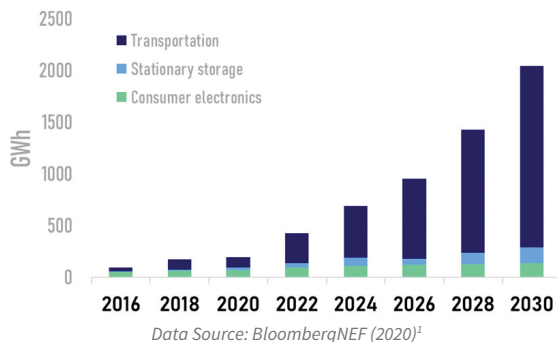




# LITHIUM ION BATTERY ENERGY STORAGE END-OF-LIFE MANAGEMENT

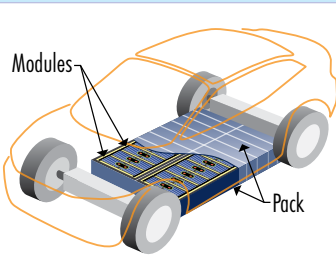
## GLOBAL DEPLOYMENT BY APPLICATION



Current volumes of spent lithium-ion batteries (LIB) are modest, but deployment is projected to scale up dramatically—most notably for electric vehicles (EV). In turn, EPRI estimates that annual global capacity reaching end of life (EoL) across all platforms and cathode chemistries will result in more than 2 million metric tons of LIB materials requiring reuse, recycling, or disposal by 2030—and roughly 10 times that amount by 2040.

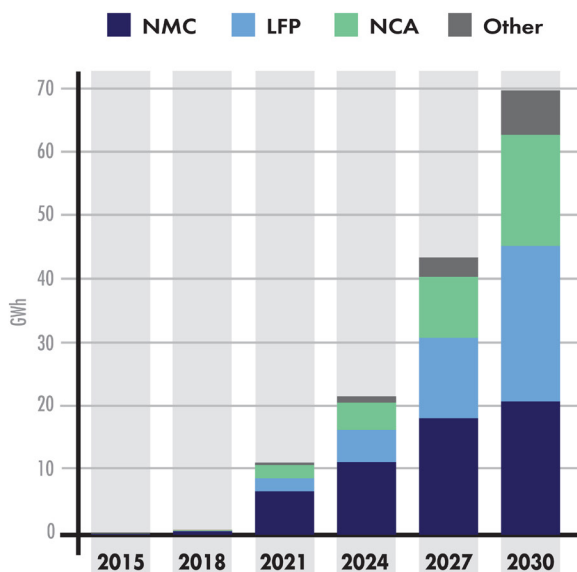
## STATIONARY STORAGE & EV PLATFORMS

EoL management for the EV and battery energy storage (BES) industries is inextricably linked due to shared reliance on large-format LIB modules comprised of pouch, prismatic, or cylindrical cells. EV battery modules are integrated within a

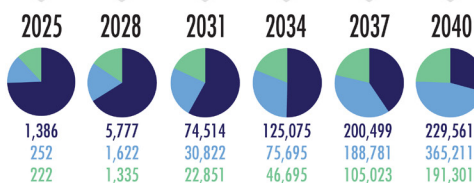


horizontally oriented pack secured to, and protected by, the vehicle chassis. BES modules, often rectangular, are vertically stacked in racks inside cabinets, containers, or buildings. Going forward, EV applications will account for a large majority of LIB materials inputs and EoL volumes, and the lithium nickel manganese cobalt oxide (NMC) chemistry is projected to remain the market leader in this segment for some time, even as other chemistries gain ground.<sup>2</sup>

## U.S. STATIONARY STORAGE DEPLOYMENT & EOL PROJECTIONS



ANNUAL U.S. DEPLOYMENT BY BATTERY CHEMISTRY



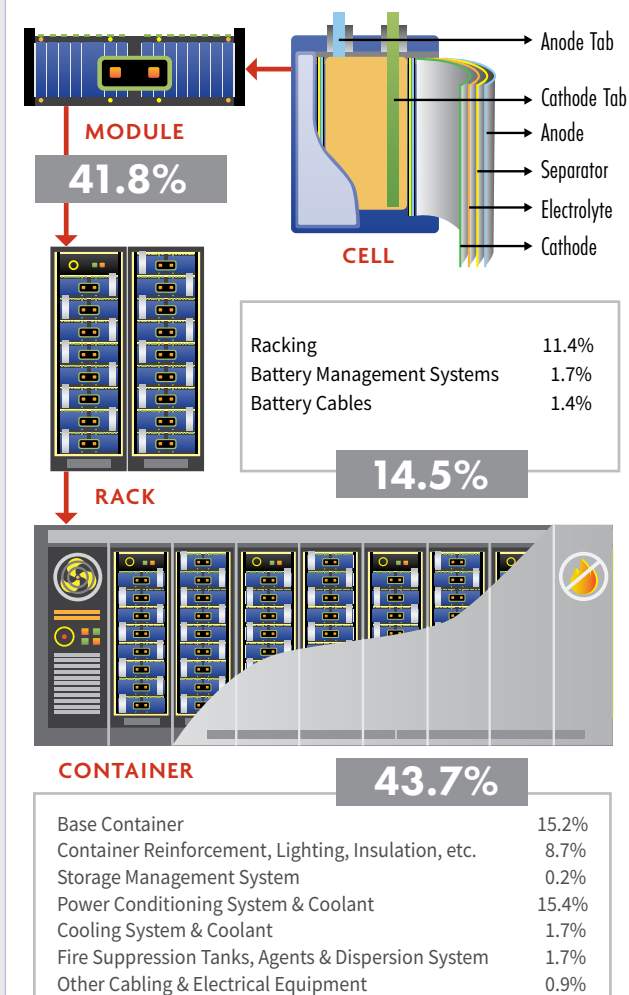
EOL VOLUME BY LEADING CHEMISTRY  
(% BY MASS; METRIC TONS)

Data Sources: WoodMackenzie (2021)<sup>3</sup>, Gupta (2020)<sup>4</sup>, EPRI (2017)<sup>5</sup>

The stationary storage market is expected to become increasingly competitive as lithium iron phosphate (LFP) and lithium nickel cobalt aluminum oxide (NCA) continue to erode NMC's current leadership position in this segment.<sup>3</sup> Divergence in preferred LIB chemistries for stationary and EV applications will alter waste stream characteristics. Assuming a 10-year battery lifetime, LFP will assume the lead in EoL stationary storage tonnage by about 2038—due both to rising market share and lower energy density.

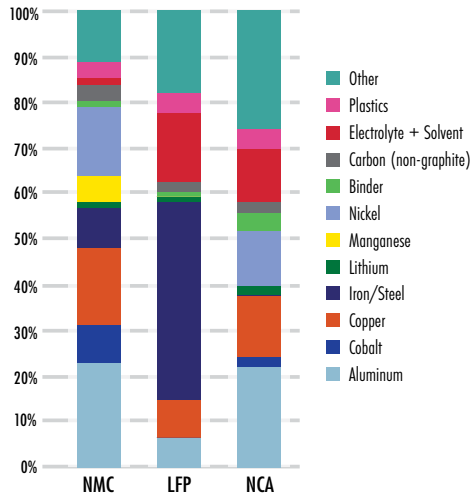
## BATTERY CONTAINER WEIGHT BREAKDOWN

Cells packaged into modules account for the largest weight fraction among BES system components, as shown below for a 1-MWh NMC system. By EPRI's estimate, a containerized 1-MWh battery can vary from about 24 to 40 metric tons, depending on cathode chemistry and cell design. For example, LFP's lower energy density, relative to NMC and NCA, translates to more cells and racks per unit of capacity.



Data Source: EPRI (2017)<sup>5</sup>

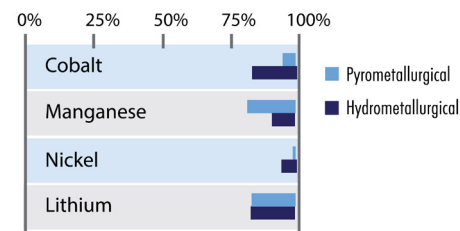
## MODULE COMPOSITION BY CHEMISTRY



Data Source: Winslow et al. (2018)<sup>6</sup>

At the module level, the composition of cathode and other components influences the ease of recycling, the value of recoverable materials, and the toxicity of residuals. NMC contains significant fractions of high-value cobalt, manganese, and nickel, but LIB manufacturers are reducing cobalt content. NCA incorporates less cobalt and nickel and no manganese, while LFP offers even lower materials value.

## MATERIALS RECOVERY EFFICIENCY

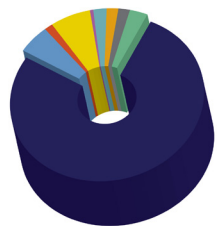


Data Source: Chen et al. (2019)<sup>7</sup>

Recycling is best practice for EoL LIB modules, but complex and changing chemistries and high costs pose challenges. Commercial and pre-commercial processing methods offer a range of recovery rates for key constituents. Novel recycling processes are being tested globally to reduce costs, improve recovery, and increase salvage values.

## SYSTEM & MODULE DECOMMISSIONING COSTS

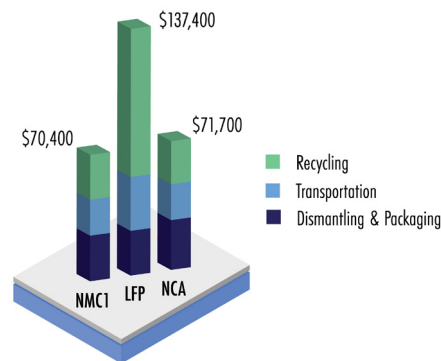
Total Net Cost: \$ 91,500



- Site Preparation & Cleanup
- Battery Modules
- Battery Racks, Controls & Cables
- Container & Modifications
- Power Conditioning Systems
- Storage Management Systems
- Cooling Systems
- Fire Suppression Systems
- Other

NET DECOMMISSIONING COST, 1MWh NMC CONTAINER

Data Source: EPRI (2017)<sup>5</sup>



MODULE DECOMMISSIONING COST, 1MWh SYSTEMS

Decommissioning cost estimates for containerized 1-MWh LIB systems indicate that modules account for about 75% of the total. Modules must be packaged and transported as hazardous materials, and they require manual disassembly then multi-step processing for materials recovery. Costs are much higher for LFP than NMC and NCA.

## R&D NEEDS

### Technology

- EoL projections by LIB chemistry at national and state/provincial scales, incorporating insight from operating experience
- Emergency decommissioning procedures
- Viability assessments of second-life opportunities for large-format modules, considering performance, cost, and safety
- Advanced recycling processes optimized for individual chemistries, including direct cathode recycling
- Advanced cell, module, and system designs optimized for reuse and recycling
- Techno-economic and life-cycle assessments evaluating the entire value chain for large-format LIB technologies
- Circular economy structures and evolution pathways for LIBs at regional/national levels

### Business & Policy

- Standardized approaches and tools for estimating gross and net decommissioning costs for battery modules and systems
- Frameworks for managing liability, insurance, and financial surety aspects of reuse or second life
- Battery module collection and handling systems and commercial recycling facilities and infrastructure
- Clarity and consistency in regulatory and policy action, including avoidance of disincentives for recycling and reuse
- Voluntary or required certifications for manufacturers, project developers, recyclers, and reuse companies
- Defined circular economy roles for utilities and other LIB end users



## ADDITIONAL EPRI RESEARCH



This fact sheet summarizes current and prior EPRI research deliverables on EoL management topics for renewable energy and BES technologies:  
[EPRI Research Activities on Renewable and Battery End-of-Life Management](#).  
 EPRI, Palo Alto, CA: 2020. 3002019572.

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Learn more about Environmental Aspects of Energy Storage: <https://www.epri.com/research/programs/109403>

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