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Supporting the Li-Ion Battery Supply Chain via PEV Battery Reuse

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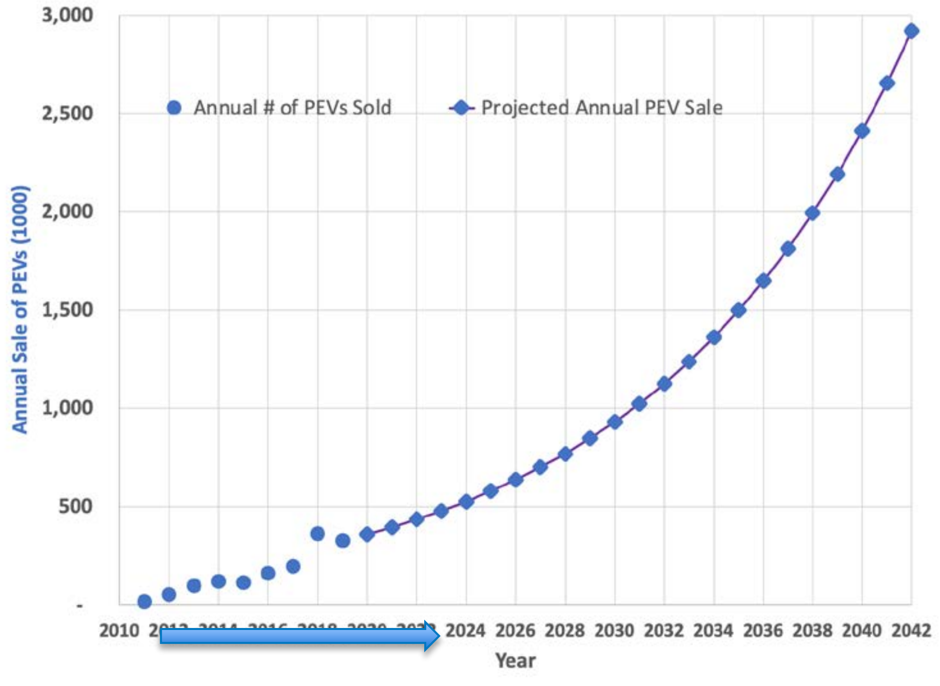
How Much PEV Batteries Retiring in the U.S.?

- Plug-in Electric Vehicle (PEV) Sales: Actual 2010 – 2019; 10% annual growth from 2020 (conservative)
- Battery Capacity: Actual 2010 – 2019; 10% annual growth from 2020
- Assumes batteries retire after 12 years with 75% of original capacity

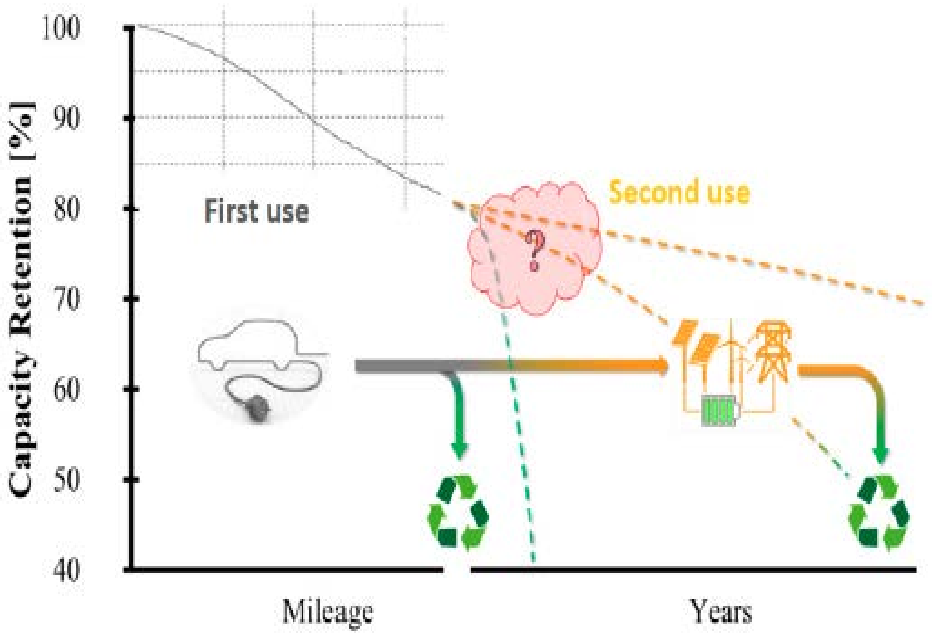


Li-Ion Batteries	2025	2030
To be retired after 12 years (annual)	2.1 GWh*	13.9 GWh~
*Can power 72,000 U.S. homes for a day ~May replace eleven 250MW/4hr natural gas peaking plants (80% efficiency) These represent significant storage resource for the grid (see below)		
Guestimate to be installed in grid (annual)	11 GWh	44 GWh

https://publications.anl.gov/anlpubs/2020/06/158307.pdf

Li-Ion Battery Degradation and Life after Retirement

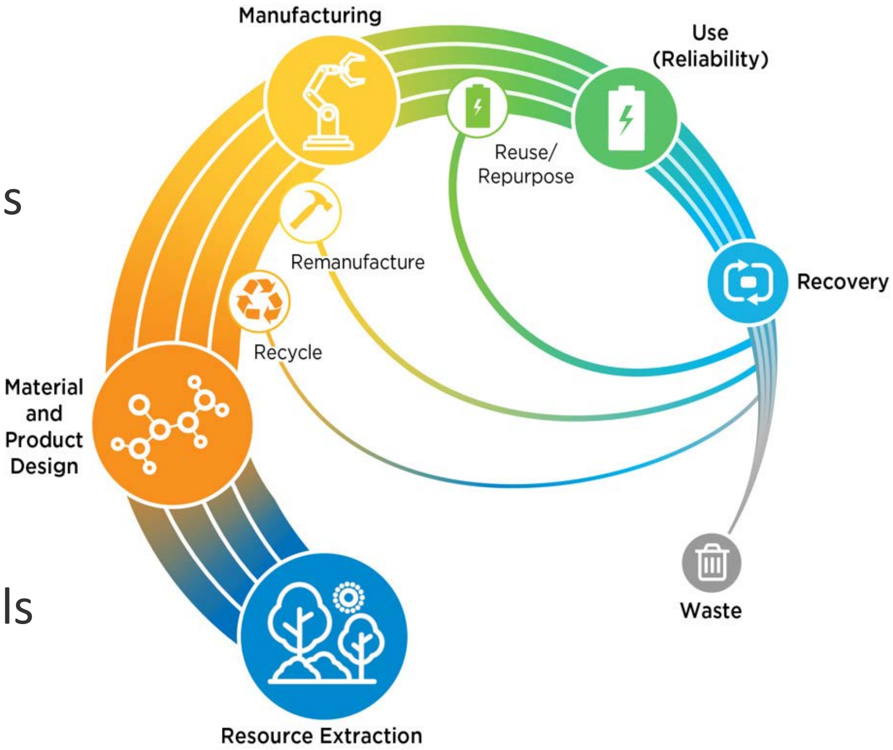
- Life of current Li-Ion batteries: 1,000–2,000 deep charge/discharge cycles; 8–12 years
- Rate of degradation, in addition to cell chemistry/design, depends on C/D rate, voltage range, duty cycle, and operating temp
- At the end-of-life in EVs, most LIBs may have 70-80% of their original capacity
- State of health (SOH) measurements could determine if Li-Ion batteries should be reused or recycled



From: Sustainability Assessment of Second Use Applications of Automotive Batteries: Ageing of Li-Ion Battery Cells in Automotive and Grid-Scale Applications

Benefits of Reuse and Recycling

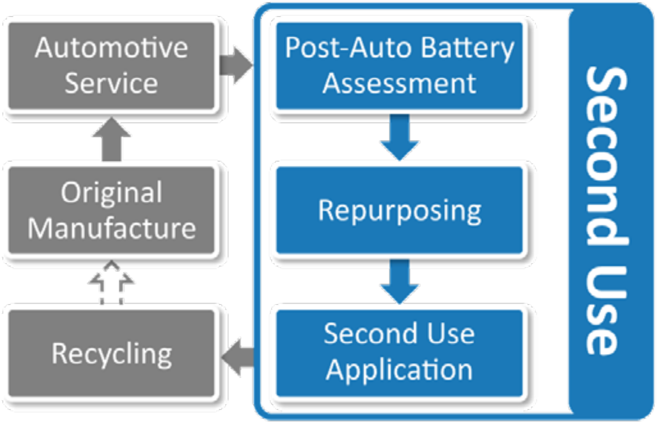
- Could alleviate supply chain issues
- Compensate for costs associated with end-of-life decommissioning
- Reduce possible material supply shortages or price spikes
- Reduce cost of future batteries by using recovered batteries and materials
- Reduce energy consumption and environmental footprint vs. making new batteries with virgin (or recycled) materials
- Show corporate responsibility and avoid negative perception of disposal as waste
- Create jobs/businesses in local communities



https://www.nrel.gov/docs/fy21osti/77035.pdf

Investigation of Second-Life PEV Battery Use

- NREL collaborated on a comprehensive testing and analysis study of second-life batteries for reuse (2010–2016) https://www.nrel.gov/transportation/battery-second-use.html
- A few PEV and Battery makers and system integrators have been demonstrating the technical merits of second-life batteries in different applications
- Studies have been conducted by academia, industry, integrators, and public agencies to demonstrate and understand the potential and barriers to second-life applications.



Example: B2U supporting PV CAISO grid
Courtesy of B2U Storage Solutions (b2uco.com)

B2U Studies Support Similar Findings – 1

- **Technically feasible** to reuse second-life batteries for **grid storage** and other niche applications
- Second-life batteries may **last another 10 years** in second-use applications
- **Lower Environmental footprint** to reuse second-life batteries vs. manufacturing new batteries or recycling when their SOH is good
- Reuse could **delay the manufacturing** of new batteries and **the need for new battery materials for several years**
- Second-life battery price discount could be be 50%–70%
- Second-life batteries may have the potential to compete with new batteries and other ES technologies based of levelized cost

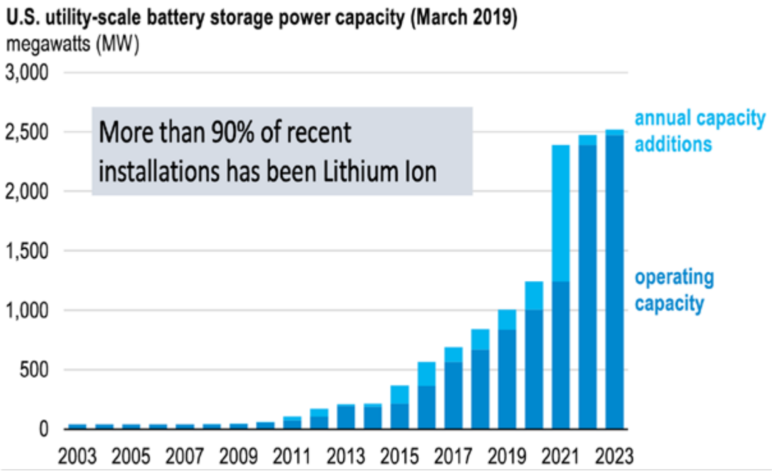
B2U Studies Support Similar Findings – 2

- The **economic viability** of utilizing second-life batteries in large but low-value applications remains **uncertain**
  - However, there are viable business models for **high-value small and niche** B2U applications (e.g., aftermarket PEVs, backup power)
- **The cost of repurposing** plus lower prices for new batteries may decrease the economic viability of B2U
- Recycling and reuse have **synergy and competing** potentials
- Some regulations and practices add to the cost of reuse
- An independent large scale (5-10 MW) demonstration, second life degradation study, and a techno-economic in collaboration with various stakeholders needed to address barriers and skepticism

Suggested Applications for Second-Life Batteries

Grid Storage:

- Megawatts (MW) of new Li-Ion systems now used in residential, commercial, and industrial applications
- Renewable firming, voltage support, demand charge management, spinning reserve, are examples
- Second-life batteries could technically compete with new batteries in this application.



Source: Source: U.S. Energy Information Administration, Annual Electric Generator Report and the Preliminary Monthly Electric Generator Inventory

Niche Applications:

- Forklifts, replacing diesel back up generators, after-market replacement packs for PEVs, 2 or 3 wheelers e-cycles
- Replacing lead-acid batteries in developing countries as back up power
- Emerging markets with a different set of performance expectations and cost targets.

For niche applications, battery prices are higher than applications with larger volume purchases

Significant New Market Opportunities

Renewable Power Generation

- Wind and solar power generation continue to be added to the grid (200 GW–400 GW)
- Many GWh of energy storage is needed to address variable generation
- Adding energy storage will enable larger penetration of renewable power.

Providing Peaking Capacity

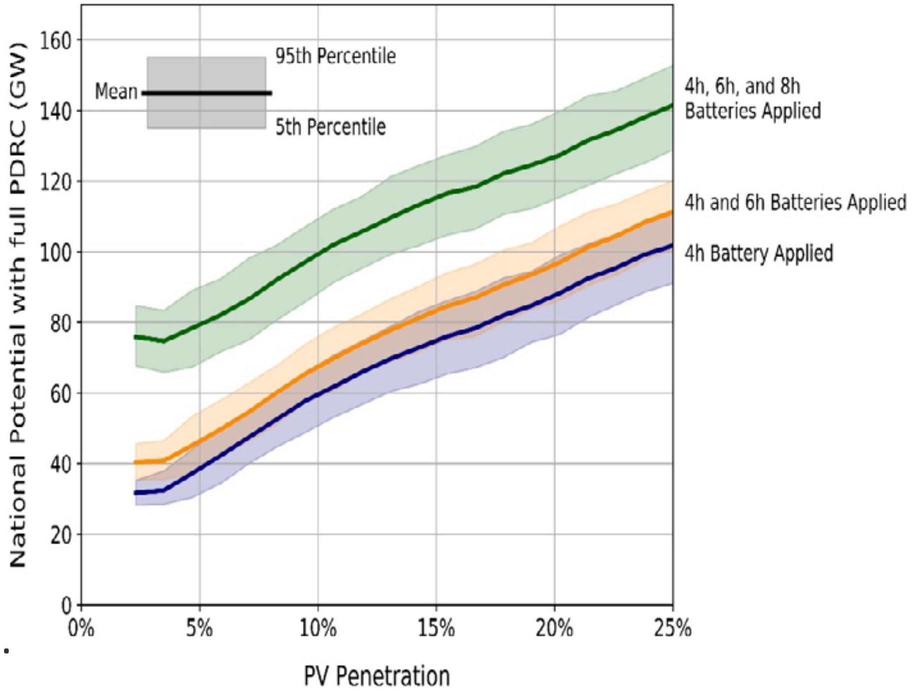
- Batteries with a four-hour duration have the potential to achieve life-cycle cost parity with combustion turbines (~28 GW nationally, or equivalent to 112 GWh)
- If batteries sustain a six-hour discharge, the capacity could be doubled (more than 200 GWh).

Peak Demand Charge Reductions

- Cost saving due to lower demand charges

Resiliency

https://www.nrel.gov/docs/fy19osti/74184.pdf



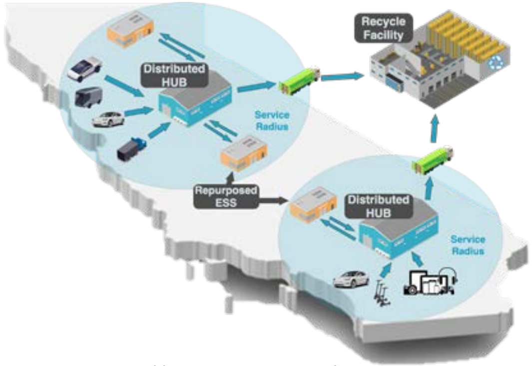
These energy storage needs could be filled with either new or second-life batteries if requirements are met.

Challenges for Substantial B2U Adoption

- Knowledge of the SOH of second-life batteries – how long they would last
- Lower price of new batteries
- Collecting and shipping second-life batteries to repurposing centers
- Cost of repurposing from facility capital cost, disassembly, testing, binning, and making new batteries (based on NREL's estimate order of $20/kWh–$40/kWh)
- Integrating and operating different second-life chemistries and sizes (from many different PEVs)
- Finding or combining applications that will provide high value (>~ $40/kWh) and profit
- Battery ownership chain (liabilities from one party to another)
- Federal and local regulations, lack of incentives and supporting policies
- The completion to recycle and recover materials for new batteries
- Quality control and customer distrust in second-life batteries.
- Investment risks

Addressing B2U Challenges – 1

- **Digital tracking** every PEV battery pack (+ modules and cells) with information on its content and history
- PEV makers to provide predetermined snapshot of history and **SOH of each battery**
- **Synergy between reuse and recycling:**
  - End-of-life PEV batteries collected and shipped (from dealers, salvage yards, etc.) using recycling infrastructure (distributed, hub and spoke, local and regional)
  - Co-locate refurbishing and recycling facilities next-door to each other
  - Utilize fast testing/screening techniques (such as ultrasounds) for separating reusable vs. recyclable end-of-life batteries.
- **Develop technologies to combine different packs types/sizes**

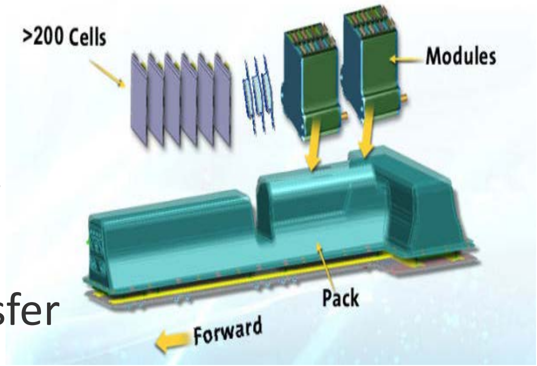


https://www.herox.com/BatteryRecyclingPrize/round/460/entry/23295

Titan Advanced Energy Solutions Ultrasound-based technology to determine SOH
www.titanaes.com

Addressing B2U Challenges – 2

- **Minimizing cost of refurbishment (to less than $15/kWh)**
  - Reduce standard battery testing and associated capital investment, labor, energy, and space need by trusting the SOH from PEV makers
  - Reduce amount of cell disassembly—keep at least to module levels.
- **Designing LIBs for recycling & repurposing**
- Developing well established local and national practices on transfer of **battery ownership and liabilities** from one party to another
- **Improving regulatory** environment and market conditions
- Providing **incentives** (local, state, and federal) and reduce risks
- **Perform demonstration and techno-economic analysis** at a large-scale project to convince potential customers that 2nd use batteries will work in their application (independent evaluation with stakeholders)
- **Evaluate alternative** business models such as ”battery-as-a-service” or ”battery-as-a-circular-economy-service.”



Summary – B2U Alleviates Supply Chain Issues

- Significant amount of energy storage needed for future grid
- Second-use of end-of-life PEV batteries are technically and environmentally viable – could support Li-Ion Supply chain
- The economic value of the B2U has been uncertain due to challenges and cost of refurbishment, regulatory requirements, investment risks
- Concepts are being developed to address economic, infrastructure, and technical challenges
- Significant number of healthy retired batteries coming, investment and collaboration efforts will make "reuse-then-recycle" reality
- Local jobs could be created with B2U businesses
- A multi-partner, multi-year demonstration and evaluation project is needed to convince major adoption by large end-users.

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Thank You

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