Advanced Energy Storage for Flexible Nuclear Power and Resilient Low-Carbon Grids



A battery-materials perspective on commercial Li-ion storage and SMR integration

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UIUC Nuclear Energy and Applications Workshop
20 October 2026

Grid services define the battery duty cycle

Fast power	Frequency response and ramp smoothing Fast changes in MW, with energy held in reserve
Energy shifting	Peak support and renewable firming Sustained output consumes usable MWh
Operating commitment	Specify response, duration and availability Allocate headroom before combining services

MW sets the rate. Usable AC MWh sets the duration.

[1] IEA (2024)

300 MWe SMR + 100 MW / 400 MWh Li-ion BESS

300 MWe

SMR electrical output

100 MW / 400 MWh

Battery power / nominal stored energy

2.365 TWh/year

300 × 8,760 × 0.90
Illustrative 90% capacity factor

4 h arithmetic ceiling

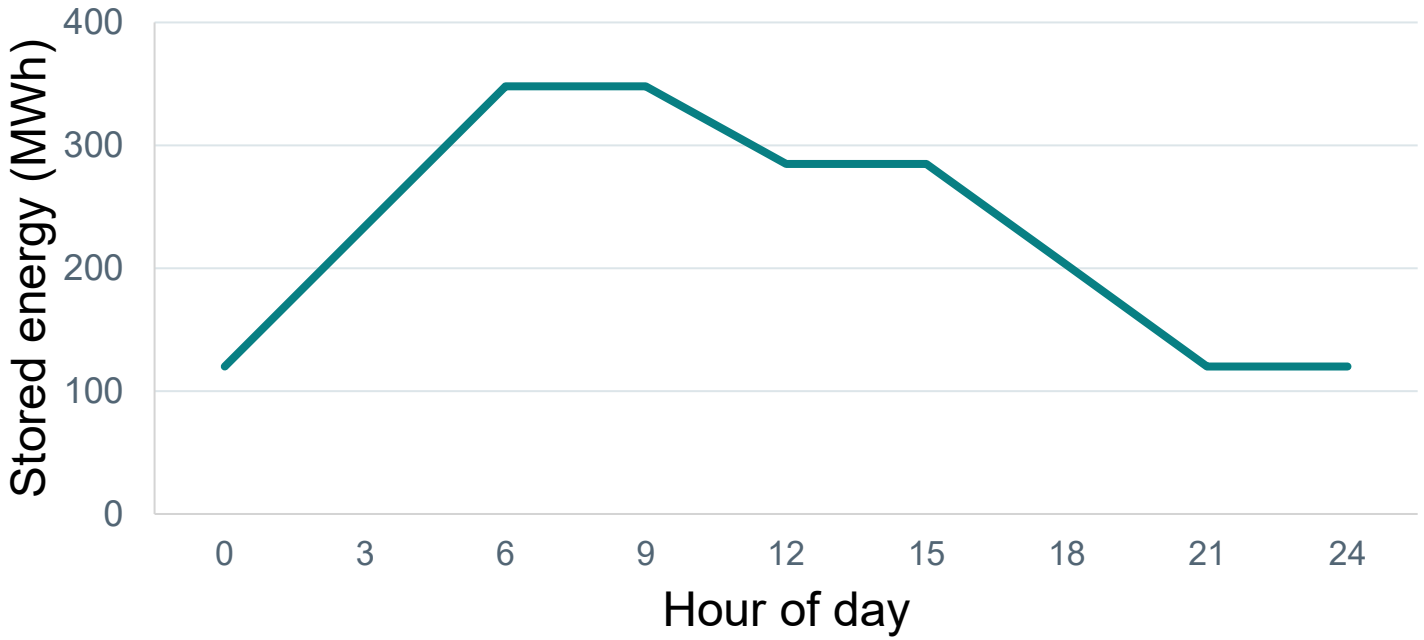
400 MWh ÷ 100 MW
Only if all 400 MWh are deliverable as AC

Actual duration = usable AC energy at the agreed meter ÷ AC power

[1] IEA (2024)

Daily battery operation

Charge overnight. Discharge during demand peaks.



00–06 Charge at 40 MW

09–12 Supply 20 MW
15–21 Supply 26.1 MW
Other hours: idle

240 MWh charged
216.6 MWh delivered
23.4 MWh lost

Same stored energy at the start and end: 120 MWh
Assumptions: constant 300 MW SMR, 400 MWh nominal DC, 95% efficiency each way.
Operating SOC: 10–90%. Auxiliary use and self-discharge excluded.

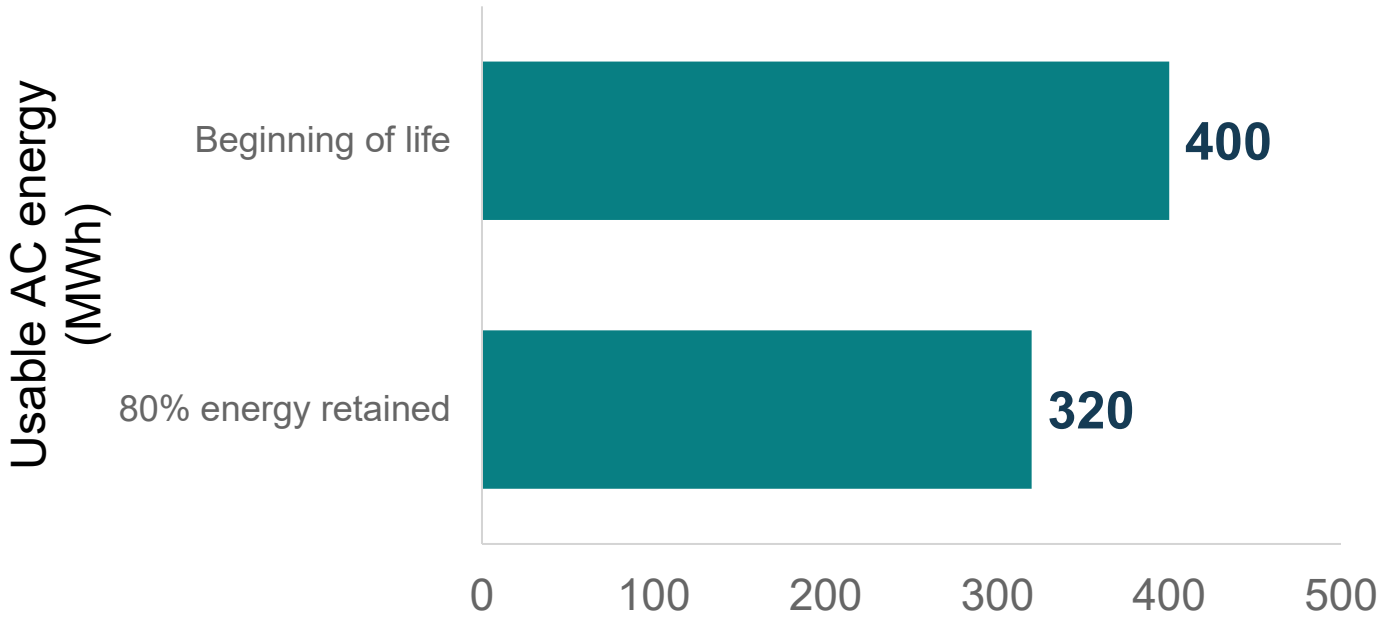
LFP and NMC involve different system trade-offs

Attribute	LFP	NMC
Cathode family	Lithium iron phosphate	Nickel manganese cobalt oxide
Typical cell trade-off	Greater thermal stability Lower energy density	Higher energy density More thermal-risk management
Stationary application	Often attractive for cost and cycling duty	Useful when space or weight has a high value

Cell chemistry alone cannot establish pack safety or lifetime.

[1] IEA (2024) [2] PNNL

Energy fade reduces the duration available for service



4.0 h

at 100 MW initially

3.2 h

at 100 MW after energy fade

This comparison assumes 400 MWh usable AC initially.
80% retention is a scenario, not a calendar-life forecast. Power assumed unchanged.

[3] NREL (2024) [4] Preger et al. (2026)

Phosphorus-anode research and the evidence gap

96.7%

capacity retention after 1,500 cycles at 4C

Published half-cell anode result
Fluorinated weakly solvated electrolyte

What our materials work addresses

- Electrolyte solvation and interface stability
- Reaction kinetics and active-material loss

Separate full-cell result

92.4% retention after 100 cycles
LFP cathode paired with the anode

Next evidence: practical loading, cell balance, pack safety and field AC performance

[5] Xie et al. (2025)

Tesla Megablock illustrates commercial storage scale

20 × 20 MWh

400 MWh on the manufacturer’s stated AC basis

Architecture	Four Megapack 3 units per Megablock Integrated transformer and switchgear
Reported density	248 MWh AC/acre gives about 1.61 acres About 6,530 m² for 400 MWh

Density does not define nuclear-site acreage or prove nuclear suitability.

[6] Tesla (8 September 2025) [7] Tesla

Nuclear integration requires a defined safety boundary

Interface	Evidence required
Grid-side electrical connection	Inverter transients, fault behavior, harmonics and coordinated protection
Nuclear safety systems	Plant-specific isolation, independence and safety case Separate qualification for credited emergency power
Fire and explosion	Installation-representative propagation data, separation, gas management and emergency response
Cybersecurity and control	Protected nuclear functions, segmented communications, access control and fail-safe loss of BESS control

Concept: BESS connects through its transformer to the grid-side switchyard. Nuclear safety buses retain their own qualified supplies and protection.

[8] NRC [9] NRC [10] NFPA (2026) [11] UL Solutions (23 April 2026)

Research gaps at the project boundary

01	**Service and sizing**	Co-optimize MW, usable AC MWh and reserve
02	**Lifetime**	Validate energy fade and power fade under grid duty
03	**Controls and protection**	Test faults, transients and cyber failure modes
04	**Siting and safety**	Demonstrate propagation control and segregation
05	**Lifetime value**	Measure availability, augmentation cost and revenue

Proposed sequence: cells, practical packs, grid emulator, staged site demonstration

[13] U.S. DOE [14] INL

Findings and recommendations

Finding	Recommendation
Nuclear supplies sustained energy. Li-ion adds limited-duration flexibility.	Specify power, usable AC energy, response and reserve together.
Aging changes deliverable energy and service duration.	Contract and test lifetime performance. Plan oversizing or augmentation.
Commercial BESS maturity does not establish nuclear-site suitability.	Validate electrical, fire and cyber interfaces within the plant safety case.

Future SMR energy systems

Batteries provide electrical flexibility. Separate designed pathways can supply industrial heat, hydrogen or water treatment when temperature and economics allow.

[12] U.S. DOE [14] INL