate their deployment.

It responds to the rolling workplan (activity A.2.1) of the Technology Executive Committee (TEC), under which the TEC analyses the research, development and demonstration (RD&D) needs for high-impact emission-reduction technologies to help countries implement their Nationally Determined Contributions (NDCs) and other climate strategies.

How this policy brief supports… The brief is a concise document designed for policymakers, national governments, international organisations, multilateral development banks, and the private sector. It aims to:

- **Analyse the role of storage** in facilitating renewable energy integration, improving energy system resilience, and enabling cross-sector electrification.
- **Present a structured assessment of technology solutions**, evaluating the maturity, commercial viability and deployment readiness of key storage technologies to support differentiated policy recommendations.
- **Examine the enabling policy and regulatory frameworks** that determine the speed and cost of deployment, alongside innovative business and financing models.
- **Keep developing countries central**, with particular focus on least developed countries (LDCs) and small island developing States (SIDS), including while analyzing the issues of energy access, just transitions, climate finance and technology transfer.

Box 1

2. Executive Summary

To be developed

3. Why energy storage matters now

Human societies have always depended on stored energy. What is changing is the form in which energy must be stored, and the speed and scale at which it must be made available to the energy systems.

3.1 An old need in a new energy system

Long before electricity networks existed, households stored firewood to preserve the solar energy captured by trees and make heat available when it was needed. Communities later impounded water behind reservoirs, turning river flows into a resource that could be released over time. The industrial economy extended the same logic through stocks of coal, oil and gas: primary energy could be accumulated, transported and consumed on demand. Energy storage is therefore not new. What is new is the need to store and manage energy within an increasingly electrified system while simultaneously integrating large shares of variable renewable generation, where supply and demand must be balanced continuously, and where much of the new supply comes from the variable flows of sun and wind. (Sterner and Stadler, Energy Storage Through the Ages, 2019).

In fossil-based power systems, the fuel stock itself provided a form of storage. Coal piles and gas tanks allowed thermal plants to rapidly and readily increase or reduce output in line with demand. In a renewables-based system, the primary resource cannot be stockpiled in the same way: sunlight and wind must be used when available, shifted to another time, transmitted elsewhere or curtailed. This changes the problem from storing fuel before generation to managing electricity and energy services after variable generation becomes available.

Electrification reinforces this shift. Electric vehicles, heat pumps and industrial processes add new loads, but they can also provide flexibility if consumption is managed intelligently. IRENA's updated roadmap sees electricity rising from about **23%** of global final energy consumption today to **35% in 2035** and more than 50%? by 2050. A growing share of the wider economy will therefore depend on the power system maintaining balance at each moment. Storage responds to both sides of that transformation: it helps harness variable renewable output and gives electrified demand more scope to consume power when it is plentiful and low-cost. (IRENA, Transitioning Away from Fossil Fuels, 2026).

3.2. From renewable deployment to system integration

Renewable power is expanding at unprecedented speed. Global renewable capacity reached **5 149 GW** at the end of 2025 after additions of **692 GW**, annual growth of **15.5%**. Solar and wind supplied 96.8% of the additions. Yet a substantial gap remains to the roughly 11.2 TW indicated for 2030 in IRENA's 1.5°C pathway. The pace of deployment must therefore continue to rise while the system's ability to connect and use the new capacity improves. (IRENA, Renewable Capacity Statistics 2026).

The transitions is now entering a more demanding phase. IRENA's latest tracking assessment finds that, despite a record **582 GW** of renewable capacity additions in 2024, global deployment must rise to around **1122 GW annually from 2025 to 2030** to reach the 11.2 TW target. This requires annual capacity growth to accelerate to **16.6%**, while renewable-power investment needs to more than double from **USD 624 billion in 2024 to at least USD 1.4 trillion per year** over the remainder of the decade. Deployment at this scale cannot be achieved by adding generation capacity alone. Grids, storage and other flexibility resources must expand in parallel so that growing volumes of variable renewable electricity can be connected, balanced and used reliably. The policy focus must therefore shift from maximising renewable capacity additions in isolation to building a fully integrated, flexible and investable power system. (IRENA, COP30 Presidency and GRA, Delivering on the UAE Consensus, 2025)

Solar and wind vary across different timescales. Cloud cover and gusty wind can change output within minutes. On a longer scale, the solar cycle creates a stable daily pattern and forecasts have made wind resource predictable on large areas. However, weather systems can affect regional wind or solar production for multiple days, eventually in a simultaneous way. Demand is also changing as cooling, mobility and industrial electrification alter peaks and seasonal profiles. Due to this diversity of timescales and location constraints, no single flexibility resource can efficiently address the challenge by itself, highlighting the need for complementary technological solutions.

3.3 Storage within a portfolio of flexibility options

Flexibility is the ability of the energy system to respond to expected and unexpected variations in supply and demand. Storage contributes by absorbing electricity when it is abundant and releasing it when its value or utility is higher. It can also provide fast frequency response, reserves and local network support. Where regulations allow, one asset may combine several compatible services, improving utilisation and project economics.

IRENA estimates that global daily flexibility needs in 2030 could be around **three times** their 2019 level. The estimate is an order-of-magnitude signal rather than a universal storage requirement. Stronger grids, interconnection, demand response and more flexible operation can complement or substitute for storage. The appropriate mix depends on the resource profile, existing dispatchable capacity and the cost of each option. Storage can defer specific network investments or relieve local congestion, but it cannot replace timely transmission and distribution development. (IRENA, Flexibility for a Secure and Affordable Power Sector Transformation, 2026).

The distinction between services matters. Batteries can respond within milliseconds and are well suited to frequency control and shifting solar output into the evening. Longer periods of low wind or solar output may call for a different combination of storage, dispatchable renewables, interconnection and demand response. An asset built for a rare adequacy event (i.e., very few hours in the year in which the aggregated capacities might not suffice to supply the system demand) may have substantial system value even if it operates only a few times per year, but this value will not automatically appear in short-term energy-market revenue.

IRENA's storage valuation framework separates two questions that are often conflated: the value an asset creates for the power system, and the revenue a project can capture. Storage may reduce curtailment, avoid network reinforcement or improve adequacy while remaining commercially unviable if those benefits are spread across different institutions or are not remunerated. Sound policy begins with a transparent estimate of system benefits, compares alternative solutions and then selects an instrument that allows an efficient share of the value to support investment. (IRENA, Electricity Storage Valuation Framework, 2020).

Storage also illustrates the importance of systemic innovation. The availability of a technically capable battery does not, by itself, produce a flexible or resilient energy system. Its contribution depends on how it is combined with, and embedded within, planning, digital control, grid infrastructure, market design and viable business models. IRENA's innovation landscape therefore treats large- and small-scale batteries, long-duration storage and storage-as-a-service as elements of wider solution packages rather than stand-alone innovations. The relevant policy question is not only which storage technology to deploy, but which combination of innovations can address the specific system or development need. (IRENA, Innovation Landscape for Sustainable Development Powered by Renewables, 2026)

3.4 Energy security, affordability and resilience

A renewables-based system can reduce exposure to fossil-fuel supply and price shocks. IRENA estimates that installed renewable capacity avoided around **USD 480 billion** in fossil-fuel costs in 2025. Storage can strengthen this hedge by shifting domestic renewable electricity into periods of higher demand and reducing diesel use in isolated systems. The benefit is particularly relevant for islands and countries exposed to imported fuels, transport costs and foreign-exchange pressure. (IRENA, Renewable Power Generation Costs in 2025).

Resilience is not an automatic attribute. A grid-connected battery may stop operating during an outage unless it has islanding capability, suitable controls and a defined critical load. Resilience needs to be planned as a service, with requirements for duration, location and recovery. The same discipline applies to climate benefits. Storage supports decarbonisation when charging and dispatch reduce curtailment or displace higher-emitting generation; not every application or operating pattern produces the same outcome.

3.5 Global commitments: from ambition to implementation

Policy makers increasingly recognise that generation targets and enabling infrastructure are inseparable. The UAE Consensus at COP28 called for global efforts to triple renewable capacity and double the annual rate of energy-efficiency improvement by 2030. At COP29, the Global Energy Storage and Grids Pledge added a collective ambition to deploy **1 500 GW of energy storage by 2030**, more than six times the 2022 level, and to add or refurbish **25 million kilometres of grids** by 2030. (COP29 Global Energy Storage and Grids Pledge).

Looking ahead, the COP31 presidency has proposed a target of 35% electrification of final energy consumption by 2035, extending the "deploy → connect → use" logic from generation and infrastructure to end-use transformation. (COP31 Presidency, 2026).

Read together, the commitments describe one implementation challenge: renewable generation must be accompanied by the infrastructure and flexibility needed to integrate it. A global storage target is a signal, not a formula for allocating capacity among countries. National needs vary with the power mix, demand profile, grid conditions and available alternatives. Power capacity in GW is also incomplete: energy capacity in GWh and usable duration determine how long output can be sustained. Reporting both, alongside location and availability, would show whether the emerging fleet matches the needs identified in national planning.

Countries can translate ambition into delivery by integrating flexibility into NDC implementation, power-sector and grid plans, electrification strategies and resilience plans. Targets need institutional responsibilities, connection procedures, standards and investable pipelines. IRENA estimates that cumulative investment of **USD 31.5 trillion** in renewables, grids, flexibility, efficiency and conservation is required from 2024 to 2030 to meet the UAE Consensus energy goals; average annual investment in grids and flexibility needs to reach about **USD 717 billion**. (IRENA, World Energy Transitions Outlook 2024).

The sustainable-development case is equally conditional. Storage can support reliable access, resilient infrastructure and climate mitigation, but outcomes depend on financing, siting and operation, as well as the management of materials at end of life. A just scale-up should pair deployment with responsible supply chains, circular-economy measures and realistic opportunities for local skills and enterprise.

3.6 Storage as a strategic enabler of electrification

Storage is often discussed primarily as a renewable-energy integration tool. Increasingly, however, it should also be understood as an electrification enabler. The next phase of the energy transitions will be characterised not only by the continued growth of renewable generation, but also by the expansion of electricity demand across transport, buildings and industry. Electric vehicles, heat pumps, cooling systems and industrial electrification will increase electricity consumption and, in many cases, create new peak-demand challenges.

Storage can help manage these emerging demand patterns by shifting electricity consumption away from system peaks and enabling greater use of low-cost renewable generation. In combination with smart charging, digital energy management systems and demand-side flexibility, storage can reduce the need for network reinforcement and improve utilisation of existing infrastructure.

The interaction between storage and electrification is particularly important in developing countries, where rapid demand growth is often occurring alongside accelerated renewable deployment. In these contexts, storage can support both the reliable integration of renewable generation and the efficient expansion of electricity services. Looking ahead, the value of storage will increasingly be determined not only by its ability to balance variable generation, but also by its contribution to a more electrified and flexible energy system.

4. Understanding the Energy Storage Landscape

In this policy brief, when talking about energy storage, only non-fossil types of technologies are considered. Within these, there are many types of energy storage technologies that vary in terms of cost, duration, application, lifetime, opportunity to reduce costs, roundtrip efficiency, and maturity. These technologies must be deployed in a coordinated manner across sectors, including power, transportation, industry, buildings, and behind-the-meter/off-grid applications, to minimize costs and maximize effectiveness.

4.1. Technology Classification

One way to group storage technologies is by how they physically store energy. On this basis, four storage families can be distinguished - electrochemical, mechanical, thermal, and chemical - each comprising several distinct technologies at different stages of readiness (see Figure 1). However, some storage technologies fall into multiple categories. In this policy brief, we distinguish by the dominant storage mechanism.

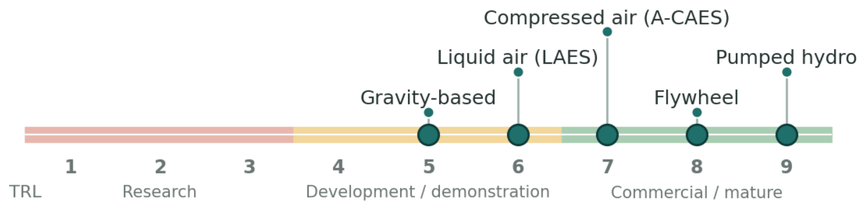
4.1.1 Electrochemical

How it works	Commonly known as battery storage, electrochemical storage holds energy in chemical bonds within a battery cell.
Relevant technologies	It spans lithium-ion - the dominant short-duration technology suited to power quality, peak shaving, and the daily solar cycle - through longer-duration chemistries such as redox-flow (e.g. vanadium); sodium-ion and sodium-sulphur; lead-acid; metal-air (e.g. iron-air), to name a few.
Maturity (TRL)	
Applications	Batteries are central to managing daily variability on the grid. Emerging chemistries such as metal-air are now being deployed at utility scale to secure supply for large loads.
Advantages / Risks	**Advantages:** Modular and scalable, fast response, high round-trip efficiency, and steeply falling costs. **Risks:** NMC chemistries[1] rely on cobalt and nickel; LFP[2] (now ~90% of deployments) avoids both and is more thermally stable, at slightly lower energy density. All lithium chemistries still need lithium, whose mining and processing are heavily concentrated in China. Also: cell degradation, and lower energy density for flow batteries.

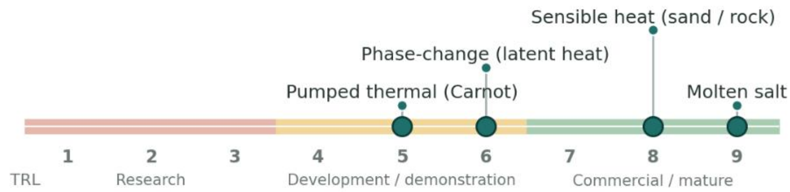
[1] NMC batteries (a combination of Nickel, Manganese, and Cobalt) are a powerful and suitable lithium-ion system that can be designed for both energy and power cell applications.

[2] A LFP battery is a type of lithium-ion battery where lithium iron phosphate is used as the cathode material and lithium source.

4.1.2 Mechanical

How it works	Stores energy as gravitational or pressure potential, or as rotational motion, and typically releases it by driving a turbine or generator.
Relevant technologies	It includes the most mature and widespread grid-scale storage technology storage technology - pumped hydro storage (PHS), which is now built mostly in low-impact, closed-loop configurations - as well as gravity-based systems and flywheels. Compressed air energy storage (CAES) and liquid air energy storage (LAES) also belong to this group.
Maturity (TRL)	
Applications	Mechanical storage underpins much of today's grid-scale balancing. It works for fast frequency regulation (flywheels) and intra-day to multi-day storage (compressed air and pumped hydro).
Advantages / Risks	**Advantages:** Very long lifetimes, high maturity, abundant low-cost materials, and independent sizing of power and energy. **Risks:** PHS requires suitable geography and decade-long build times; newer options aim to overcome siting limits but some have lower round-trip efficiency.

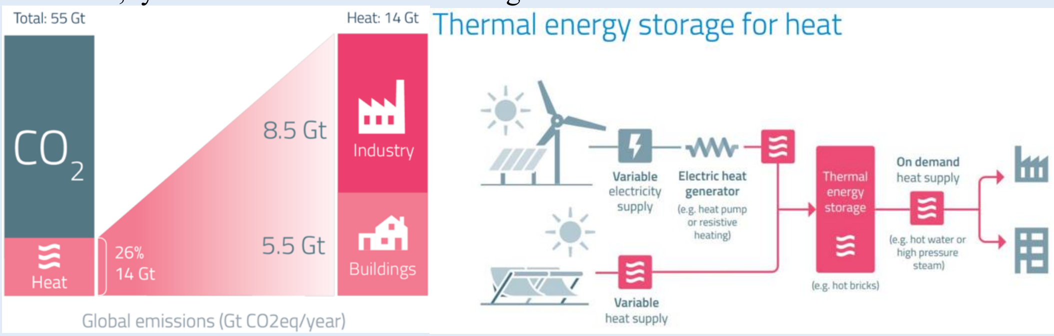
4.1.3 Thermal

How it works	Captures energy as heat (or, in some designs, cold) in a storage medium and releases it on demand – either reconverted to electricity through a heat engine (like a conventional thermal power plant, but without combustion) or delivered directly as heat to a specific application such as an industrial process.
Relevant technologies	Thermal energy storage is grouped by storage mechanism into three families: sensible-heat storage, which stores energy by changing the temperature of a medium (e.g. water, molten salt, sand, rock, concrete); latent-heat storage, which stores energy in the phase change of a material (phase-change materials); and thermochemical storage, which stores energy in reversible chemical reactions or sorption processes.
Maturity (TRL)	

Applications	Balancing power loads (molten-salt CSP) and, increasingly, delivering heat directly to industry and district heating – a cost-effective route to decarbonise heat, roughly half of global final energy use.
Advantages / Risks	**Advantages:** Low-cost, abundant materials, long duration, energy dense, and well suited to decarbonising industrial and district heat. Low cost of energy capacity. **Risks:** Lower electrical round-trip efficiency; heat-to-power (power-to-heat-to-power) conversion is still maturing. High cost of power capacity.

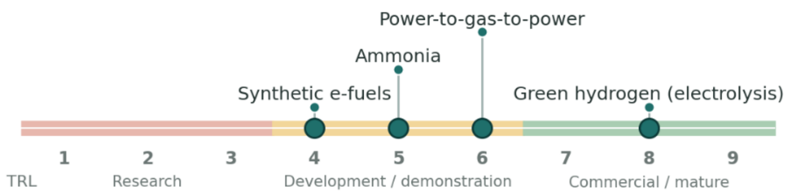
Why heat matters in the context of energy storage

Heat accounts for roughly 50% of global final energy use[3] and over 25% of global greenhouse gas emissions,[4] yet is often overlooked in storage discussions.



Box 2

4.1.4 Chemical

How it works	Uses electricity to produce a storable chemical carrier (e.g. hydrogen by electrolysis of water) through reversible reactions; the carrier is stored and later converted to electricity (e.g. in a fuel cell) or used directly.
Relevant technologies	These include green hydrogen - the most advanced technology within the family - as well as ammonia, electrofuels, and other non-hydrogen chemical carriers (such as metal powders).
Maturity (TRL)	
Applications	The family best suited to storing energy over the longest timescales (multi-day to seasonal) and to coupling the power sector with sectors that are hard to electrify directly - via hydrogen-derived fuels and feedstocks ("Power-to-X"),

[3] IEA (2021). Key World Energy Statistics. https://www.iea.org/reports/key-world-energy-statistics-2021/final-consumption.

[4] Total global GHG emissions, around 55 Gt CO2eq: Our World in Data (2023), "Greenhouse gas emissions" and UN environment program (2022), "Emissions Gap Report 2022" (page 6, table 2.1).

	such as sustainable aviation fuels, shipping fuels (e.g. ammonia, methanol), and chemical feedstocks
Advantages / Risks	**Advantages:** Highest energy density and longest storage duration; can link multiple sectors. **Risks:** Low round-trip efficiency (<40%); high cost; limited dedicated infrastructure; green hydrogen faces significant logistical challenges and strong competing industrial demand (e.g. fertiliser, chemicals).

4.2. Storage by Duration

Besides a classification along technological families, another useful lens to look at energy storage is through their discharge time – how long they can store energy. There is no official categorization according to storage duration, but this report uses the common distinction between short-, medium-, and long-term duration energy storage. Figure 2 provides an overview of technologies by discharge duration and maturity.

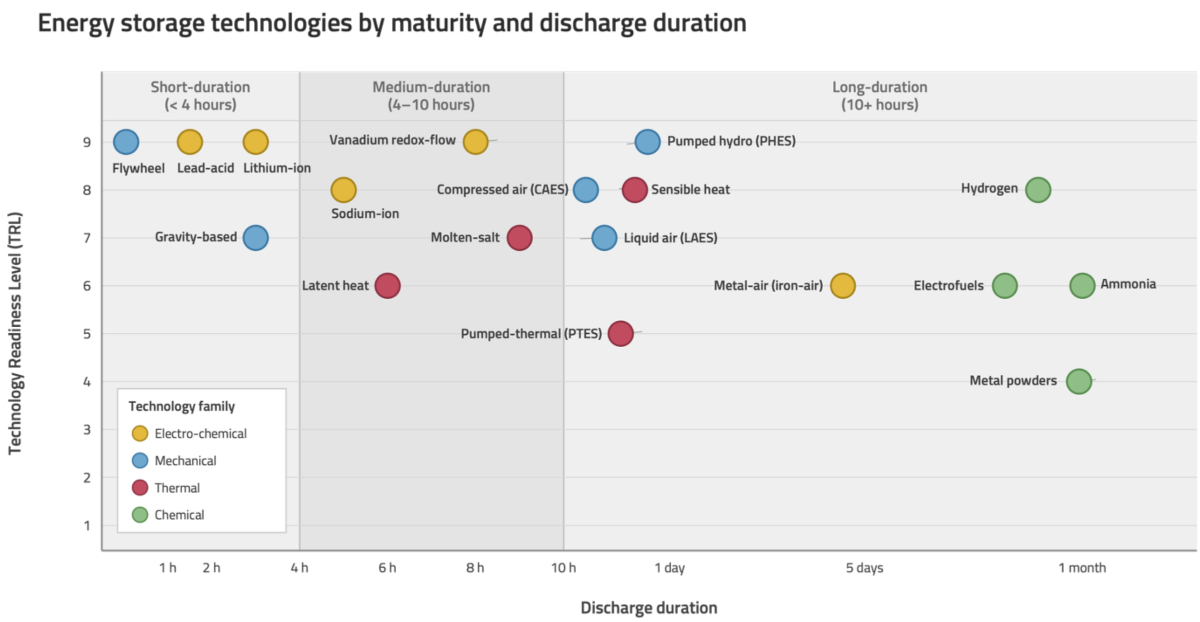


Figure 2: Energy Storage Technologies by maturity and discharge duration. Own chart based on IEA (2026) and Energy Transition Expertise Center (EnTEC) (2023) and Schmidt & Staffell (2023)

4.2.1 Short-duration storage technologies

0.5-4 hours

They support daily renewable energy integration and address the fastest fluctuations in the power system: frequency regulation, voltage support, peak shaving, and balancing the daily solar cycle. Lithium-ion batteries dominate this segment.

Short-duration storage is now commercially mature and increasingly cost-competitive. However, as described in Chapter 3, storage requirements grow exponentially as the share of renewables on a grid increases. Technologies optimised for four hours or less cannot, on their own, manage the variability that emerges at higher renewable penetrations across multi-day and seasonal timescales.

Project	Technology	Country	Capacity (Power | Energy)
Edwards Sanborn Solar and Energy	Lithium-ion Battery	United States	1252 MW | 3287 MWh
Beacon New York Flywheel Energy Storage Plant	Flywheel	United States	20 MW | 5 MWh
Collie Battery Energy Storage System (CBESS)	Lithium-ion Battery	Australia	500 MW | 2400 MWh

Table 1: Examples of Short-duration Storage Technologies.

4.2.2 Medium-duration storage technologies

4-10 hours

They balance grid operations over longer timeframes (4-10 hours) and bridge the gap between daily cycling and the longer fluctuations that arise from weather patterns lasting several days. Technologies in this range include longer-cycle lithium-ion configurations, redox flow batteries, advanced compressed air (A-CAES), and some thermal storage systems. Gravitational systems also belong to this category.

Project	Technology	Country	Capacity (Power | Energy)
Huntdorf	Compressed Air Energy Storage (CAES)	Germany	320 MW | 600 MWh
Sodium Sulfur Battery In Abu Dhabi	Sodium Sulfur Battery	United Arab Emirates	108 MW | 648 MWh
Ouarzazate (NOOR I, II, III)	Molten Salt Thermal Energy Storage	Morocco	510 MW | 3005 MWh

Table 2: Examples of Medium-duration Storage Technologies.

4.2.3 Long-duration storage technologies

10+ hours

They enable energy storage and system resilience over several days, with some up to 1 month and even seasonal. It balances supply and demand, enabling the integration of large shares of wind and solar energy into the power grid.

Long-duration storage technologies, such as pumped hydro, thermal energy storage, and power-to-gas (chemical fuels such as hydrogen), are much better at storing large amounts of energy. Hence, they will be needed in applications that require electricity over long periods of time, ranging from 10 hours to seasonal. Most LDES technologies are free from geographical constraints, are highly scalable, rely on modular designs, and use relatively inexpensive and abundant materials. However, several are still in early stages of development and commercialization, which has an impact on their cost.

Project	Technology	Country	Capacity (Power | Energy)
Fengning Station	Pumped Hydro	China	3600 MW | 40 GWh
Guoxin Suyan Huai'an	Salt Cavern compressed air energy storage (CAES)	China	600 MW | 2400 MWh
Pine Island	Iron-air batteries	United States	300 MW | 30 GWh
Energy Dome Ottana	CO_2 battery	Italy	20 MW | 200 MWh

Table 3: Examples of Long-duration Storage Technologies.

4.3. Sector Coupling and Cross-Sector Applications

Cross-sectoral applications of energy storage offer the opportunity to better align with the sectoral transformation approaches identified in the Global Stocktake. This includes the linkages between energy storage and energy generation, as highlighted above, but also the linkage between energy storage and energy use in transport, buildings, and industry, amongst other sectors.

> **Policy relevance of sector coupling**
> It’s important to recognise storage's cross-sector value - in heat, transport and industry - within market design, grid fees and system planning, rather than treating it as an electricity-only asset; and reflect storage across all durations (including TES and hydrogen) in NDCs and long-term strategies.

Box 4

Examples

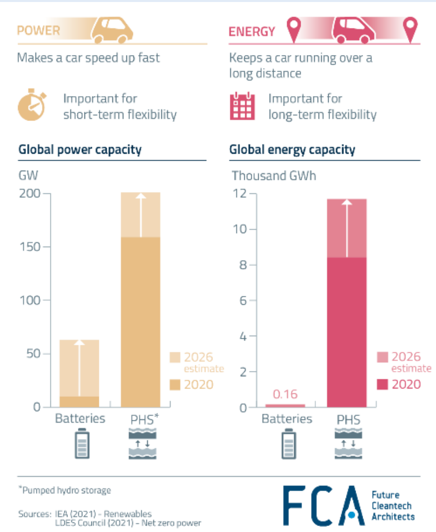
	Power sector	Storage soaks up surplus wind and solar and releases it at peak, so less clean power is wasted and the grid is less congested. Shorter-duration storage smooths the daily cycle, while longer-duration and seasonal storage covers extended shortfalls.
	Buildings	Home batteries and hot-water or thermal stores let households use more of their own rooftop solar and move demand away from peak hours. Pairing heat pumps with thermal storage is particularly valuable for the grid: buildings can heat when electricity is cheap and abundant, lowering evening peaks and easing the need to reinforce local distribution networks.
	Transport	Electric-vehicle batteries are a fast-growing flexible resource. Smart charging - timing charging to when renewable power is plentiful, and in time feeding some back to the grid - flattens local demand peaks, cuts network losses and defers costly grid upgrades, making the Vehicle-to-Grid (V2G) integration a storage solution. Retired EV batteries can also gain a second life in stationary storage.
	Industry	Thermal energy storage banks cheap surplus electricity or waste heat and delivers it on demand, making it possible to electrify industrial heat now supplied by fossil fuels - most of which is at temperatures within reach of today's technology. Retiring coal plants can be repurposed by adding thermal storage while reusing their turbines and grid connections, creating large-scale storage and preserving jobs. More on the TES Factsheet of Future Cleantech Architects.

H_2	**Hydrogen systems**	Electrolysis converts surplus renewable electricity into hydrogen that can be stored and turned back into power, and can supply clean fuel and feedstock to industry (fertiliser, chemicals, steel) and to hard-to-electrify transport such as shipping and aviation. It is well suited to seasonal storage and can draw on existing gas infrastructure. Because green hydrogen still faces cost and efficiency limits and strong competing demand, it works best alongside other long-duration options rather than as a replacement for them.
	District heating and cooling	Large seasonal heat stores - big insulated tanks, water-filled pits or rock caverns - capture surplus heat and solar power in summer and release it as heating in winter, linking the power and heat sectors across a whole city.

5. Deployment Trends and Investment

5.1 Current Global Deployment

5.1.1 How much capacity of which storage technology is installed?



The difference between power and energy in the context of energy storage

Over the last two decades, Li-ion battery technology has risen in popularity, becoming a common choice for grid-scale energy storage facilities. However, when thinking about energy storage it is important to consider and distinguish between both power and energy.
Power, by definition, is the speed at which energy is delivered (e.g. how fast a car can go, thanks to its engine).
→ **Power capacity (MW)** is how *fast* it can charge or discharge at any moment - the size of the "tap".

Energy is obtained by delivering power over a certain period of time (e.g. how far the car can get, thanks to its tank).
→ **Energy capacity (MWh)** is how *much* it can store in total, and therefore how *long* it can keep delivering - the size of the "tank".

Most conventional batteries are great at delivering power, which is useful for rapid, short-term fluctuations in the electrical grid. However, they are not able to economically deliver large quantities of energy, which is necessary to tackle seasonal fluctuations.

Examples:
A 100 MW battery with 200 MWh runs at full output for 2 hours; the same 100 MW paired with 800 MWh runs for 8. Same power, four times the energy. The ratio of the two is the duration.
This distinction drives cost. In a battery, power and energy are bundled: the same cells provide both, so storing more hours means adding more cells - cost rises almost in step with duration. That makes batteries cheap for short, sub-daily balancing but expensive once you need multi-day storage.
Pumped hydro, for instance, decouples the two: power comes from the turbines, energy from the size of the reservoir. Adding hours means a bigger reservoir, not more turbines.

Box 3

Figures for the cumulative installed capacity of energy storage systems around the world vary and often exclude pumped hydro storage. According to the IEA, in 2025 the world had approximately **272 GW of global installed energy storage power capacity.**

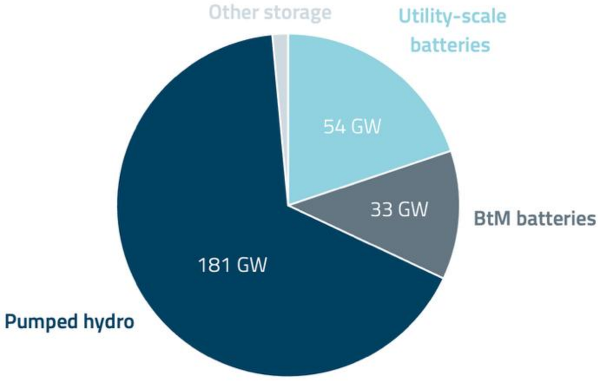
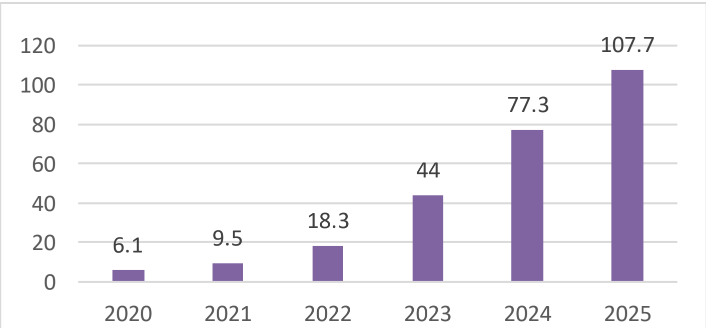


Figure 3: Global installed power capacity of energy storage in 2023. Other storage includes compressed air energy storage, flywheel and thermal storage. Hydrogen electrolysers are not included. Source: IEA (2024)

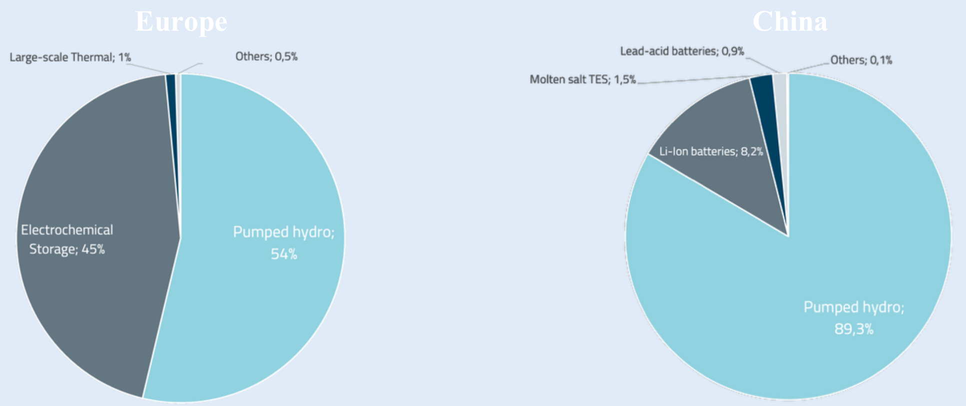
- **Pumped hydro still dominates global cumulative capacity**. In 2025, over 60% of energy storage was pumped hydro , while in 2020, it accounted for around 90% of installed storage worldwide.[5] It is still Europe's and China's largest single storage technology, with electrochemical storage (batteries) close behind. However, the distributions vary.
- **Batteries dominate new deployment**. Lithium-iron phosphate (LFP) batteries account for around 90% of deployments - up from well below 50% only five years ago.[6] **Battery storage is now the fastest-growing power technology in the world**. As shown in Fig. x, in 2025, 108 GW of new battery storage was deployed worldwide - 40% more than in 2024 - leaving installed battery capacity roughly eleven times its 2021 level.[7] A single year of current additions now exceeds the entire non-pumped-hydro stock that existed in 2020, and it took only four years for annual additions to climb from 10 GW to over 100 GW - versus about eight years for solar and fifteen for wind.[8]



[5] Schmidt & Staffell (2023).
[6] IEA (2026).
[7] IEA (2026)
[8] Due to this incredible acceleration of deployment, the Figure above is merely an indicator of the distribution of storage technologies and might not be representative anymore at the time of publication of this policy brief.

Figure 4: Global battery storage additions in GW, 2020-2025. Source: IEA (2026).

Regional examples: Energy storage (by power, in GW) in the EU and China in 2025



Source: Energy Storage Europe

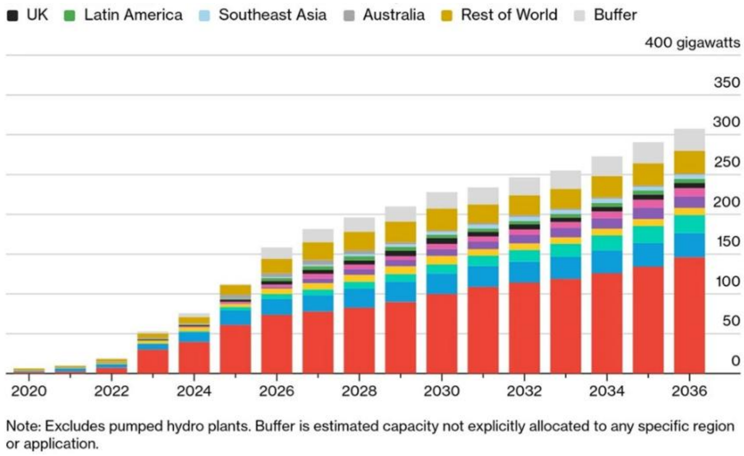
Source: IEA & CNESA

Box 5

5.1.2 Where in the world is capacity installed?

Deployment remains regionally concentrated, but is widening.

- **China** dominates the market (see Fig 5). It makes up over half the global market and accounted for 54% of additions last year.
- The **United States** followed with a **16%** share.



- **Australia** deployment rose nearly sixfold from 2024, driven by favourable power-market conditions and a new residential-storage subsidy.
- **Saudi Arabia** leapfrogged several peer markets as Chinese suppliers began tapping into it.
- **Sub-Saharan Africa** quadrupled year-on-year since 2023.

Figure 5: Global Energy Storage Additions 2020-2036. Note: Pumped hydro is excluded because its large, infrequent capacity additions would dwarf those of other storage technologies, obscuring the year-on-year growth of batteries and other forms of storage shown here. Source: BNEF.

5.1.3 What is the difference in deployment looking at utility-scale versus distributed storage?

	Utility-scale ***„Front of the Meter“ (FoM)***	**Distributed** ***„Behind the Meter” (BtM)***
Typical size	MW–GW	kW–MW
Main uses	Grid balancing, capacity, arbitrage	Self-consumption, backup, bill management
Key driver	Wholesale markets, mandates, auctions	Retail tariffs, subsidies
Example	Grid-connected battery parks and pumped-hydro plants	Home batteries with rooftop solar, and commercial/industrial systems.

Table 4: Comparison of utility-scale and distributed storage

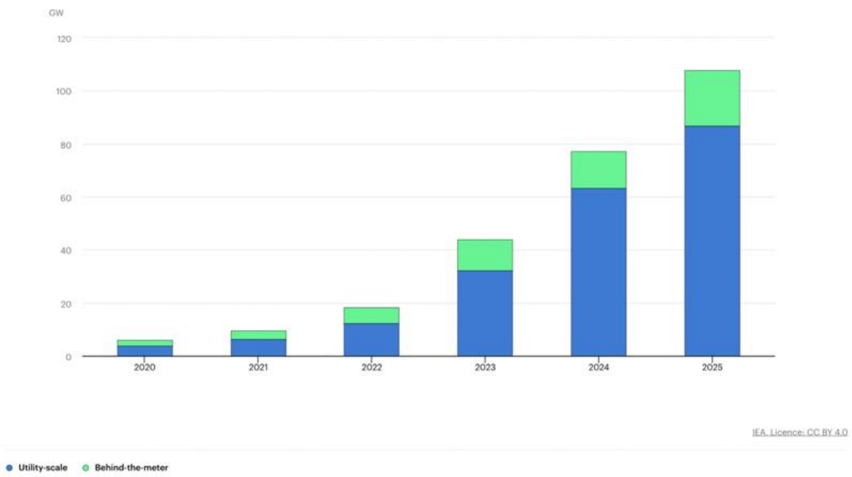


Figure 6: Global battery storage capacity additions, 2020-2025.IEA (2026)

The balance has shifted markedly. *In 2020*, stationary battery capacity was split **roughly equally** between utility-scale and customer-sited systems (Schmidt & Staffell, 2023). *By 2025*, new build had tilted decisively toward the grid: **around 80% of new battery capacity was utility-scale**, with the remainder behind-the-meter capacity installed by commercial and residential consumers.[9]

5.2 Cost trajectories

5.2.1 Declining technology costs

Storage costs are falling faster than almost any other clean-energy technology.

[9] IEA (2026).

- **All major electricity storage technologies are on a cost reduction trajectory** towards 100–500 USD/kWh once 1 TWh of energy capacity of the respective technology has been installed.[10]
- **Batteries set the pace.** Battery costs have fallen more than 90% over the last decade and are projected to fall a further ~40% by 2030.[11] In 2024, core BESS equipment costs dropped ~40% year-on-year to a record-low global benchmark of $165/kWh.[12]
- By October 2025, the all-in capex for a **large, long-duration (≥4h) utility-scale project**[13] had reached ~$125/kWh (~$75/kWh equipment + ~$50/kWh installation and grid connection), with LFP cells at ~$40/kWh.[14]
- BNEF's global benchmark for a four-hour project fell 27% year-on-year to a record-low $78/MWh in 2025.[15]

THREE MATURITY STAGES OF STORAGE COST[16]

- **Emerging:** < 1 GWh deployed, > US$1,000/kWh
- **Growing:** 1–100 GWh deployed, > US$300/kWh
- **Mature:** > 100 GWh deployed, < US$300/kWh - e.g. utility-scale lithium-ion today

5.2.2 The role of learning curves in energy storage cost trajectories

Every doubling of deployment brings a predictable step down in cost. Storage follows classic experience curves: investment cost falls by a roughly constant percentage - the **experience rate** - for every doubling of cumulative installed capacity. Across storage technologies, these rates span **−3% to 30%**:[17]

Lithium-ion cells 30% | packs (EV) 24% | utility-scale systems 19% | Alkaline electrolysis ~20% | nickel-metal hydride 11% | **pumped hydro −3%**[18]

One caveat: Experience curves are based on historical trends and are therefore ill-suited to capture potential step- change effects like radical innovations.

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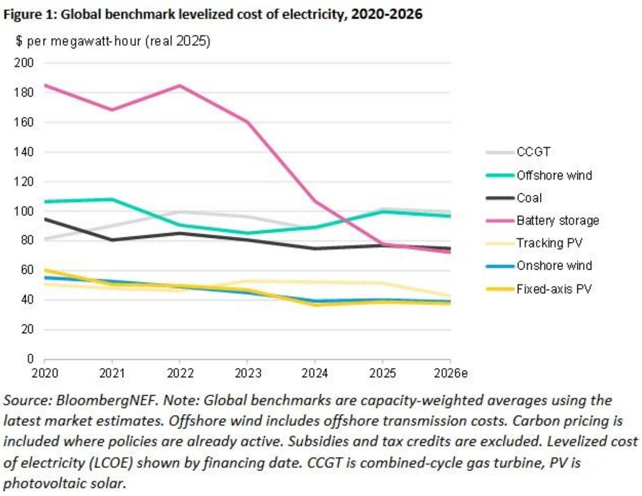
[10] Schmidt & Staffell (2023).
[11] International Energy Agency (IEA), as cited by the UNFCCC Technology Executive Committee.
[12] BloombergNEF global battery benchmark: core BESS equipment costs fell ~40% year-on-year in2024 to a record-low $165/kWh.
[13] outside China and the US.
[14] Ember (2025). How cheap is battery storage. Large, long-duration (≥4h) utility-scale projects outside China and the US, as of October 2025.
[15] BloombergNEF (2025): the four-hour battery-project benchmark fell 27% year-on-year to a record-low $78/MWh, the lowest since BNEF began tracking in 2009.
[16] Schmidt & Staffell (2023).
[17] Schmidt & Staffell (2023).
[18] Schmidt & Staffell (2023).

5.2.3 The economics and cost competitiveness of energy storage

Figure 7: Global benchmark levelized cost of electricity, 2020-2026.
Source: [BNEF](#) (2026)



Falling costs have pushed the combined cost of renewables-plus-storage below that of new fossil generation in a growing number of markets, positioning storage as a core enabler of clean energy transitions. In markets outside China and the US - based on 2025 auctions in Saudi Arabia, India and Italy - storing electricity now costs ~$65/MWh (LCOS).[19] Storing half of a day's solar output therefore adds ~$33/MWh, turning solar priced at the 2024 global average of $43/MWh into ~$76/MWh dispatchable solar - cheaper and faster to build than a new gas plant, especially where power relies on imported LNG.

Against 2025 generation benchmarks - fixed-axis solar $39/MWh, onshore wind $40/MWh, offshore wind $100/MWh - storage-firmed solar is already in the same cost band as new-build renewables and undercuts much thermal generation. BNEF forecasts a further **~25% reduction in battery-storage levelized cost of energy (LCOE)[20] by 2035**.[21]

⚠ **However, falling costs are only half the story.** Whether storage earns its keep depends on how often it can be used. Here, the economics have real limits that policy needs to anticipate:

Storage lives on price spreads. A battery earns most of its money through arbitrage: charging when power is cheap and discharging when it is expensive. Because storage still carries a relatively high cost per unit of capacity (~USD 125/kWh, with ~90% round-trip efficiency), it must cycle frequently to spread that fixed cost over as many MWh as possible. This makes batteries an excellent fit for shifting solar and wind within the day, but a poor fit for energy that would be stored only occasionally.

Arbitrage is self-limiting. The more storage a market adds, the more it flattens the very peaks and troughs it profits from. Price spreads narrow as storage scales - a so-called cannibalisation effect that caps the revenue any single value stream can provide. This is why **revenue stacking** matters: to be bankable, a project typically needs to earn across several markets at once - energy arbitrage, ancillary services, capacity, and network

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19 *Levelized cost of storage* (LCOS) quantifies the overall cost per unit of discharged electricity for a storage technology serving a specific application. It takes all costs incurred during the lifetime and divides them by the cumulative delivered electricity.

20 The Levelized Cost of Energy (LCOE) is defined as the total lifetime cost of an investment divided by the cumulated generated energy by this investment.

21 BloombergNEF ([2025](#)): 87 GW of co-located solar-and-storage added in 2025 at an average $57/MWh; 2025 generation benchmarks - fixed-axis solar $39/MWh, onshore wind $40/MWh, offshore wind $100/MWh; forecast ~25% reduction in battery-storage LCOE by 2035.

deferral. Markets that reward only one of these leave much of storage's system value unpaid, and many viable projects unfinanced.

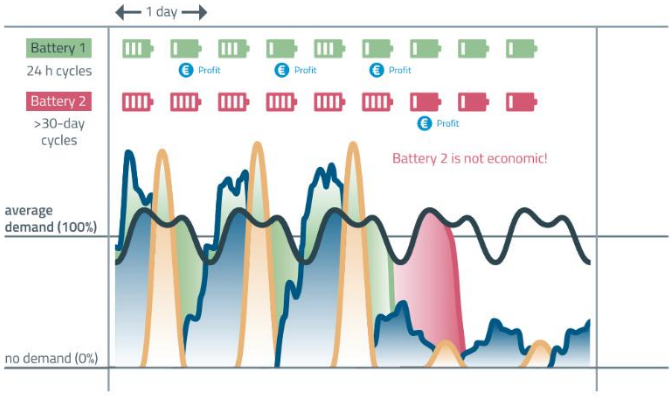

Figure 8: The limits of batteries for long-duration shortfalls. While batteries are economic for short-term mismatches, they do not work for Dunkelflaute. Source: FCA.

Longer durations are much harder. The economics deteriorate sharply as duration increases. An asset sized to cover multi-day "Dunkelflaute"[22] or seasonal shortfalls runs too few hours each year to recover its fixed costs, so its cost per delivered MWh climbs steeply. Hydrogen shows the bind: an electrolyser can run only in the cheapest hours (cheap power, but too little output to pay for itself) or run most hours (good utilisation, but higher average power prices). The two conditions rarely combine, which is why short-duration batteries cannot simply be scaled up to cover seasonal gaps (see Fig. 8).[23]

5.3 Scale-up requirements

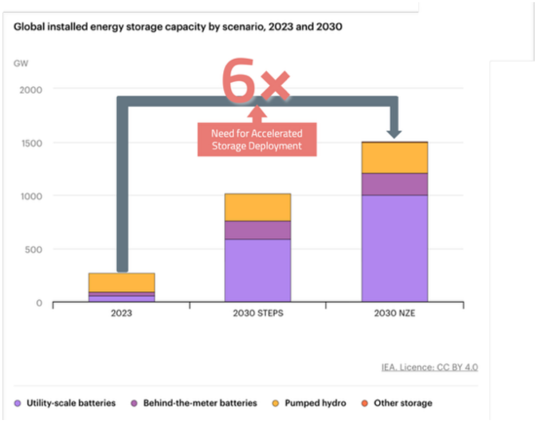

Figure 9: Cumulative installed capacity, worldwide, in GW - 2023 and 2030 goal

5.3.1 What is the capacity needed by 2030?

A roughly six-fold increase compared to 2025 in global power capacity of storage by 2030 is key to keeping emissions reductions on track.

- The IEA finds a **six-fold increase** in electricity-sector storage compared to installed capacity in 2022 is needed by 2030 to stay on a net-zero-by-2050 pathway - around **1,500 GW (1.5 TW)** online by 2030. Battery storage in this scenario delivers 90% of that growth, rising 14-fold to 1 200 GW by 2030, complemented by pumped storage, compressed air and flywheels.[24]
- IRENA indicates that **1–2 MW of storage may be needed for every 10 MW** of new renewable capacity added by 2030.[25]
- Consistent with this, stationary storage is projected to reach on the order of **1 TWh by 2030**, implying deployment of roughly **100 GWh of utility-scale lithium-ion per year** by the end of the decade.[26]
- **Storage duration must lengthen as renewables scale.** As solar and wind penetration rise, the duration of storage must increase relative to power capacity to continue reducing emissions at least cost.

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22 Dunkelflaute is a German word that in energy circles refers to a prolonged period of low wind and solar generation, e.g. a week of low wind in the middle of winter in Europe. An equivalent English expression sometimes used is "dark doldrums," but this is less common. Its direct opposite, the Hellbrise, is a period of high solar production that coincides with strong winds, but this term is also uncommon as of yet.

23 FCA (2026).

24 IEA, *Net Zero Roadmap (2023)* and *Batteries and Secure Energy Transitions (2024).*

25 International Renewable Energy Agency (IRENA).

26 Schmidt & Staffell (2023).

- **Thermal Energy Storage deployment needs to accelerate.** The global market for TES could triple in size by 2030. This means an increase from 234 GWh of installed energy storage capacity in 2019 to over 800 GWh within a decade.[27]

5.3.2. What are the investment requirements?

Storage must capture a rising share of clean-energy investment, but the sums required are modest relative to total spending on renewables and the grid. Global investment in renewable power generation and electricity networks was around USD 300 billion per year over 2018–2020, of which storage attracted only USD 3–4 billion (~1%).[28]

30-100 bn USD — Global cumulative investment needed by 2030 on energy storage

- **Reaching the competitive price range** of 100–500 USD/kWh at ~1 TWh cumulative capacity requires deployment investment of:
    - **USD 80 bn** for lithium-ion EV pack
    - **USD 1,150 bn** for lithium-ion residential system
    - **~USD 240 bn** for hydrogen storage (fuel cell + electrolysis)[29]
- Per technology, this equals **1–35% of the investment** made into electricity networks and renewables (a **USD 70–400 bn** to **USD 100–6,800 bn** range once experience-rate uncertainty is included).
- As the largest country-specific investments into the renewable energy industry in general range from USD 5 bn (Germany) to USD 80 bn (China) in 2019, the **global cumulative investment of USD 30 bn to USD 100 bn for storage technologies by 2030** does appear conceivable.[30]
- Different energy storage technologies have different power-specific and energy-specific investment costs as shown in Figure 10:

[27] IRENA (2020).
[28] Schmidt & Staffell (2023).
[29] Schmidt & Staffell (2023).
[30] Schmidt & Staffell (2023).

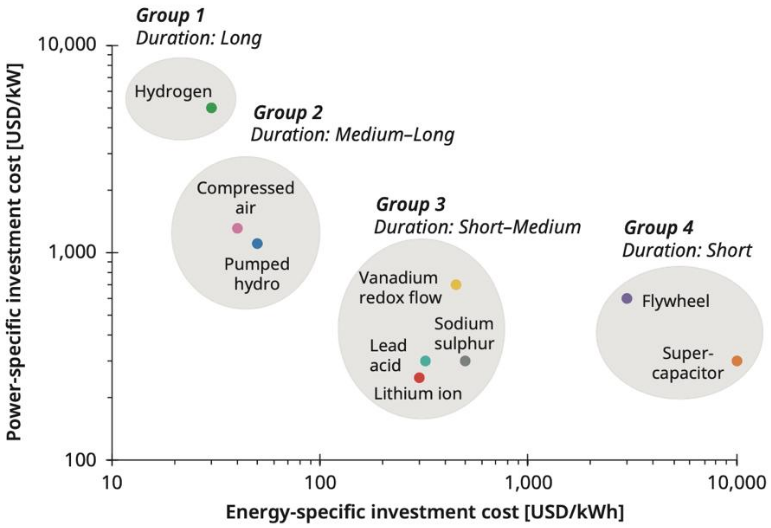

Figure 10: Grouping of the nine most widely deployed stationary electricity storage technologies along their power-specific and energy-specific investment costs. Source: Schmidt & Staffel (2023).

5.4. Supply chain

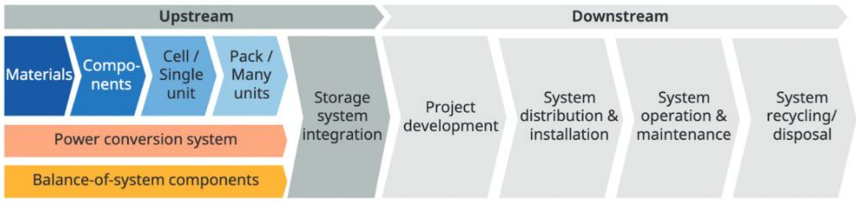

Figure 11: An exemplary supply chain for energy storage technology.

Global supply chains for energy storage technologies, critical materials, and required inputs, particularly for batteries, are heavily concentrated, which raises concerns about the reliability and resiliency of supply. That concentration is not uniform across technologies and stages of the supply chain, and the differences matter for how it can be addressed.

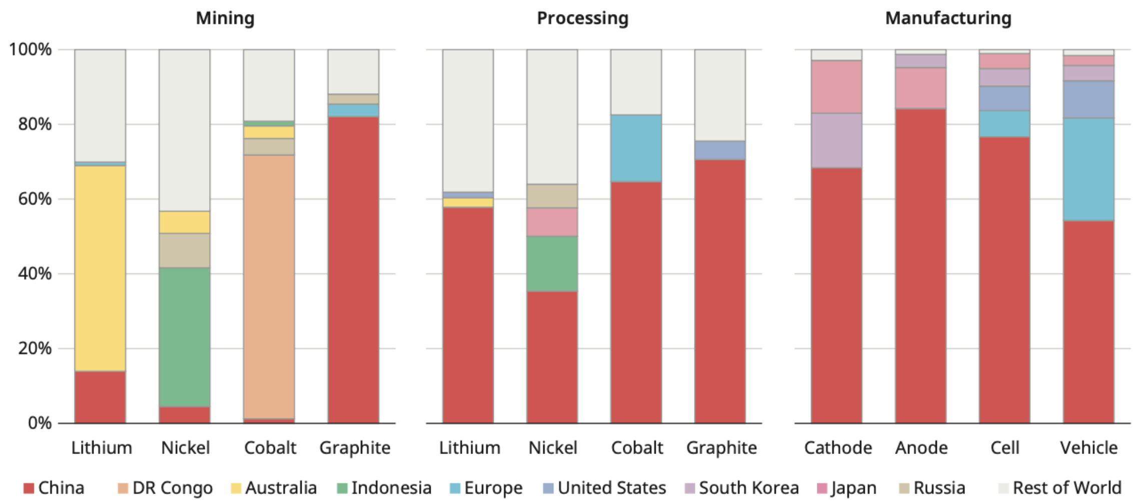

Figure 12: The geographical concentration within different stages of the lithium-ion battery value chain. Source: Schmidt & Staffel (2023).[31]

Battery value chains are heavily concentrated. Lithium-ion is a highly modular and mass-produced product. Each step in its supply chain -- from raw materials through to the cell and pack components -- is dominated by a few regions, especially China (see Fig. 12). China manufactured around three-quarters of the world's lithium-ion batteries in 2020[32] and dominates component and material production; in 2021 it commissioned roughly one battery "gigafactory" per week, compared to only one every four months in the United States. It is also one of the largest miners of lithium and graphite and the largest processor of these plus nickel and cobalt - covering almost the full spectrum of materials a battery needs. Batteries are therefore more exposed to greater geopolitical tension than solar PV or wind, given the scale of their mineral requirements and reliance on the highest-risk materials.

Other storage technologies are less exposed and a source of resilience. Pumped hydro and many thermal systems are built largely on site rather than mass-manufactured, so they depend on civil construction and local inputs rather than a globally concentrated component chain, and they use little or no critical minerals. Thermal storage is a particular opportunity: its key systems rely on abundant materials and have less complex supply chains. Deploying a diverse portfolio of technologies is therefore not only a flexibility strategy but also a supply-chain resilience strategy.

Focus: The manufacturing needs to scale batteries

Capacity targets translate into a step-change in manufacturing, which today is concentrated in a small number of producer regions. Scaling to roughly 100 GWh per year of utility-scale lithium-ion by 2030 requires a matching build-out of cell, component and pack manufacturing capacity.[33]

[31] Mining and processing refer to four key materials: lithium (Li), nickel (Ni), cobalt (Co), and graphite (C), and shares are based on mass of raw material produced and refined respectively. Manufacturing of electrodes and cells is based on production capacity data, and for electric vehicles (EVs) is based on number produced. Note that Indonesian nickel production is primarily not battery grade and is used outside of the sector.

[32] Schmidt & Staffell (2023).

[33] Schmidt & Staffell (2023).

> **Broadening the manufacturing base will be easier for some manufacturing stages than others.** Processing and cell/component manufacturing are the hard part. These midstream stages are the most concentrated in China and the slowest and most capital-intensive to replicate.
>
> Analysts estimate that around **USD 20 billion per year** of investment in domestic manufacturing across other regions could substantially diversify global battery supply chains by 2030.[34]

Scaling storage depends on supply chains that can grow quickly, diversify, and close the loop. The concerns can be addressed by diversifying supply chains, including through an emphasis on strengthening end-of-life product management and recycling. Design for recyclability and recyclability standards are still lacking.[35]

Placeholder for the information on converting gas plants to hydrogen-ready storage, leveraging existing infrastructure

What about critical minerals ?

Critical minerals are essential for a range of today's energy technologies and for the broader economy. Lithium, nickel, cobalt, manganese, and graphite are crucial to battery performance. Energy storage technologies, however, compete with other sectors' demand for critical minerals. For instance, rare earth elements[36] are essential to the permanent magnets used in wind turbines and electric vehicle.[37]

From a quantitative perspective, availability is not the limiting factor. Concerns about raw material availability and cost are usually based on supply and demand imbalances, which can be resolved with new raw material mining and processing capacity. There is no fundamental shortage of the key raw materials required for any major electricity storage technology.[38] With current technology, all materials have a reserve base sufficient for the production of beyond 10 TWh storage capacity with current technology.

Supply concentration is a key challenge. The main responses are diversifying where materials are mined and processed, continuing to improve battery designs, and scaling up recycling so that materials are recovered and reused.[39] The exponentially growing demand, nevertheless, can not merely be met with recycled materials. Furthermore, critical energy transitions minerals come with environmental, social, economic, geopolitical, trade, and partnership challenges that need to be taken into consideration.[40]

Placeholder: how resource-rich countries can move beyond resource extraction and achieve greater value addition in their economies.

6. Policy and regulatory frameworks

[34] Schmidt & Staffell (2023).
[35] UNFCCC TEC (2021). Emerging climate technologies in the energy supply sector.
[36] Seventeen elements are classified as Rare Earth Elements (REEs), a group of chemically similar metals critical for many advanced technologies. They include the 15 lanthanide elements plus Scandium and Yttrium. Despite their name, REEs are relatively abundant in the Earth's crust, but rarely found in economically exploitable concentrations.
[37] IEA (n.d.). Critical Minerals. A new frontier for global energy security.
[38] Schmidt & Staffell (2023). Monetizing Energy Storage.
[39] Schmidt & Staffell (2023). Monetizing Energy Storage.
[40] UNEP (n.d). Critical Energy Transition Minerals.

Technology cost reductions will not be sufficient to scale storage. Policymakers and regulators are encouraged to provide the frameworks that recognise storage as a multifunctional resource, enable operators to provide, and be paid for, system services, and create predictable routes from planning to investment.

6.1. Establishing enabling conditions

Many electricity laws were designed around a centralised, one-way system of generators, networks and consumers, and were finetuned during decades, while the rapidly changing power system contexts demand regulatory evolution at a challenging speed. Storage can act as load when charging, supply when discharging and, in some cases, a network or consumer-side resource and a provider of ancillary services for power stability. This makes it challenging to get the right policy and regulatory approach in place to enable storage operators to play the most beneficial role they possibly can in a given energy system. If storage is forced into only one category of operation, projects may face duplicative licensing, inappropriate charges or restrictions on ownership. Flexible, adapted legal frameworks are therefore needed to recognise this multifunctional role and clarify the treatment of stand-alone, co-located, behind-the-meter and network-owned assets.

Clear institutional responsibilities are equally important. Ministries, regulators and system operators can be optimized with well-defined roles in planning, procurement and market participation, while safety and environmental authorities need the mandate and capability to oversee installation and end of life. Where regulated network companies own storage, safeguards should prevent discriminatory dispatch or crowding out of competitive services.

Integrated planning allows the identification of the system needs before a solution is specified. Technology-neutral assessments can compare storage with network reinforcement, interconnection and demand response while recognising that location and timescale shape value. Scenario analysis can be used to address uncertainty in demand growth, renewable deployment and fuel prices. Procurement can then translate the identified need into measurable requirements for response, duration, availability and location.

Planning also benefits from being iterative. Storage economics can change as equipment costs fall, ancillary-service markets saturate and renewable penetration rises. Periodic flexibility assessments can reveal these changes and reduce the risk of procuring too much of one service while another remains unmet. They can also show where better forecasting, shorter dispatch intervals or improved system operation provide lower-cost flexibility before new infrastructure is built.

A national target that is not spatially resolved may encourage projects where connection is easiest rather than where value is highest. Locational signals or targeted tenders can direct assets towards constrained substations, renewable-rich zones or areas with reliability needs. This is especially relevant in distribution systems, where charging from electric vehicles and cooling loads can create local peaks before they appear as a national adequacy problem.

6.2. Symptoms of slow storage deployment

Storage deployment may remain slow even where technology costs are falling and policy interest is growing. The underlying constraint is often not a single regulatory gap, but the accumulation of barriers across the project-development chain. These barriers become visible through three broad groups of symptoms: institutional and administrative uncertainty, difficulty capturing market value, and limitations in implementation capacity and inclusion.

- **Institutional and administrative symptoms** include ambiguous legal classification, fragmented mandates and lengthy permitting and connection procedures. Because storage can act as load, generation, network infrastructure and a provider of system services, it may not fit comfortably within regulatory categories developed for a more conventional power system. Different authorities may consequently apply different requirements or interpret responsibilities inconsistently. Developers can face overlapping approvals, sequential procedures and uncertainty over ownership, operation and end-of-life obligations. Limited capacity among permitting authorities, inspectors and emergency services can add further uncertainty, particularly where technologies and associated safety risks are evolving rapidly.

- **Market and revenue symptoms** arise when the services storage can technically provide do not translate into accessible and predictable revenues. Participation rules may exclude storage from certain energy, balancing, ancillary-service or capacity arrangements, or prevent smaller and distributed resources from participating through aggregation. Storage may also face network charges, taxes or levies when electricity is both withdrawn and reinjected, increasing costs in ways that do not always correspond to its actual use of the system.
  Weak temporal and locational signals can further obscure the value of charging during periods of abundant renewable generation, discharging during scarcity or locating storage in constrained parts of the network. Even where participation is possible, projects may depend on volatile energy-price differences or relatively small ancillary-service markets. Revenues can therefore decline as markets saturate or remain too uncertain to support long-term financing. This creates a recurring gap between the value storage may provide to the power system and the revenue an individual project can capture.
- **Capability and inclusion symptoms** are particularly visible where storage markets, institutions and project pipelines are at an early stage. Limited system data and modelling may prevent planners from identifying the location, duration and response characteristics of the flexibility required. Procurement processes may consequently rely on incomplete specifications, unclear allocation of risks or capacity targets that do not adequately reflect operational performance. Developers and financiers then face additional due diligence, contract negotiation and project-preparation costs.
  These transaction costs weigh most heavily on smaller projects, distributed applications and countries with limited deployment pipelines. The effects can extend to consumers. High upfront costs may restrict access to behind-the-meter storage, while tariff structures may transfer a greater share of network costs to users unable to invest in their own assets. In mini-grid and off-grid contexts, projects with high social and development value may remain commercially unviable where consumers cannot support full cost recovery. Storage deployment can therefore increase without its reliability, affordability and resilience benefits being distributed equitably.

The symptoms frequently reinforce one another. Regulatory uncertainty increases project-development costs; connection delays postpone revenue; weak market signals reduce financing prospects; and limited institutional capacity slows the resolution of each problem. The result can be a technically viable project that cannot progress, or a socially valuable application that does not meet conventional investment criteria. The following subsections examine these barriers in their respective regulatory and market contexts before drawing out principles that can be adapted across different power-system structures.

6.3. Connection, permitting and charging rules

Administrative conditions can be as consequential as technology costs. In the United States, **2 061 GW** of generation and storage was actively seeking transmission interconnection at the end of 2025, including about **749 GW of storage**. The queue declined by 10% during 2025, but the median time from request to commercial operation exceeded five years for projects completed that year. Most queued projects will not be built, yet the figures show why transparent studies, firm milestones and co-ordinated network planning matter. (Lawrence Berkeley National Laboratory, Queued Up: 2026 Edition).

Connection reform should standardise data requirements, publish timelines and costs, manage speculative applications and treat hybrid renewable-storage projects efficiently. Permitting should be streamlined without weakening environmental and community safeguards. Procedures must also reflect technology differences: pumped-storage hydropower has longer development periods and broader environmental interfaces than modular batteries, while thermal storage may fall under building and heat-planning rules. Connection agreements should not impose network charges on storage operators both for the charge and discharge of their assets. Network tariffs, taxes and levies should reflect cost causation, losses and congestion. Reform should nonetheless protect vulnerable consumers to prevent that exemptions could shift network costs onto users who cannot invest in distributed energy resources.

6.4. Safety, quality and lifecycle governance

Safety frameworks should cover the full project chain, from product certification and commissioning to emergency response and end-of-life collection. Internationally compatible standards can reduce costs, but standards alone do not ensure safe deployment. Competent inspectors, trained operators and co-ordination with emergency services are needed to translate technical requirements into practice. Lifecycle rules should encourage repair, repurposing and recycling and assign responsibility for decommissioning.
A risk-based approach can be preferable to blanket restrictions. Requirements can reflect chemistry, system size, siting and exposure rather than treating all installations alike. Early engagement with local authorities and communities can address concerns over fire safety and land use while avoiding inconsistent rules that delay sound projects. Standardised permit packages can reduce burden for mature technologies; monitored demonstrations can build the evidence needed to regulate emerging solutions.

6.5. Design markets around services and system value

Storage will be deployed where market and procurement arrangements reveal its value and offer sufficient revenue certainty. Assets should be eligible, directly or through aggregation, to participate in energy, balancing and capacity arrangements whenever technically capable. Performance-based requirements allow technologies to compete while ensuring that the procured response and availability meet the system need.
FERC Order No. 841 provides an influential example. It required US regional market operators to establish participation models allowing electric storage to provide all capacity, energy and ancillary services for which it is technically capable, and to be dispatched as both a wholesale buyer and seller. (US Federal Energy Regulatory Commission, Order No. 841).
Rules could permit value stacking across compatible services, with clear metering and settlement to avoid double counting. Temporal and locational signals tend to improve charging and siting decisions. Where sophisticated wholesale markets do not exist, tenders or regulated contracts can approximate these signals. The objective does not need to aim at reproducing a market model from another jurisdiction, but at favouring that the services identified in planning have a credible buyer and payment mechanism.
Short-term energy and balancing revenues may be too volatile to finance capital-intensive or longer-duration assets. Competitive tenders, availability payments or cap-and-floor arrangements may be appropriate depending on market maturity. Support could remunerate verified performance, preserve competition and be reviewed as the system evolves. Otherwise, temporary support can become detached from the underlying need.
The EU electricity-market reform illustrates the move towards system-wide flexibility planning. Regulation (EU) 2024/1747 establishes national flexibility-needs assessments and indicative objectives for non-fossil flexibility, including storage and demand response. It links planning evidence with the possible design of support schemes rather than treating storage targets in isolation. (Regulation (EU) 2024/1747).
Distributed assets bring another layer of market design. Aggregators can combine household batteries, electric vehicles and flexible loads into a resource large enough to serve the system, but participation requires proportionate metering, data access and settlement. Consumer consent and cybersecurity are essential. Without co-ordination, the technical flexibility of distributed assets remains fragmented and may instead increase local peaks through simultaneous charging.
Decarbonisation outcomes should remain visible. Arbitrage based only on price does not always align with emissions or network needs. Better temporal signals and information on congestion and the generation mix can improve operating decisions. Support schemes should avoid rewarding cycling for its own sake and assess whether storage reduces curtailment, displaces high-emitting generation or provides a defined reliability service.

6.6. Systemic innovation for storage deployment

Experience across different power systems points to a small number of principles that are more transferable than individual and specific policy instruments:

1. Governments should plan for the flexibility service before choosing the technology.
2. Market and procurement arrangements should allow technically capable assets to combine compatible revenues, while providing longer-term certainty where short-term markets cannot remunerate adequacy or resilience.
3. Storage policy should be developed alongside grid, renewable-energy and electrification planning rather than as a separate capacity programme.

Implementation also matters. Connection rules, licensing and safety requirements need to be clear enough for projects to progress without weakening public safeguards. Distributed resources should be able to participate through aggregation under proportionate data and consumer-protection rules. Finally, policy frameworks should address sustainability and inclusion from the outset, because retrofitting recycling obligations, workforce capability or access provisions after deployment has scaled is likely to be more costly and less effective.

These principles do not imply a single market model. Vertically integrated systems may rely more heavily on integrated resource planning and competitive procurement, whereas liberalised markets may use price signals and service markets. The common test is whether the framework identifies a genuine system requirement, creates a credible route to recover efficient costs and assigns responsibility for delivery.

7. Country contexts and development priorities

In developing countries, storage is more than an integration technology. It can expand access, reduce imported-fuel dependence, improve essential services and strengthen resilience. Yet high financing costs, weak utilities and small project sizes can prevent projects with high social value from becoming financially viable.

7.1. Start from diverse country and system contexts

There is no single developing-country storage pathway. Priorities differ among rapidly growing interconnected systems, capacity-constrained grids, Small Island Developing States and remote communities. Some systems need utility-scale flexibility to integrate solar and wind; others need decentralised storage to provide a basic level of reliable service. Policy design should begin with local demand, grid conditions, institutional capability and development priorities.

This diversity affects technology choice and policy sequence. In a growing interconnected system, the first priority may be operational data and competitive procurement for balancing. In a remote diesel system, the relevant comparison is the full delivered cost of fuel, including transport and volatility. In a fragile setting, modularity, ease of maintenance and the ability to power a clinic or water system during disruption may matter more than maximising market revenue. These objectives should be explicit before projects are selected.

7.2. Expand access through reliable energy services

Renewable mini-grids and stand-alone systems combined with storage can extend service beyond the main grid, shift solar electricity into evening hours and reduce diesel consumption. System sizing should reflect current and expected demand, including productive uses, rather than present household consumption alone. Storage that is oversized relative to demand can raise tariffs and replacement costs without improving long-term viability.

The objective is reliable energy services, not battery deployment in itself. Storage-enabled electricity can support medical equipment, water pumping and agricultural processing. These uses improve welfare and can create anchor loads that strengthen revenue. In energy-access settings, the most effective intervention is rarely a storage asset in isolation. Storage creates greater development value when combined with efficient appliances, productive-use equipment and a delivery model adapted to local income and demand. For example, a solar-storage system may improve electricity availability, but pairing it with cold storage, water pumping or agricultural processing can also strengthen livelihoods and increase asset utilisation.

Mini-grids are a great example of the value of this integration, as by using storage entire communities are enabled to rely mostly on renewable energy. Renewable-based mini-grids, and solar PV mini-grids in particular, could provide electricity access to as many as half a billion people worldwide, the scale required to help achieve Sustainable Development Goal 7 (ESMAP, 2022). Realizing this potential, in developing countries depends on the reliability that battery storage brings, allowing solar generation to be delivered as a round-the-clock service rather than an intermittent one. This ensures essential services that rural development deepens on are powered reliably. IRENA's forthcoming assessment of solar PV mini-grids with battery storage in selected West African counties finds that decentralized renewables must work alongside grid extension to close the access gaps. However, access is progressive process where communities move from stand-alone systems to mini-grids and eventually national grid as they incomes and demand grow. Storage-enabled mini-grids provide the dependable, scalable step that sustains this trajectory, and are therefore best planned as one step in a longer electrification process rather than as permanent, stand-alone asset.

When planning and regulating them, however, it is recommended that the eventual arrival of the national grid is anticipated to maximise synergies. Interconnection, asset compensation or transitions to a distribution franchise should be addressed in advance. Technical standards should enable interoperability, while tariffs and concessions should balance affordability, service quality and battery replacement. Public support is likely to remain necessary where social benefits are high but commercial demand is limited.

Quality assurance is central to sustainability. Certification, warranties, monitoring and clear responsibility for end-of-life collection can reduce stranded assets. Local technician training should be part of infrastructure delivery. In weak-grid areas, community or public-facility storage may support critical loads more efficiently than separate household systems, although targeted grid reinforcement should remain part of the comparison. Quality infrastructure also affects finance. Standardised testing and certification reduce uncertainty over performance and replacement, making operating-cost and revenue assumptions more credible to lenders. IRENA has found that inadequate quality infrastructure can lead to failed investments and lost production, while stronger standards and monitoring can lower risk and support market development. Requirements should mature with the market without excluding smaller developers through disproportionate compliance costs. (IRENA, Quality Infrastructure for Smart Mini-grids, 2020). Blended finance and other de-risking instruments will be instrumental in overcoming the high upfront capital and the elevated cost of capital that constrain mini-grid and storage deployment in many developing markets.

The volume of battery storage required to meet access ambition open opportunity in developing region to move from exporting raw mineral towards local manufacturing of high value-added battery components. Smart local content strategies, supported by regional co-operation, can reduce foreign-exchange risk, create jobs and lower system costs as the domestic market matures.

7.3. Deploy storage beyond mini-grids: rural and off-grid applications

The role of storage in rural electrification extends beyond mini-grids. Solar home systems, stand-alone systems for public facilities and dedicated installations for productive uses can provide reliable services where grid extension or a larger mini-grid is not yet viable. Stand-alone solar systems also serve as a back-up solution in weak-grid zones, where frequent or lengthy outages and voltage fluctuations undermine an existing connection. Around 775 million people were connected to such unreliable grids in 2020, a figure projected to approach one billion by 2030, and an estimated 186 million are expected to use off-grid solar to complement a weak grid (ESMAP et al., 2022). The relevant design question is the service required and the least-cost way of providing it. In a household system, this may be evening lighting and communications; in a clinic or school, reliability and continuity may be more important than daily energy volume.

IRENA's off-grid work emphasises the need to combine enabling policy, suitable finance and viable business models rather than treating equipment delivery as the end point. Storage can also support telecommunications, water pumping and cold chains, linking electricity access with local econo mic activity. IRENA estimates that global off-grid renewable power capacity reached 11.1 GW by the end of 2024, nearly twice its 2015 level. The statistics cover uses ranging from solar home systems to rural schools, clinics and remote commercial facilities, illustrating the diversity of applications that policy and quality frameworks need to accommodate. (IRENA, Off-grid Renewable Energy Statistics 2025). Because stand-alone systems place large volumes of small batteries safe end-of-life management and extended producer responsibility are especially important to prevent an e-waste burden as deployment scales .

For productive uses, storage should be sized together with the load and the renewable resource. Cold storage, irrigation and processing equipment can improve livelihoods and raise asset utilisation, but they may also require complementary finance for appliances and enterprise development. An access programme that finances generation and batteries without addressing demand, maintenance and replacement risks leaving technically sound systems economically fragile.

7.4. Make affordability, equity and resilience explicit

Lower system cost does not automatically mean affordable service. Regulation determines whether fuel savings, avoided outages or deferred investment reach consumers. Procurement should consider lifecycle cost, efficiency and degradation rather than initial price alone. Pay-as-you-go finance, leasing and storage-as-a-service can reduce upfront barriers, but support must preserve maintenance and replacement funding. Affordability and utility sustainability must be considered together. Very low tariffs may protect consumers in the short term but leave no provision for replacement, while full cost recovery may be beyond the means of low-income users. Transparent public support can bridge this gap where storage provides wider benefits, such as avoided diesel subsidies or reliable health services. The question is not whether support exists, but whether it is targeted, fiscally durable and linked to service quality.

Equity also requires attention to who invests and who pays for shared infrastructure. Wealthier grid customers may install batteries and reduce purchases, shifting network costs to those unable to do so. Tariff reform should reward useful flexibility while maintaining fair contributions to the grid. Public programmes can prioritise hospitals, schools and water systems; community-scale assets may distribute benefits more widely than individual subsidies.

Projects should engage communities in needs assessment, siting and benefit sharing. Local value creation should be grounded in realistic capabilities. Installation, controls, operations, maintenance and recycling may offer earlier opportunities than cell manufacturing. Skills strategies should include local enterprises and groups under-represented in the energy workforce.

The storage impulse should also be assessed through its implications for employment and skills development. While battery manufacturing can provide strategic industrial opportunities in selected countries, a broader set of employment opportunities is likely to emerge across project development, engineering services, installation, software and controls, operations and maintenance, battery repurposing and recycling. Workforce-development strategies should therefore focus on building capabilities across the entire storage value chain rather than concentrating exclusively on manufacturing activities. Such an approach is likely to produce more geographically distributed economic benefits while supporting long-term market development. (IRENA and ILO, Renewable Energy and Jobs: Annual Review 2025, 2026)

For SIDS and other climate-vulnerable settings, decentralised renewables with storage can reduce fuel exposure and maintain essential services during disruption. IRENA's analysis of least-electrified SIDS highlights the economic, health and well-being gains of decentralised solutions and the importance of customised capacity building and results-based finance. Resilience still needs to be designed through critical-load definitions, islanding capability and climate-appropriate siting. (IRENA, Small Island Developing States at a Crossroads, 2024).

7.5. Align climate finance with project and market realities

Translating sustainable-development objectives into investable projects requires financing frameworks that address the specific risk, scale and revenue characteristics of storage in developing-country settings. The challenge, however, is not simply a shortage of capital.

The financing challenge is not only a shortage of capital. It is a mismatch between project risk, scale and revenue and the requirements of commercial finance. Currency and regulatory risk, weak off-takers demand and limited operating history raise the cost of capital. Storage may also create value for utilities, consumers and the wider economy without one actor being able to pay for the whole benefit.

Small mini-grid and public-facility projects face high transaction costs. Standard specifications and portfolio aggregation can create investable scale. Equally important is early-stage preparation: demand data, feasibility studies, environmental assessment and bankable contracts. Grants and project-preparation facilities can therefore be as catalytic as construction finance.

Public finance remains essential where markets do not serve last-mile communities. IRENA estimates that about **USD 30 billion per year** is required between 2021 and 2030 for grid, mini-grid and stand-alone renewable generation and associated networks to reach universal electricity access. Public resources can bridge affordability gaps, strengthen the enabling ecosystem and de-risk private capital. (IRENA, Public Finance for Universal Energy Access, 2024).

MDBs and climate funds should deploy concessional resources against defined barriers. Guarantees, subordinated debt and local-currency finance can address risks commercial financiers cannot reasonably absorb. Results-based disbursement can reward verified reliability rather than equipment installation. Demonstration support should include monitoring and dissemination so that early projects establish a track record for replication.

Finance also needs to strengthen utilities and institutions. Payment security, procurement quality and operational capability can be more decisive than project-level subsidies. Public finance should crowd in private capital where possible, with transparency on concessionality and additionality, and should be reviewed as markets mature.

The wider financing landscape shows why concessionality matters. Global energy-transitions investment reached **USD 2.4 trillion** in 2024, but remained concentrated in advanced economies and China. Renewable-energy investment reached **USD 807 billion**, while grants accounted for less than 1% of transitions finance. In many developing countries, market-rate debt can raise tariffs or public liabilities even as technology costs fall. Low-cost debt and grants should target public goods that commercial capital will not finance, including early-stage preparation, institutional capacity and access for low-income users. (IRENA and CPI, Global Landscape of Energy Transition Finance 2025).

Currency risk deserves particular attention because projects generally earn local-currency revenue while equipment investment costs and debt may be denominated in foreign currency. Local-currency lending, hedging and guarantees can prevent exchange-rate movements from overwhelming sound project economics. Portfolio aggregation can then diversify risk and reduce due-diligence costs, provided common contracts do not erase important differences in local demand and operating conditions.

7.6. Treat technology transfer as capability development

Technology transfer extends beyond hardware. It includes system design, controls, installation, maintenance, safety, testing and recycling. Capacity is required across ministries, regulators, utilities, financiers and the local workforce, with content tailored to each function. A regulator assessing stacked revenues needs different expertise from a technician maintaining a remote mini-grid.

Country ownership is strongest when training is linked to real planning, procurement and project development. Long-term institutional partnerships, regional centres and South-South cooperation can support shared standards and specialist expertise. Open load data, resource assessments and transparent modelling

can improve preparation and allow countries to define their own needs rather than rely only on vendor proposals.
Capability development should be judged by institutional practice rather than workshops delivered. Useful indicators include whether a utility can specify performance in a tender, whether a regulator can assess competing value streams and whether local technicians can diagnose and safely repair equipment. Regional power pools and development banks can help smaller markets share testing facilities, model documentation and scarce expertise.

7.7. Embrace capacity building as enabling "infrastructure"

Human and institutional capabilities are as important as the physical asset. Storage decisions cut across power-system planning, network operation, regulation, procurement, finance and safety. A one-off training course cannot substitute for institutions that can update models, evaluate tenders and oversee projects throughout their operating lives. Capacity-building programmes should therefore be anchored in national processes and designed around the decisions that institutions are expected to make.
Planning capability is especially important because storage needs change with renewable deployment, demand and network development. IRENA's approach combines tools and training with hands-on support for national teams, placing country ownership at the centre of the planning process. The same principle can be applied to regulators and utilities: practical work on actual tariff reviews, connection studies or procurement documents is more likely to leave durable capability than generic instruction. (IRENA, Capacity Building for Energy Planning and Modelling).
Regional institutions can help countries share scarce expertise. Power pools, standards bodies and development banks can support common technical requirements, model contracts and specialist training, while national institutions retain responsibility for decisions. This can lower costs for smaller markets and improve interoperability without imposing a single technology pathway.

7.8. Strengthen storage in NDCs and national energy planning

Despite the growing recognition of energy storage as a critical enabler of the energy transitions, storage remains underrepresented in many climate and energy planning processes. While a growing number of countries reference storage in Nationally Determined Contributions (NDCs), Long-Term Low-Emission Development Strategies (LT-LEDS), Technology Needs Assessments (TNAs) and national energy plans, these references are often qualitative and are rarely accompanied by quantified deployment targets, flexibility assessments or investment roadmaps.
As renewable penetration increases, countries will increasingly benefit from moving beyond general commitments towards more structured approaches that identify system flexibility needs and assess the potential contribution of storage alongside grids, demand response and other flexibility resources. This can help ensure that storage deployment is grounded in system requirements rather than technology-specific ambitions.
Storage can be integrated into NDC implementation plans, electricity-sector master plans, grid-development strategies and electrification programmes. Linking storage needs to investment planning and project pipelines can improve policy credibility and facilitate access to international finance. In this context, storage planning should be viewed not as a separate exercise, but as an integral element of broader energy-transitions planning.

8. RD&D Priorities

The IEA estimates that almost 35 % of the cumulative CO_2 emissions reductions seen in the Sustainable Development Scenario by 2070, compared with the current trajectory, come from technologies that are currently at the prototype or demonstration phase. These technologies will not become available at scale without further R&D (including commercial demonstrators) and technical improvements.[41] The acceleration of research, development, and demonstration (RD&D) in critical sectors such as energy storage is imperative to ensure these gaps are closed on time.

8.1. Key gaps

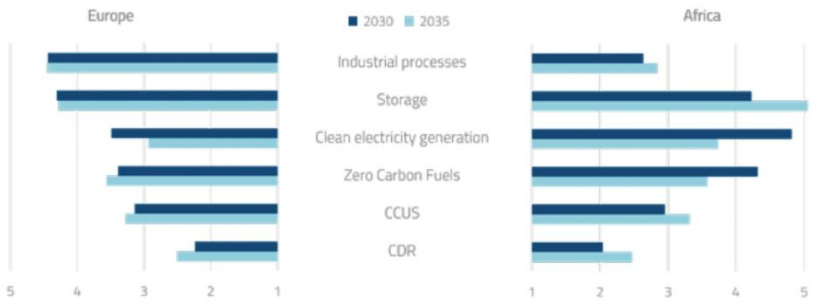

Figure 14: RD&D Priorities Mature Technologies | 2030 & 2035 | Developing vs. Developed Economies (RD&D Survey)

Overall | In a survey conducted by the [UNFCCC TEC on RD&D needs globally](), **energy storage was the stand-out technology sector** across almost all regions and professions, ranking among the biggest RD&D needs overall - and the single most urgent area to accelerate for long-term sustainable energy supply, ahead of energy system integration. Respondents from developed economies placed storage top to 2030 (industrial processes leading to 2035), while those from developing economies prioritised clean electricity generation to 2030, with storage becoming the top priority from 2030 to 2035.[42]

Respondents whose work focus was storage and clean electricity generation were also asked to rank RD&D needs on long-term environmentally sustainable energy supply from most to least urgent for RD&D acceleration. Energy Storage was ranked as the most urgent RD&D acceleration area, followed by Energy System Integration.

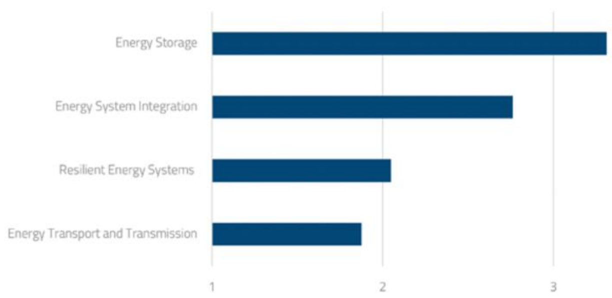

Figure 13: RD&D Needs Long-Term Environmentally Sustainable Energy Supply Globally | All Respondents (RD&D Survey)

Technological |

- **Gaps concentrate in the least-mature technologies.** Mature options - above 100 GWh installed and below 300 USD/kWh, such as pumped hydro, lead-acid, and lithium-ion for electric vehicles and electronics - are already competitive, whereas emerging options (below 1 GWh installed, above 1,000 USD/kWh) still need substantial RD&D, particularly demonstration, to close cost and performance gaps.[43]

> **Emerging, pre-commercial technologies**
>
> **1. Bio-batteries**
> They produce electricity by chemically breaking down organic materials (such sugars and starches), in contrast to traditional batteries that depend on heavy metals and synthetic chemicals. The possibility for sustainability of biobatteries is one of its most alluring benefits.
>
> **2. Structural battery composites**
> Carbon-fibre laminates that serve simultaneously as load-bearing structure and as battery electrode. The system-level benefit arises from eliminating a separate battery pack rather than from higher cell energy density.

[41] IEA (n.d.).
[42] UNFCCC TEC (2024).
[43] Schmidt & Staffell (2023).

3. Metal-air batteries
For instance lithium-air batteries: The cell draws oxygen from its surroundings instead of storing the oxidant internally, giving a theoretical specific energy roughly four times that of lithium-ion. The principal interest is in aviation and long-range transport.

4. Thermochemical heat storage
Heat drives a reversible chemical reaction, for example the dehydration of calcium hydroxide; the reaction products are stored separately at ambient temperature and recombined to release the heat. Because no material is held at elevated temperature, losses over long storage periods are minimal.

- **Priority technical improvements.** Industry innovation roadmaps focus on higher energy density (e.g. silicon anodes and solid electrolytes), lower raw-material cost and processing, and cobalt- and nickel-free chemistries. Across the portfolio, longer discharge durations and higher cycle life are needed so that different technologies can serve different applications.[44]
- **Sustainability across the lifecycle.** Resource extraction, carbon emissions, ecological impacts, and end-of-life management must be addressed through improved materials, cleaner processing, and scaled-up recycling.[45]
- **Research attention is uneven.** Publication activity is concentrated in electrochemical storage, with progressively less on chemical, thermal, and mechanical options - a signal that some promising technologies may be under-researched relative to their potential.[46]

Focus | Long Duration Energy Storage
Long-duration energy storage spans the four technology families at very different maturity levels. RD&D gaps concentrate in the least mature: novel electrochemistries such as metal-air, thermochemical storage, and non-hydrogen chemical carriers, which need targeted RD&D.[47]

8.2. Innovation Pathways

1. Treat deployment as an important innovation lever - alongside R&D. Deployment is one of several drivers of cost reduction: each doubling of cumulative installed capacity reduces investment costs at a predictable "experience rate," and most emerging technologies could reach the competitive ~1 TWh threshold within 5–20 years. Early demonstration and deployment work in tandem with laboratory R&D, rather than substituting for it.[48]

2. Pair deployment with R&D and large-scale demonstrators to unlock step-changes. Experience curves capture learning-by-doing but cannot predict step-change innovations. Those come from R&D ("learning-by-searching"), user feedback ("learning-by-using"), and research–industry–end-user networks. So funding lab R&D *and* de-risking pre-commercial (emerging) technologies through demonstration is one important pathway.

3. Rebalance effort toward the under-researched families (technology diversity). Publication and innovation activity is skewed to electrochemical storage, leaving chemical, thermal and mechanical options

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[44] Schmidt & Staffell (2023).
[45] Schmidt & Staffell (2023).
[46] Delu Wang, Nannan Liu, Fan Chen, Yadong Wang, Jinqi Mao (2024). Progress and prospects of energy storage technology research: Based on multidimensional comparison, Journal of Energy Storage, Volume 75. https://doi.org/10.1016/j.est.2023.109710.
[47] Future Cleantech Architects (2023).
[48] Schmidt & Staffell (2023).

under-researched relative to their potential. However, these are precisely the technologies needed for longer durations.

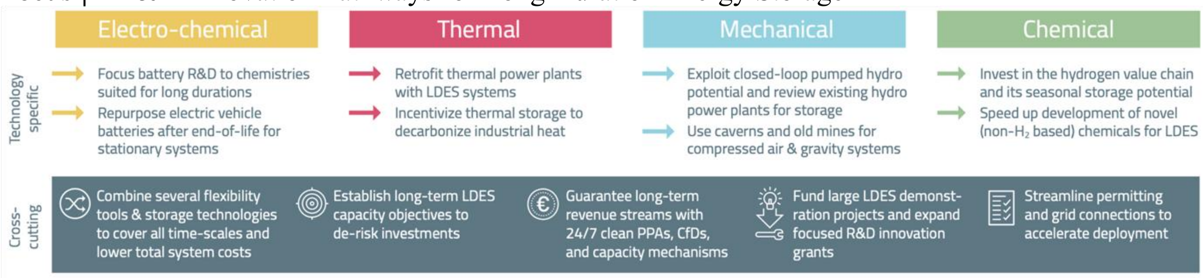
4. Target the specific technical levers behind cost and performance. Higher energy density (silicon anodes, solid electrolytes), cobalt- and nickel-free chemistries, lower raw material costs and cleaner processing, and longer discharge durations with higher cycle life, so each technology matches its application.

5. Build sustainability, circularity and standardisation into the innovation agenda. Design for recyclability, cleaner processing and scaled-up recycling and second-life use; and standardise cells, packs and systems to unlock economies of scale. International collaboration (pairing hardware with policy/standards work, and including developing-country researchers) shares cost and risk.

BOX - GOOD PRACTICES FOR INTERNATIONAL COLLABORATIVE RD&D[49]

What works	Priorities to strengthen
• High-level political buy-in combined with pragmatic implementation. • Joint ownership and funding, and equal partnership between developed and developing countries. • Broad stakeholder engagement from the outset, aligned with national priorities and capabilities. • Hardware RD&D combined with software and orgware, and designed for long-term sustainability.	• Independent, public evaluation so lessons learned are transparent. • Flexible participation matched to differing national needs and capacities. • Earlier private-sector engagement (e.g. on intellectual-property arrangements). • Sustained investment in local capacity in developing countries.

Focus | RD&D Innovation Pathways for Long Duration Energy Storage



[49] UNFCCC TEC (2021).

9. Conclusions

To be developed

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