LFP BATTERY LIFE CYCLE ANALYSIS

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INTRODUCTION

The production of electric vehicles (EVs) has become increasingly common in combatting climate change and adding diversity to the transportation industry. [1] However, as more EVs are put into commercial use, there is concern surrounding the efficiency and safety of disposing batteries that have less than 80% of their initial capacity.

By 2025, approximately 250,000 metric tons of Li-ion batteries used in EV's are predicted to hit end-of-life (EOL), and **by 2040, millions of kilos of Li-ion EV battery cells may end up in the waste stream** [2]. Direct disposal of Li-ion batteries can have dangerous impacts on human and environmental health [3]. Not recycling or re-using these Li-ion batteries could exacerbate battery materials shortages, thereby slowing or halting battery production. As such, it is critical to **explore potential uses for these batteries in the form of a second life** and how best to recover materials, notably lithium, once these batteries can no longer be used.

Figure 1: PACCAR/Kenworth K270E EV Truck

METHODS

Second Life

- Conducted literature reviews encompassing relevant parameters required for batteries suitable for second life, different second life applications, and economic and environmental impacts
- Selected top 3 second life applications
- Cycled an LFP cell approximate to ones used in PACCAR vehicles under conditions simulating the selected applications, to verify its ability to succeed in a second life.
- Applied results to a preliminary life cycle analysis of an LFP battery

Recycling

- Conducted literature reviews concerning different recycling methods and its economic and environmental impacts
- Selected best recycling method
- Recycled the cycled cell to verify that selected recycling method is viable and scalable to an industrial level

MATERIAL

Figure 2. An image of the A123 LFP cell that was both cycled and recycled.

- Battery: **A123 LFP 26650 Cell**
- Received pack of cells after use in a King-country Metro hybrid bus that had reached 80% state-of-health - 1.75 Ah of capacity.

BATTERY CYCLING

To adequately cover the possible options of both home, grid, and EV charging use cases, a "peak-shaving" cycling test was developed. Peak shaving is a way to handle unstable power use or availability, as well as lower the costs of energy by using energy stored in a supplementary battery during hours of peak energy consumption.

The peak-shaving test was developed through using grid use data scaled to a single home in the Pacific Northwest, as well as Puget Sound Energy's peak use data.

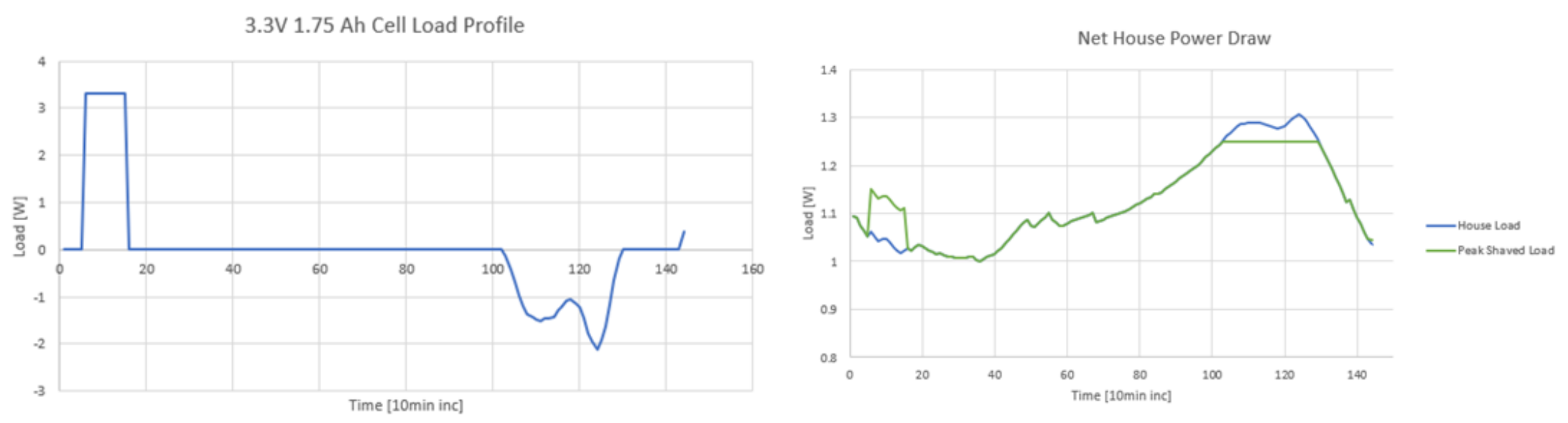

Figure 3: (left) individual cell load profile, (right) net house power draw using peak shaving.

The battery cell was cycled according to this scheme for **10 days**, with a diagnostic cycle at the end for capacity validation.

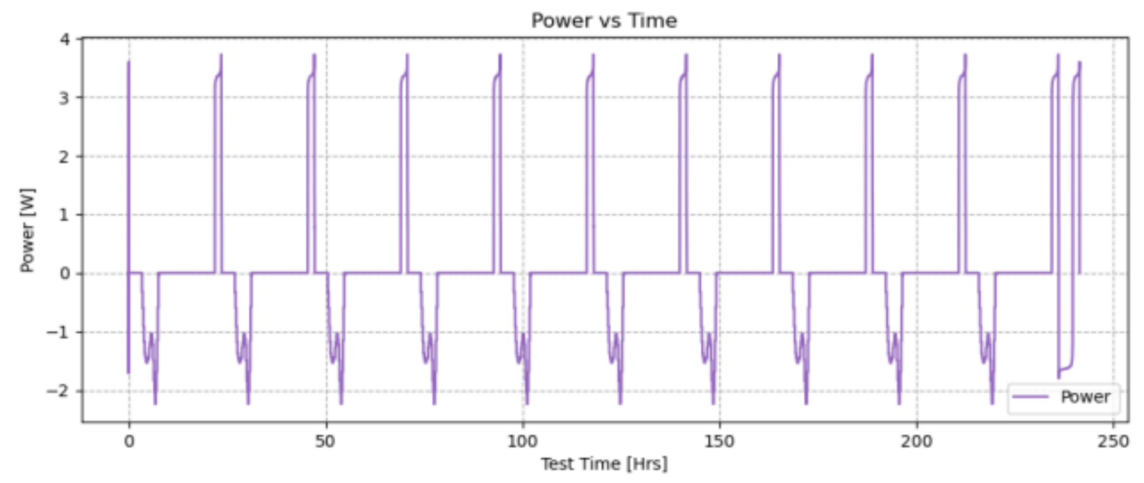

Figure 4: Chart of load experienced by cell over time under peak-shaving conditions

DIRECT CHEMICAL RECYCLING

Direct Recycling is one of three recycling methods for batteries. Compared with Hydro- and Pyro-metallurgical recycling, direct recycling has **significant upfront costs** due to mechanical disassembly. The method produces significantly **less byproducts and consumes less energy** than the hydro and pyrometallurgical recycling. Direct Recycling can yield a **higher quality** of recycling material. Considering the benefits, the U.S. EV battery recycling industry can more quickly and more sustainably introduce a circular economy for valuable materials used to make more Li-Ion batteries. As such, Direct Recycling was selected as the method for recycling validation for this project.

After being cycled, the spent LFP battery was disassembled and the LFP material was separated from the current collector by dissolving the binder using NMP. Subsequent relithiation was done based on the work of Xu et al., in which the material was immersed in a mixture of citric acid and LiOH for a period of 24 hours. X-ray diffraction was performed before and after recycling to determine the effect of the relithiation process.

LIFE CYCLE ANALYSIS

A simple life cycle analysis of an LFP battery was performed, from literature and the test results, with the resulting decision tree diagram to represent multiple pathways one of PACCAR's EV batteries may take after their initial use.

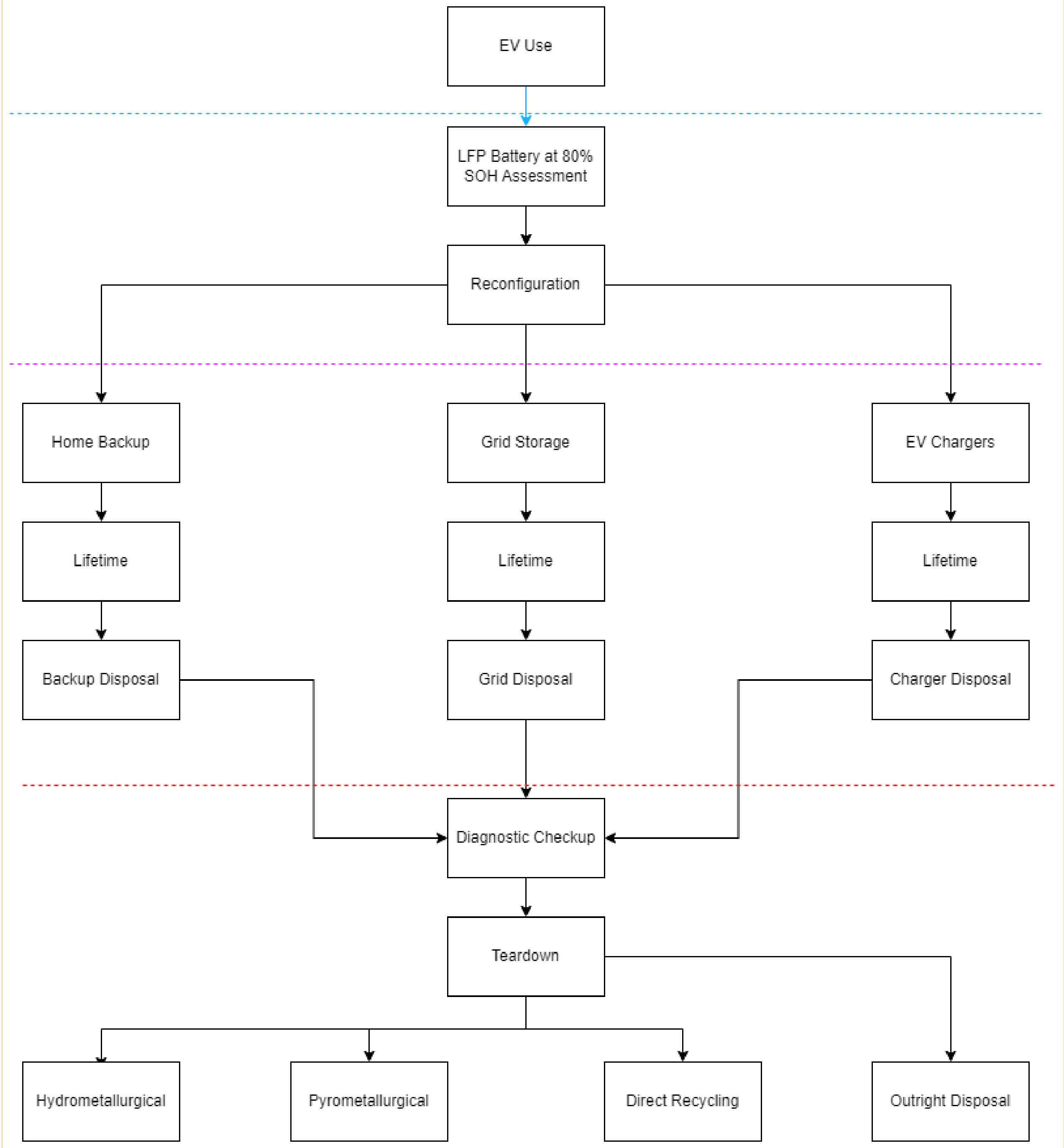

Figure 4: Decision tree visualizing EV battery life cycle options

Three Major 2nd Life Applications

- **Grid-storage**
  - Use of multiple LFP batteries to store energy for later use
  - Likely **most viable** solution, batteries may be used in conjunction with other electrical supplying methods
- **Home Back-up**
  - Use of single LFP battery to store energy for later use
  - Second most viable solution, batteries must be reconfigured, **costing more** than grid storage
- **EV Charging**
  - Use of single or multiple batteries to act as a static energy supply for other electric vehicles
  - Least viable solution of the three, most **unpredictable** in terms of load imposed

CONCLUSIONS & RECOMMENDATIONS

Viability of 2nd Life

- Cell successfully performed the peak-shaving power curve for 10 days, showing no signs of decay in energy retention.
- Sudden differential capacity peak decrease suggests possible issues were the cycling to continue.

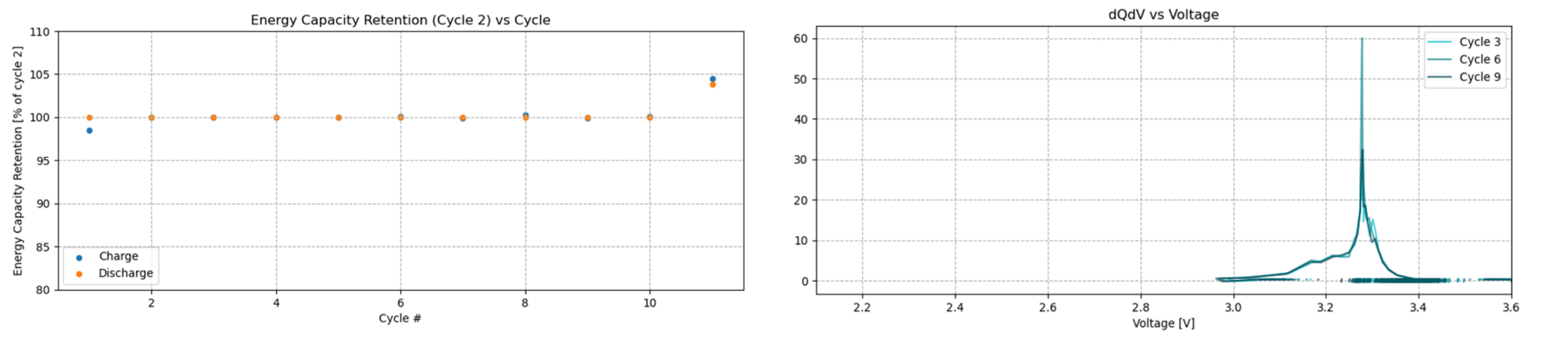

Figure 5: (left) Energy capacity retention, (right) differential capacity of cycles 3, 6, and 9

- From the test of the single cell, scalable peak-shaving is possible for second-life LFP cells, enabling the possibility of both grid storage and residential storage.
- Further cycling alongside FRA tests are recommended for further review of this possibility.

Viability of Direct Recycling

- Disassembly and procedure were performed successfully with limited materials and experience.
- Non-relithiation XRD demonstrates decayed LFP peaks [4], relithiated XRD pending at time of writing.

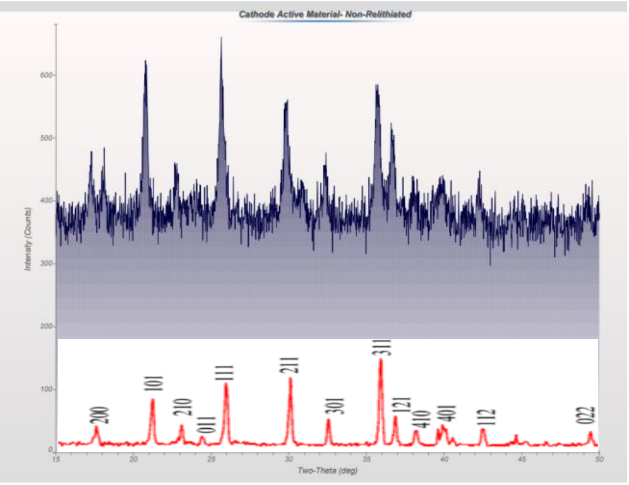

Figure 6: Cathode Active Material XRD data – Non-relithiated, with new sample literature comparison overlaid [4]

Best 2nd Life LFP Uses

Economic Perspective

- Grid-storage > Home Back-up > EV Charging
- **Grid storage requires the least amount of physical reconfiguration** to be used, costing ~$128.47 for removal of the battery from an electric vehicle [5]
- Home Back-up requires some configuration to best power a home, leading to a cost of ~ $677.50 for both removal of the battery, disassembly to modules, and reassembly into a smaller battery [5]
- **EV charging is often unpredictable** in the kind and duration of loads it is subjected to; it may be suitable for a particular battery given its cycling conditions experienced in its first life

Environmental Perspective

- Reduction of production and waste has the largest environmental impact
- Reusing is more sustainable than directly recycling or waste
- EV Batteries used down to 80% but could potentially be used for **another 2,000+ cycles** until capacity falls to 60% [6]

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