ASIA CLEAN ENERGY FORUM 2026

Beyond Transition: Building Secure, Resilient, Inclusive, and Intelligent Energy Systems

8–11 June | ADB Headquarters, Metro Manila, Philippines

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PHES vs BESS
Comparative Assessment

8–11 June 2026 | Metro Manila, Philippines

In cooperation with

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Agenda

1. Energy storage context and paper objective
2. PHES and BESS technology overview
3. Comparison: technical, economic and ancillary-service
4. Hybrid PHES+BESS opportunities
5. Global trends and planning implications
6. Conclusions and strategies

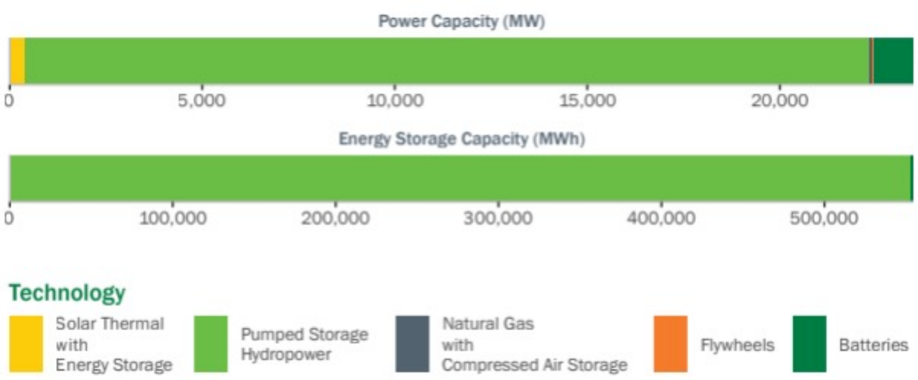
Two technologies, different roles

Storage is essential for balancing supply and demand, maintaining system stability, and integrating variable wind and solar generation.

PHES = PUMP HYDRO ENERGY STORAGE	BESS = BATTERY ENERGY STORAGE SYSTEM
PHES	**BESS**
A structural, long-duration infrastructure asset for bulk energy shifting, adequacy, inertia and resilience over multi-decade horizons.	A modular, fast-response system component for frequency regulation, local constraints, short-duration services and rapid deployment.

PHES and BESS should not be viewed as competing technologies, but as complementary components of a resilient low-carbon power system

Storage value depends on the timescale



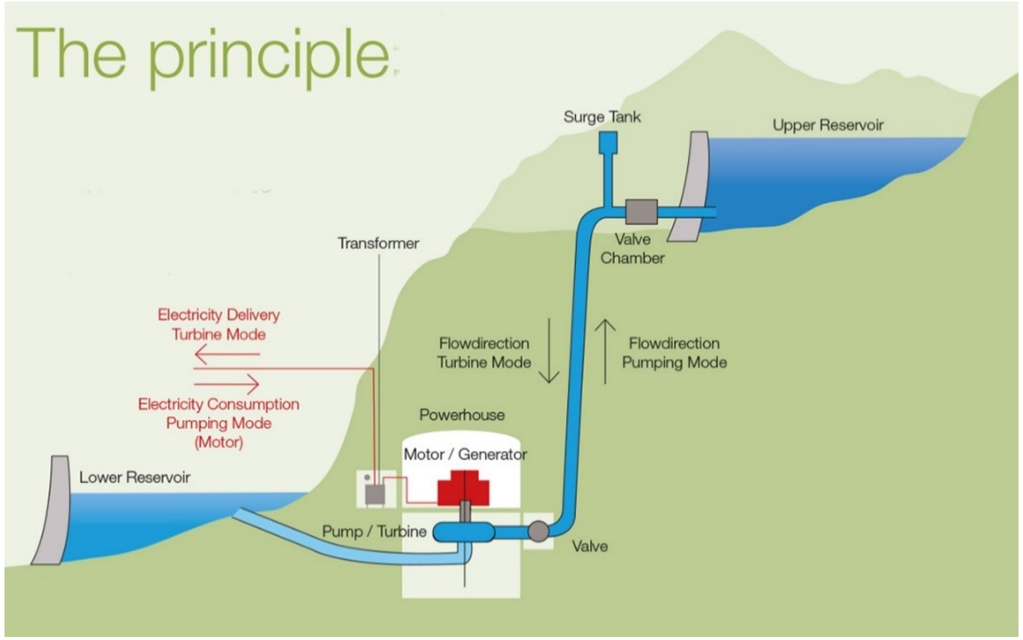
U.S. Utility-scale electrical energy storage capacity by technology type[1]

Timescale	System issue	Relevant services
Sub-seconds to minutes	Dynamic stability and frequency control	Inertia, voltage and primary/secondary frequency response
Minutes to hours	Real-time and day-ahead balancing	Balancing market, intraday energy shifting
Hours to days	Longer Variable Renewable Energy surplus or deficit	Scheduling adequacy and energy over longer durations
Months to years	Seasonal and inter-annual variability	Hydro-thermal coordination and system planning

Different timescales of power system flexibility[2]

Storage and investment decisions selection based around consider duration, capacity, response speed, lifecycle and cost

PHES overview: mature long-duration storage

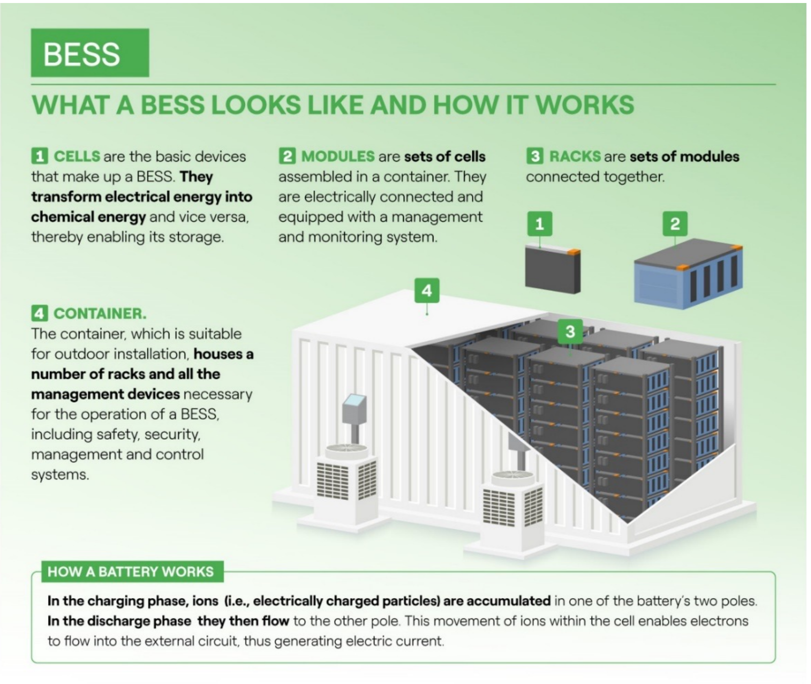


- Uses two reservoirs at different elevations to store and release energy
- Typical projects: several hundred MW to multi-GW; several GWh to tens of GWh
- Typical duration: 8–10 h for daily shifting; 10–24+ h for multiday balancing
- Start-up in generating mode: seconds to minutes
- Provides inertia, spinning reserve, voltage regulation and black-start capability
- Good round-trip efficiency (up to ~85%)

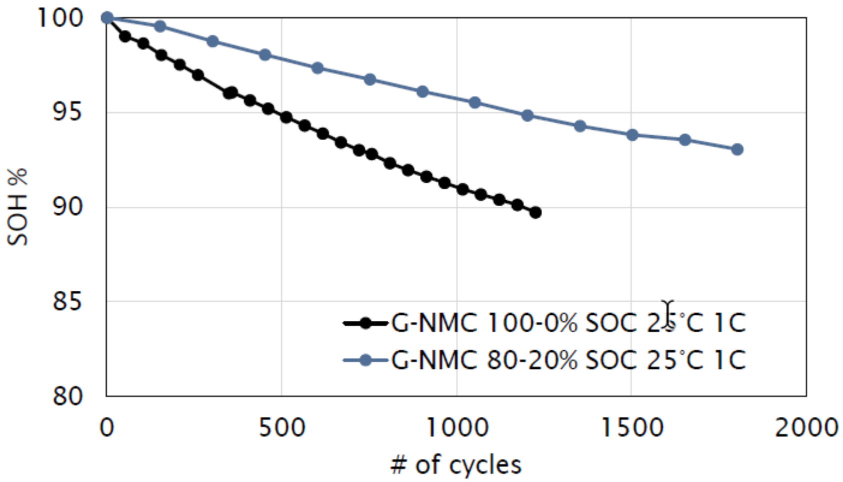
PHES: strengths and limitations

Strengths	Limitations / risks
✓ Very long asset life: 60–100+ years	× High upfront capital cost and major financing need
✓ Large-scale, long-duration storage: hours to multi-days	× Long development and permitting timelines: often 5–10+ years
✓ No storage degradation with cycling or age	× Site-specific geography, water availability and geology
✓ Low OPEX: typically ~1–2% of CAPEX/year	× Environmental, social and construction risk
✓ Strong system-level services: inertia, reserves, black start	× Limited siting flexibility and transmission integration needs

BESS overview: fast, modular and scalable



- Electrochemical storage that converts electrical energy into chemical energy and back
- Commercially common duration: 1–4 h; 6–8 h possible but less common today
- Millisecond-level response and high round-trip efficiency (80-90%)
- Modular deployment near load, generation or substations
- Capacity fades with cycling; after ~2,000 cycles, capacity can decline to ~85–90%



Battery degradation for graphite–NMC lithium-ion cells, showing how state of health (SOH) diminishes over cycles

BESS: strengths and limitations

Strengths	Limitations / risks
✓ Millisecond response: ideal for frequency regulation	× Limited duration: most economical around 0.5–4 h
✓ Modular and scalable, with predictable incremental costs	× Costs scale roughly linearly with duration and energy capacity
✓ Short development/build time: months rather than years	× Degradation and typical economic life of 10–20 years
✓ High efficiency and high controllability	× Fire/safety risks and complex safety systems
✓ Flexible siting and multi-service revenue stacking	× Exposure to battery supply chains and residual-value uncertainty

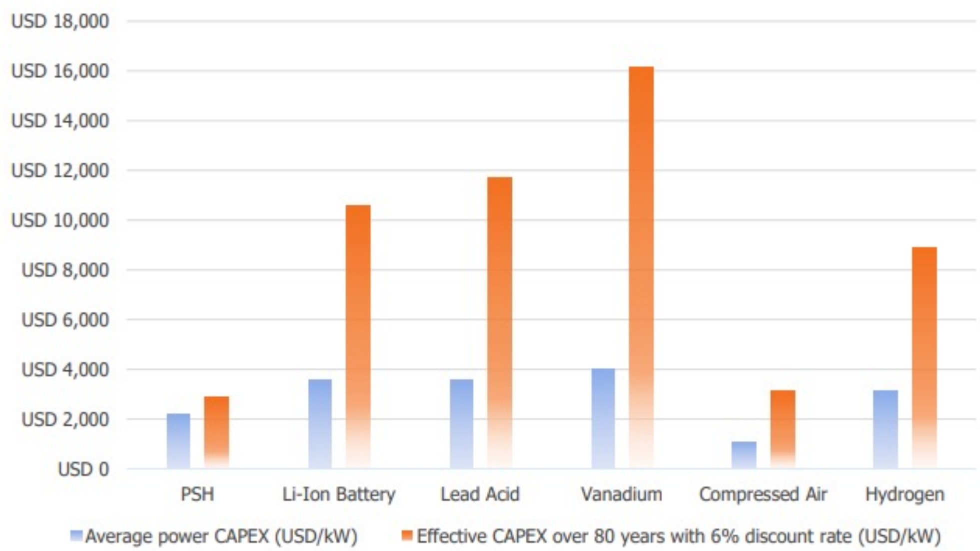
PHES vs BESS

Planning implication

BESS is strong at short-duration, high-precision grid services.
PHES naturally aligns with bulk, long-duration and system-adequacy needs

	PHES	BESS
Capacity scale	Hundreds of MW to multi-GW	Tens to hundreds of MW; typically <400 MW
Storage duration	2 hours to multi-day	0.5–4 hours
Response time	Seconds to minutes	Milliseconds to seconds
Design life	60–100+ years; refurbishment during life	10–20 years; capacity fades over time
Round-trip efficiency	70–85%	80–90%
Cost behaviour CAPEX Unitised CAPEX OPEX Cost Drivers	High upfront, low lifecycle cost, economies of scale ~2–3.5 M USD/MW for 1,000 MW, 10-hour plant ~3 M USD/MW over 80-year life Low: typically ~1–2% of CAPEX/year Civil works, electro-mechanical equipment, grid connection	Cost increases linearly with energy capacity/duration CAPEX: 1.5–4 M USD/MW for 1,000 MW, 10-hour equivalent ~8–11 M USD/MW including replacement and O&M Moderate-high: typically ~2–7% of CAPEX/year Battery packs, power electronics, balance of plant, fire/HVAC
Best use	Structural reliability asset for prolonged system stress	Contingency response and short-term stabilization

Lifecycle lens: replacement changes the comparison



Comparison of effective lifetime costs of energy storage technologies over 80 years

- BESS has shorter design life and replacement/augmentation needs
- PHES has higher upfront civil-works exposure, but much longer useful life.
- Over 30–50 year planning horizons, lifetime cost and risk exposure are material.

Key point

Comparing only initial CAPEX can understate the long-term cost of short-lived modular assets

Hybridization: BESS can make PHES more valuable

The report identifies growing interest in hybrid PHES–BESS configurations, although optimal control strategies are still evolving.

BESS contribution
Rapid high-precision response for small frequency and voltage fluctuations; improves FFR/FCR participation.

PHES contribution
Long-duration endurance, inertia, spinning reserve and system adequacy during prolonged stress events.

System benefits
Reduced starts/stops and ramping, lower O&M wear, improved black start, expanded reserve range, greater efficiency.

- Potential value is strongest where variable renewable penetration is high
- While hybrid schemes show potential, the combination of PHES & BESS remains at low technology readiness, with consensus not reached on optimal control strategy

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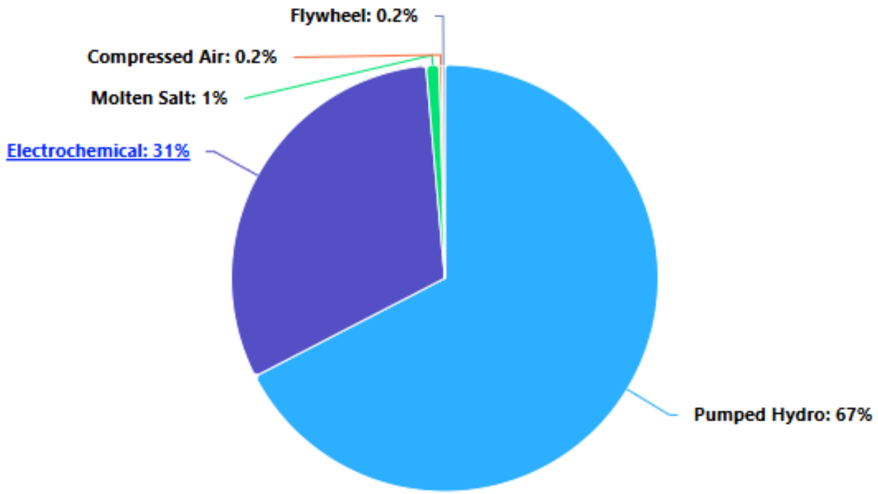
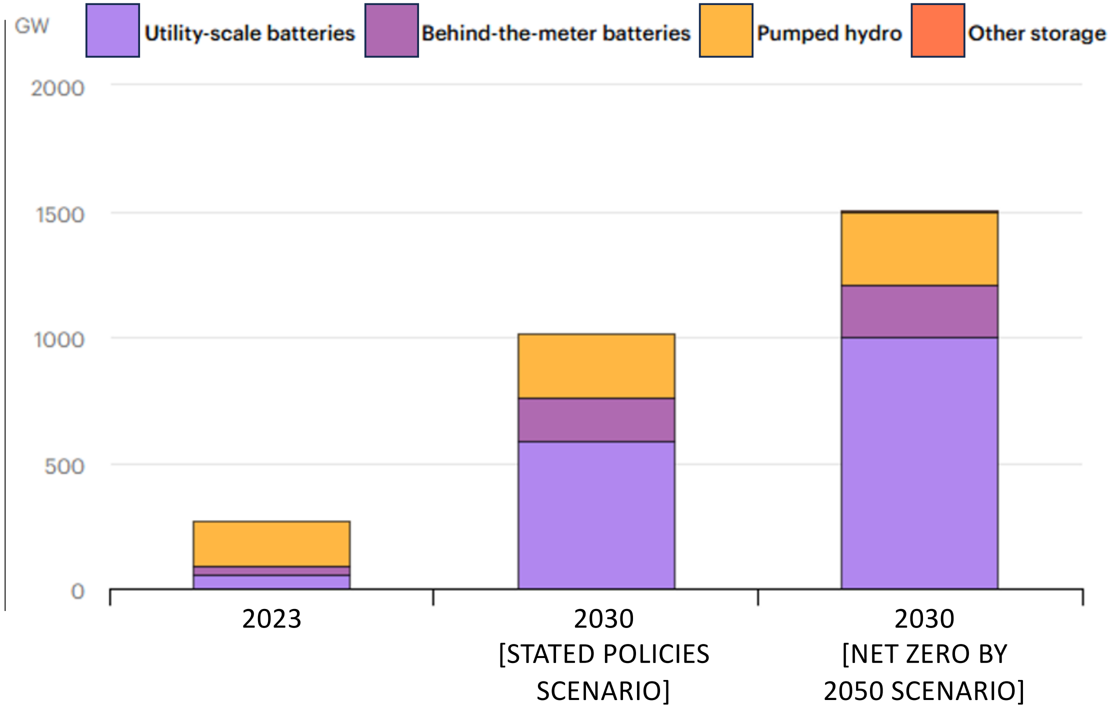
Global trends: PHES dominates capacity, BESS grows fastest



Percentage of global energy storage capacity for each type in 2023



PHES remains the dominant proven utility-scale storage technology, while battery storage is the fastest-growing technology due to cost declines, modularity and short deployment timelines.

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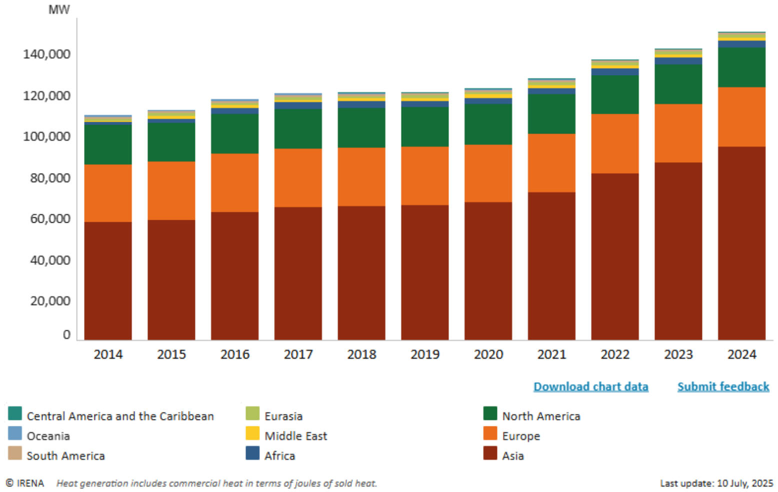
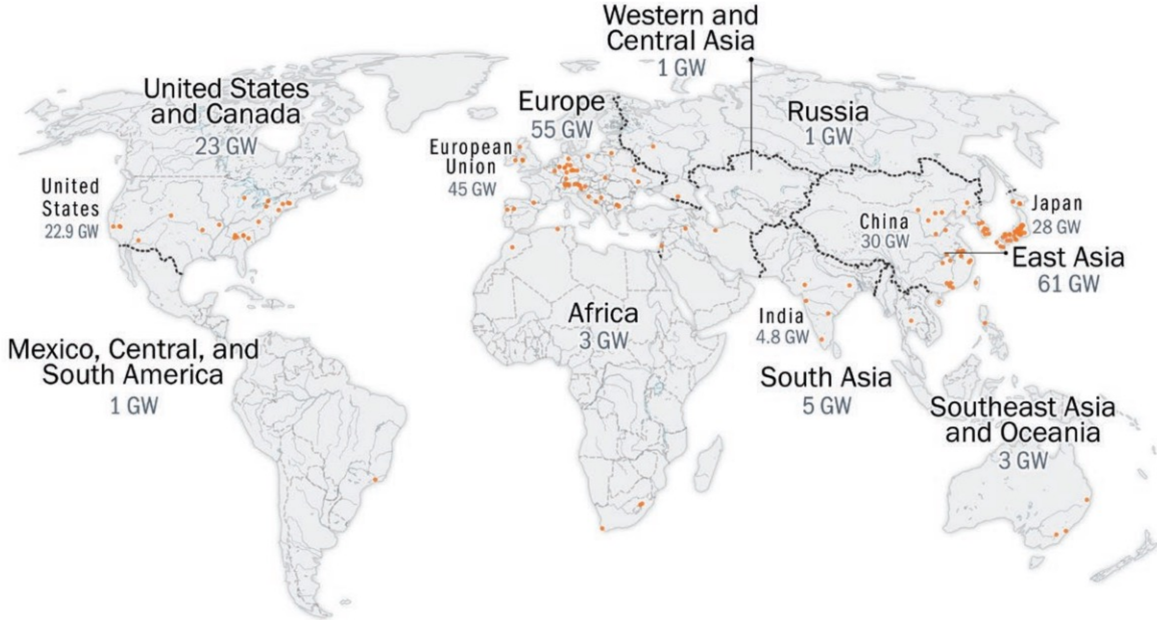
PHES global trends: long-lived infrastructure pipeline



Total installed power capacity by region



Operational PHES worldwide

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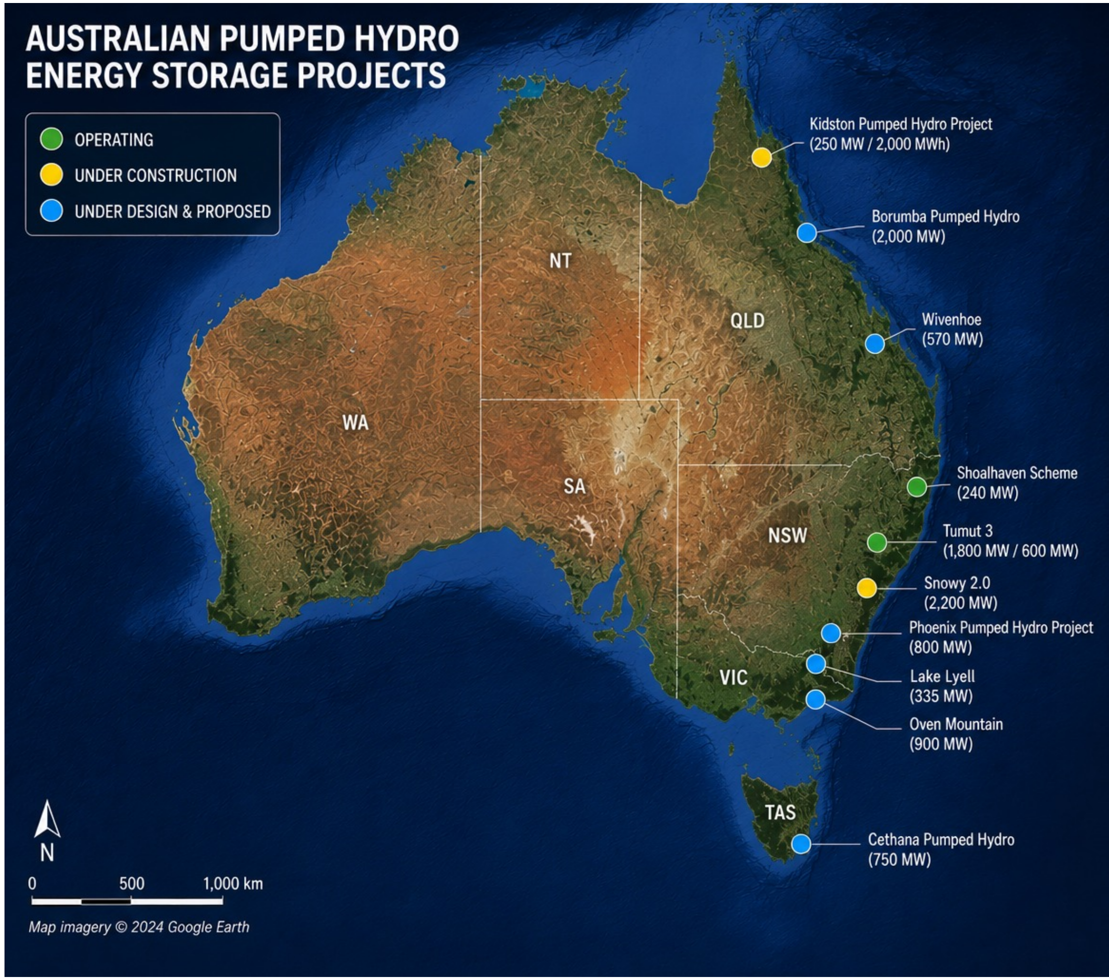


OPERATING PHES FACILITIES

Project	Capacity
Tumut 3 (NSW)	1,800 MW generation / 600 MW pumping
Wivenhoe (QLD)	570 MW generation
Shoalhaven Scheme (NSW)	240 MW generation / pumping (combined)

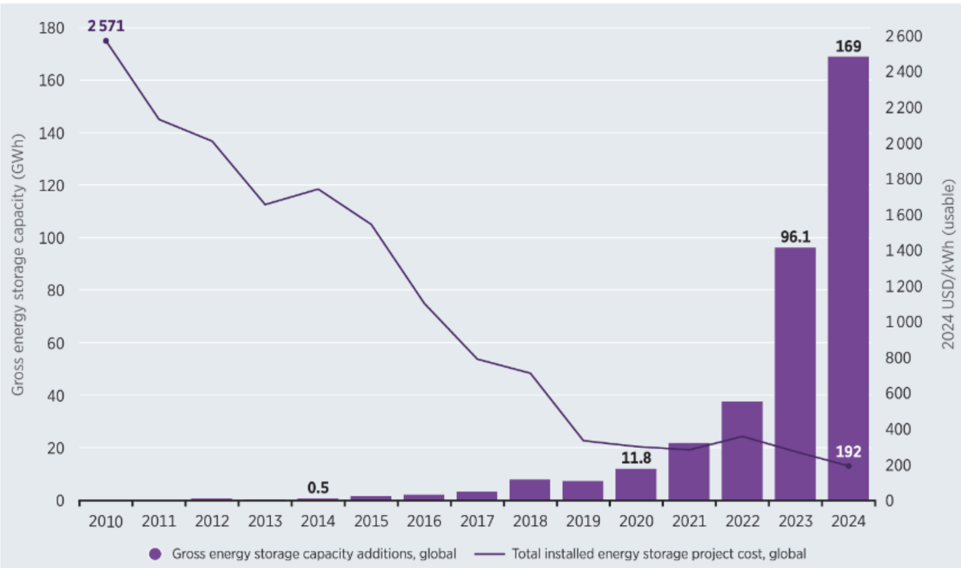
UNDER CONSTRUCTION

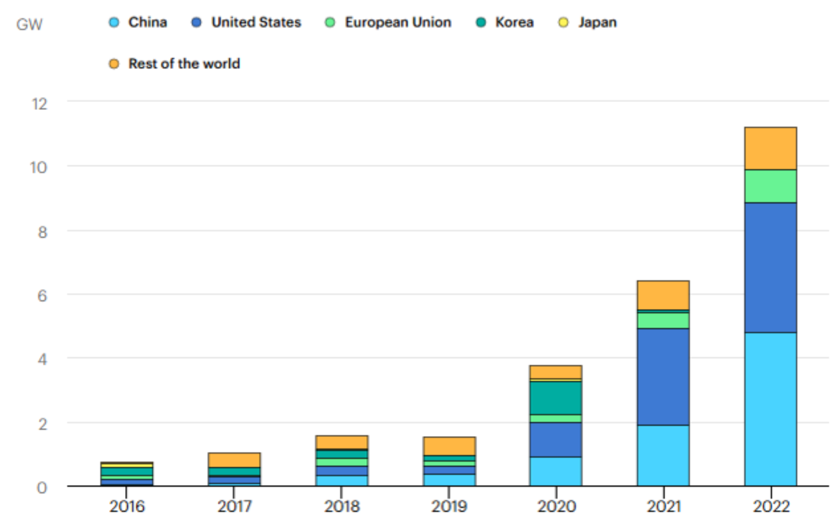
Project	Capacity
Snowy 2.0 (NSW)	2,200 MW generation
Kidston Pumped Hydro Project (QLD)	250 MW / 2,000 MWh storage

UNDER DESIGN & PROPOSED

Project	Capacity
Borumba Pumped Hydro (QLD)	2,000 MW
Phoenix Pumped Hydro Project (NSW)	800 MW
Cethana Pumped Hydro (TAS)	750 MW
Lake Lyell (NSW)	335 MW
Oven Mountain (NSW)	900 MW

BESS global trends: rapid deployment and cost decline





- Power-sector battery storage was the fastest-growing commercially available energy technology in 2023
- Global deployment more than doubled year to year; about 42 GW added across utility-scale and behind-the-meter systems
- Growth is strongest in China, the USA, Europe and Australia

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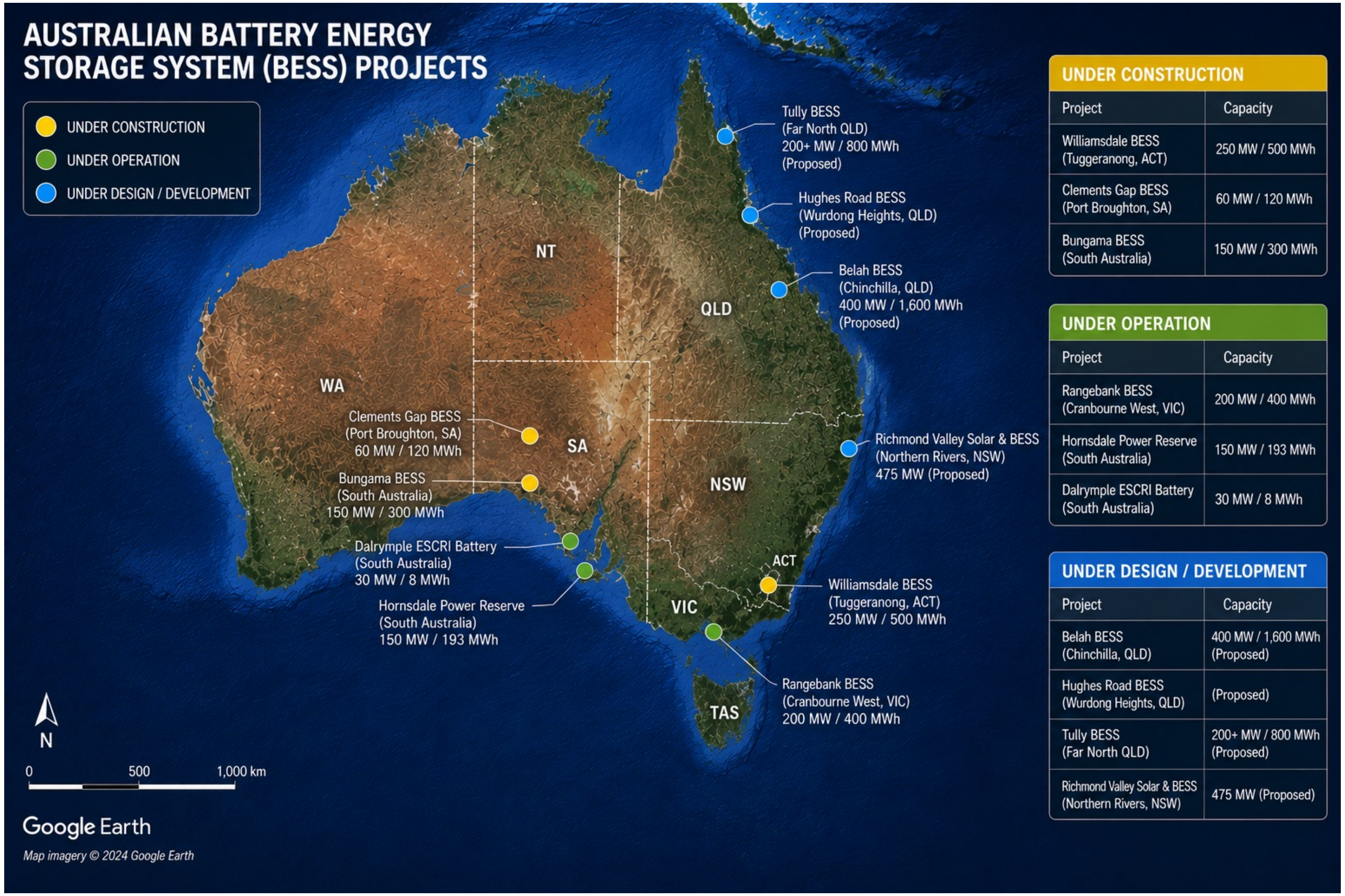

UNDER CONSTRUCTION

Project	Capacity
Williamsdale BESS (Tuggeranong, ACT)	250 MW / 500 MWh
Clements Gap BESS (Port Broughton, SA)	60 MW / 120 MWh
Bungama BESS (South Australia)	150 MW / 300 MWh

UNDER OPERATION

Project	Capacity
Rangebank BESS (Cranbourne West, VIC)	200 MW / 400 MWh
Hornsdale Power Reserve (South Australia)	150 MW / 193 MWh
Dalrymple ESCRI Battery (South Australia)	30 MW / 8 MWh

UNDER DESIGN / DEVELOPMENT

Project	Capacity
Belah BESS (Chinchilla, QLD)	400 MW / 1,600 MWh (Proposed)
Hughes Road BESS (Wurdong Heights, QLD)	(Proposed)
Tully BESS (Far North QLD)	200+ MW / 800 MWh (Proposed)
Richmond Valley Solar & BESS (Northern Rivers, NSW)	475 MW (Proposed)

Conclusions for system planning

- The choice between PHES and BESS depends on duration, installed capacity, efficiency degradation, design life, response speed, cost structure, timing and site constraints.
- BESS is highly effective for fast, precise, scalable short-duration flexibility, but cannot fully cover prolonged low-renewable periods or seasonal adequacy needs.
- PHES is better suited to bulk-system endurance: winter peaks, multiday low-renewable periods and compound stress events.
- The strongest planning approach is a portfolio: BESS acts as an optimizer; PHES provides the backbone of endurance, adequacy and long-term robustness.

PHES and BESS are complementary — not substitutes!

Thank you

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Questions & discussion

Comparative Assessment of Pumped Storage Hydropower (PHES) and Battery Energy Storage Systems (BESS)

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