Repurposing End-of-Life EV Batteries for Stationary Energy Storage

A consultant's report

Executive Summary

Second-life EV batteries can supply fast-growing stationary storage needs at lower embodied carbon and potentially lower cost than new packs. Multiple studies estimate 100 to 200 GWh of retired EV batteries will become available in 2030, creating a real supply pool for repurposed storage. Market analysts project up to 330 to 350 GWh of second-life deployments by 2030 in aggressive cases. (PMC, ScienceDirect, PR Newswire)

Key findings.

1. Economics can work when you acquire packs at 20 to 60 dollars per kWh and refurbish for 20 to 70 dollars per kWh, then integrate with balance-of-system hardware at current cost levels. A 2 MWh project can achieve a 4 to 7 year payback in favorable markets, with IRR above 20 percent in upside cases. (ICCT, Volta Foundation, NREL)
2. Safety and compliance are tractable with existing standards, including UL 1974 for repurposing, UL 9540 and UL 9540A for ESS and fire testing, and IEC 62619 and IEC 62933 for industrial cells and grid-integrated systems. (UL Solutions, IEC Webstore)
3. Real projects already operate, for example B2U's 25 MWh site in California and Nissan's 4R Energy deployments. Typical retired EV packs retain 70 to 80 percent state of health, which is well-suited to stationary duty. (Axios, Nissan, PMC)

Top-line recommendations.
• Start with a controlled 100 kWh pilot at a C&I site to validate yield, safety, and software.
• Secure multi-year pack supply from OEMs and dismantlers. Add strict grading protocols.
• Standardize a modular rack and BMS architecture built to UL 9540A tested designs.
• Target utility and C&I revenue stacks first, then expand to community hubs and disaster-relief microgrids.

Market Analysis

Global and regional market size, second-life storage (estimates)

Year	Global installed second-life capacity, GW	Global installed second-life energy, GWh	Regional split by energy, 2030 (estimate)
2025	6–8	25–30	n.a.
2030, conservative	25–60	100–250	China 45–50%, Europe 25–30%, North America 15–20%, Rest of world 10%
2030, upside	80–90	330–350	Same shares as above

Notes. 2025 and 2030 upside reflect MarketsandMarkets projections. Conservative 2030 range aligns with academic and policy studies that size available retirements and realistic conversion rates.

Regional shares are inferred from EV stock and battery demand leadership in China, Europe, and the United States in IEA's 2024 outlook. (PR Newswire, McKinsey & Company, IEA)

Supply: projected retirements by 2030

- Studies estimate 100 to 200 GWh of EV batteries will retire in 2030, depending on vehicle lifetime and chemistry mix. A recent review cites 100 to 120 GWh by 2030, while others bracket 100 to 200 GWh. If 50 percent of these are reused, practical second-life capacity would be near 96 GWh in 2030. (PMC, ScienceDirect, ICCT)
- Many retired packs show 70 to 80 percent state of health, which supports 5 to 15 additional years when cycled within gentler stationary profiles. 4R Energy reports 10 to 15 years of second-life service. (PMC, Nissan)

Target customer segments

- **Utilities and grid operators.** Frequency response, reserve, congestion management, and resource adequacy. GB battery assets earned about 51 to 65 thousand pounds per MW-year in 2023, with higher run-rates in late 2024 during market tightness. (Modo Energy, solarpowerportal.co.uk)
- **Commercial and industrial.** Demand charge reduction and peak shaving under DUoS and TNUoS structures, backup power, and solar self-consumption. Reforms since 2022 changed charging signals, which increases the value of precise control and forecasting. (TotalEnergies Gas & Power, National Energy System Operator (NESO))
- **Residential and community microgrids.** Solar time-shift, outage resilience, tariff arbitrage.
- **Public charging hubs.** Co-located storage to reduce grid connection costs and provide fast-response services.
- **Remote and island grids.** Diesel offset and voltage support.

Business Case

Revenue streams

- **Energy arbitrage.** Buy off-peak power, sell during peaks.
- **Demand-charge reduction and network charges mitigation.** Reduce peak import kW for C&I bills under local tariffs. (TotalEnergies Gas & Power)
- **Ancillary services.** Frequency containment, reserve, and balancing mechanism dispatch. GB examples show monthly run-rates that annualize to 60 to 100 thousand pounds per MW-year in strong months. Prices vary with saturation and system needs. (Modo Energy)
- **Capacity markets and tolling.** Contracted availability payments that stabilize cash flows. (Modo Energy)
- **Resilience as a service.** Backup power subscriptions for tenants or community loads.

Cost drivers and capex

Cost element	Typical range, USD per kWh	Notes
Used pack acquisition	20–60	Market dependent, chemistry and SOH dependent. (Volta Foundation)
Refurbishment and testing	20–70	Disassembly, grading, reconfiguration, module repairs, BMS enablement. (ICCT)
Balance of system, PCS, EMS, enclosure, EPC	150–250	NREL 2030 projections for Li-ion systems give total installed costs of about 245 to 403 dollars per kWh for 4-hour systems, which bound current BOS for 2-hour systems. (NREL)

Operating costs include 1.5 to 3 percent of capex per year for maintenance, monitoring, and augmentation reserves.

Financial model summary

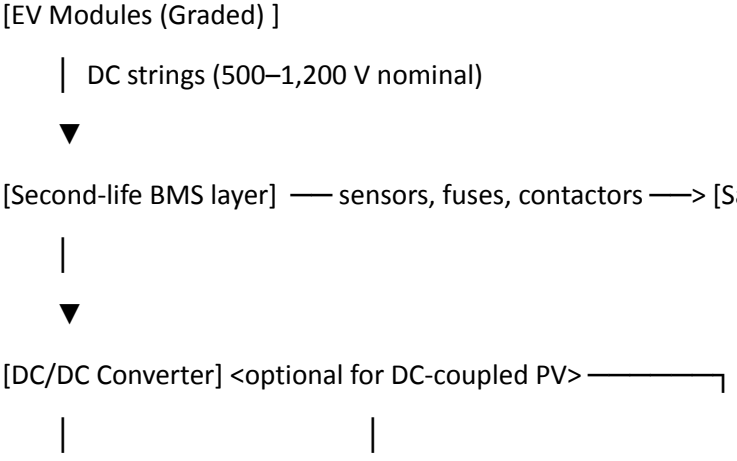
Base case: 1 MW, 2 MWh second-life system, 10 year life, 8 percent discount rate, 2 percent revenue degradation per year, 2 percent of capex annual O&M.

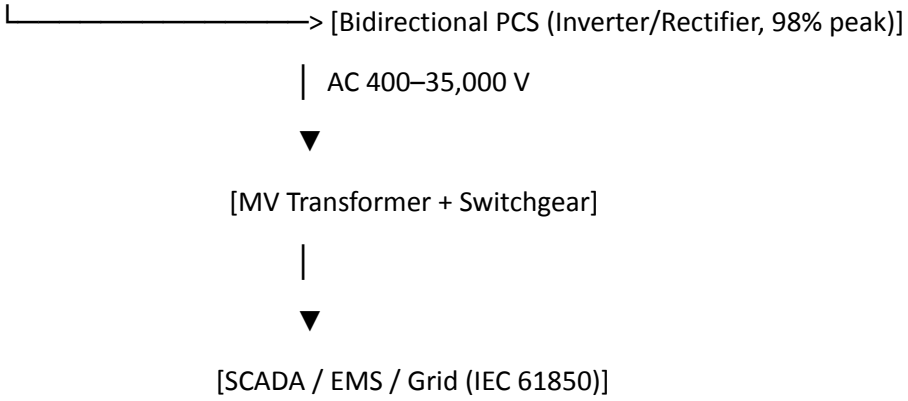
Scenario	Capex (USD/kWh)	Annual revenue (USD/MW-yr)	NPV (USD)	IRR	Simple payback
Conservative	300	60,000	−307,599	−5.9%	n.a.
Base	250	90,000	−7,717	7.6%	7 years
Upside	200	130,000	354,318	25.9%	4 years

Interpretation. Second-life economics are highly sensitive to acquisition price, BOS cost, and market revenues. In markets with robust frequency and reserve payments or strong peak prices, projects clear double-digit IRR. Where revenues are thin or BOS costs run high, returns compress. GB revenue benchmarks from 2023 to 2024 illustrate this variability. (Modo Energy)

Technical Architecture Specification

System overview





Modern PCS and DC/DC equipment operate on 1,000 to 1,500 V DC buses with peak efficiencies near 98 to 99 percent and fast response for grid services. (ingeteam.com, Dynapower)

Battery refurbishment process

1. **Intake and traceability.** Record serials, pack history, UN 38.3 transport compliance. (PHMSA)
2. **Grading and testing.** State of health estimation at module level, impedance checks, leak and insulation tests, IR thermography. Typical acceptance band is 70 to 90 percent SOH. (MDPI)
3. **Reconfiguration.** Repack modules into standardized racks. Add contactors, fuses, current shunts, and smoke sensors.
4. **Thermal management upgrades.** Retrofit air or liquid cooling, airflow baffles, and temperature sensors to limit hotspots.
5. **Safety validation and facility certification.** Follow UL 1974 process audits for sorting and grading. (UL Solutions)

Battery Management System (BMS)

- **Key functions.** Cell and module voltage monitoring, coulomb counting and model-based SOH and SOC, passive or active balancing, fault logging, and isolation checks.
- **Safety interlocks.** Pre-charge, contactor sequencing, HVIL, smoke and off-gas triggers tied to PCS trip.
- **Firmware.** Supports configurable current limits vs. temperature, charge windows that respect aged chemistries, and cybersecure updates.
- **Standards alignment.** UL 1973 for stationary battery subsystems, IEC 62619 for industrial cells, and IEC 62933 safety framework. (UL Solutions, IEC Webstore)

Power conversion and integration

- **Inverter and rectifier.** Bidirectional PCS, grid-form/ grid-follow modes, peak conversion efficiency 98 percent or higher. Support 1,000 to 1,500 V DC input and LVRT, fast frequency and voltage support. (ingeteam.com)
- **Grid-tie vs off-grid.** AC-coupled for retrofit simplicity. DC-coupled to PV with DC/DC converters improves PV clipping recapture and reduces conversion stages. (Dynapower)

- **Interoperability standards.** IEC 61850 for substation SCADA, IEEE 2030.5 and SunSpec Modbus for DER communications and smart inverter functions. (iec61850.dvl.iec.ch, IEEE Standards Association, SunSpec Alliance)
- **System compliance.** UL 9540 for ESS, UL 9540A thermal runaway propagation testing, plus local fire code references. (UL Solutions)

Software and controls

- **EMS algorithms.** Day-ahead and intra-day optimization for price-based dispatch, state-of-charge management, and degradation-aware cycling.
- **Forecasting.** Short-term load and PV forecasts with rolling re-optimization.
- **Remote monitoring.** Alarms, KPIs, firmware management, and historian, with IEC 61850 or DNP3 northbound and SunSpec or Modbus southbound. (SunSpec Alliance)
- **SCADA interface.** Role-based access, certificate-based security for IEEE 2030.5 connections. (QualityLogic)

Pros, Cons, and Benefits

Pros. Lower embodied carbon than new packs, lower material cost entry point, fast-response performance for grid services, deferment of recycling costs, and measurable social value when used in community hubs. (McKinsey & Company)
Cons. Heterogeneous modules, variable SOH, complex traceability, and non-uniform mechanical formats that raise integration costs.
Benefits. Extends useful life by 10 to 15 years in many cases, reduces critical mineral demand, and can meet near-term grid storage needs in several regions. (Nissan, NREL)

Risks and Mitigation Strategies

- **Technical risk, cell degradation variability.** Mitigate with standardized grading, module-level SOH thresholds, controlled charge windows, and augmentation plans. (MDPI)
- **Safety risk, thermal runaway.** Mitigate with UL 9540A tested rack designs, gas detection, zoned fire suppression, thermal barriers, and remote disconnects. (UL Solutions)
- **Regulatory risk, unclear second-life definitions.** Engage early with AHJs, adopt UL 1974 facility certification and ISO 14001 EMS to demonstrate process control. (UL Solutions, ISO)
- **Financial risk, price volatility.** Lock in long-term supply agreements with OEMs and dismantlers, add floor-price tolling or capacity contracts for revenue stability. GB experience shows revenue swings as markets saturate or tighten. (Modo Energy, Cornwall Insight)

Novel Use Cases and Value Rewards

- **Community energy hubs with dynamic tariff arbitrage.** Lower bills and improve resilience for social housing or campuses.

- **Mobile disaster-relief microgrids.** Trailerized packs to power clinics and shelters.
- **Vehicle-to-grid battery banks at public chargers.** Reduce connection upgrades and sell ancillary services during dwell times.

Sustainability and Circular-Economy Considerations

- **Life-cycle analysis.** Second-life use reduces the need to manufacture new packs, which carry a significant carbon footprint per kWh. Recent reviews find second-life applications can cut GHG impacts of the battery life cycle, with benefit magnitude tied to the grid mix and duty cycle. Manufacturing energy and emissions per kWh of new cells are substantial, so displacement yields material savings. (PMC, MDPI)
- **End-of-second-life pathways.** After stationary service, route modules to hydrometallurgical or direct recycling. Policy momentum in the EU and the US is pushing recycled content and traceability. (Reuters)
- **Certification and auditing.** Use UL 1974 for repurposing facilities and ISO 14001 for environmental management to formalize quality and environmental controls. (UL Solutions, ISO)

Roadmap and Next Steps

1. **Pilot deployment, 100 kWh.** One inverter string using 8 to 12 graded EV modules. Metrics: RTE, thermal stability, availability, MWh throughput, and safety alarms.
2. **Standardize procurement and refurbishment.** Approved supplier list, pack history data, and pass/fail matrix by SOH and impedance.
3. **Scale to commercial projects, 1 to 5 MWh.** Replicate module rack design, pre-certified PCS skid, and EMS playbooks by site type.
4. **Partnerships.** OEMs for supply and data, certified refurbishers, and recyclers for closed-loop returns.
5. **Go-to-market and finance.** Blend merchant and contracted revenues. Add tolling agreements with floors. Use capacity market and reserve services to stabilize cash flows. GB revenue data shows the value of stacked services across cycles. (Modo Energy)

Technical Annexes

Interoperability and compliance checklist

- **Grid and utility.** IEC 61850 for substation SCADA, IEEE 2030.5 for DER communications, and SunSpec Modbus register models for storage. (iec61850.dvl.iec.ch, IEEE Standards Association, SunSpec Alliance)
- **Safety and fire.** UL 9540 ESS, UL 9540A thermal propagation testing, and installation to local fire codes. (UL Solutions)

- **Battery.** UL 1973 subsystem safety, IEC 62619 industrial cell safety, and IEC 62933 safety considerations for grid-integrated ESS. (UL Solutions, IEC Webstore)
- **Transport.** UN 38.3 test summary and packaging for all shipments. (PHMSA)

Performance benchmarks

- **Round-trip efficiency.** 80 to 90 percent AC-AC typical for Li-ion systems, with lower values in some second-life pilots due to added conversions and thermal limits. (NREL, e3s-conferences.org)
- **PCS efficiency.** Peak 98 to 99 percent at rated load. (ingeteam.com, Dynapower)
- **Second-life service life.** 10 to 15 years reported in practice, subject to duty cycle and thermal control. (Nissan)

Data and Assumptions Appendix

Key input assumptions

- Retired battery availability in 2030: 100 to 200 GWh globally, with a central estimate near 120 GWh. Conversion to second-life depends on pass rates and economics. (PMC, ScienceDirect)
- Installed second-life capacity by 2030: 100 to 250 GWh base, up to 330 to 350 GWh upside. (PR Newswire)
- Acquisition price: 20 to 60 dollars per kWh for retired packs at module level. Refurbishment: 20 to 70 dollars per kWh. Selling price benchmarks for repurposed modules: 44 to 180 dollars per kWh. (Volta Foundation, ICCT)
- BOS and EPC: 150 to 250 dollars per kWh for a 2-hour system, bounded by NREL 2030 cost projections for Li-ion. (NREL)
- RTE: model with 80 to 90 percent. (NREL)
- Revenue reference points: GB battery revenues averaged about 51 to 65 thousand pounds per MW-year in 2023 including capacity markets, with higher monthly run-rates in late 2024. Use market-specific analysis before investment. (Modo Energy)

Sources and references

- IEA Global EV Outlook 2024, battery demand and EV stock leadership. (IEA)
- MarketsandMarkets press release on second-life market size to 2030. (PR Newswire)
- Academic and policy studies on retirements and second-life capacity. (PMC, ScienceDirect, ICCT)
- Cost and safety standards, including UL 1974, UL 9540/9540A, IEC 62619, IEC 62933. (UL Solutions, IEC Webstore)
- Real-world deployments, B2U and 4R Energy. (Axios, Nissan)

Conclusion

Second-life EV batteries are technically viable for stationary storage when you control grading, safety, and integration standards. Supply by 2030 will be large enough to matter. Economics clear in markets with healthy ancillary services or strong peak prices, especially when acquisition costs stay near the low end and BOS is standardized. Begin with a 100 kWh pilot, lock supply and recycling partners, and scale to 1 to 5 MWh projects using a pre-certified architecture. (PMC, PR Newswire, UL Solutions)