ELECTRIC VEHICLES: USED VEHICLES, BATTERY SECOND-LIFE, AND LIFE CYCLE ANALYSIS

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Topics for Today’s Webinar

- Plug-in electric vehicles (PEV) in the used vehicle market
  - PEV includes battery electric and plug-in hybrid electric vehicles (BEV, PHEV, respectively)

- Landscape of lithium ion battery (LIB) second life

- LIB electric vehicle environmental effects

- LIB recycling and the ReCell Center at Argonne
USED PLUG-IN ELECTRIC VEHICLES
USED PEV: RESEARCH QUESTIONS

- As LIB vehicles enter the used vehicle market:
  - Can used plug-in electric vehicles (PEVs) be a platform to improve low-income household mobility?
  - What are the barriers to electric mobility in low-income households?
  - What programs/incentives can increase adoption of used PEVs?
MOTIVATION

Zero-vehicle households

- Low-income households have the highest percentage of zero-vehicle households

- Reliable transportation is crucial for access to services and amenities

- Operation and Maintenance costs of PEV are lower than ICEV: – $485 vs $1,117 annually\(^1\)


Tomer, Adie. Transit access and zero-vehicle households. Metropolitan Policy Program at Brookings, 2011
PRIMARY BARRIERS TO PEV ADOPTION

Top Barriers to purchasing an electric vehicle

- Running out of power
- Low availability of charging stations
- Initial Vehicle Purchase Cost
- Cost of service and repair
- Limited Models
- Limited Performance Capability
- Risk of overwhelming the electric grid

PRIMARY BARRIERS TO PEV ADOPTION

“Running out of power” / Range anxiety

- Tesla Models S, X and 3, 2019 Chevy Bolt: > 200 miles
- 2019 Nissan LEAF, 2019 VW e-Golf: >100 miles
- 2013 Nissan LEAF: 75 miles
- Used 2013 Nissan LEAF: <75 miles*

* If prior usage results in significant battery degradation

- Vehicle ranges have increased, but used BEV will have some range reduction
PRIMARY BARRIERS TO PEV ADOPTION

“Low availability of charging stations”

- **Private**
  - Levels 1 & 2 charging found mainly in non-apartments
  - Low-income households mainly in MUDs

- **Public**

<table>
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<tr>
<th>State</th>
<th>Public charging outlets (#)</th>
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<tr>
<td>California</td>
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<td>New York</td>
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Rebates/Incentives for used cars

- Federal tax credits and most state-level incentives are for new PEVs only
- Oregon offers $2,500 rebates to low and medium-income households for purchase or lease of used BEVs

https://cleanvehiclerebate.org/eng/rebate-statistics
USED PEV: FINDINGS

- PEVs, generally, have higher adoption in higher-income households

- Used PEVs could lower both ownership and operating costs of transportation for lower-income households
  – Barriers tend to be the same as for new PEVs, but home charging opportunity may be lower for lower-income households, increasing need for public charging

- Few programs currently exist that encourage used PEV adoption within lower-income households
SECOND-LIFE OPPORTUNITIES OF LIB
BACKGROUND

- Vehicle LIB are expensive and likely to have significant storage capacity remaining when they no longer meet vehicle expectations

- Remaining capacity could provide a financial opportunity to both vehicle owners (value recovery) and battery second-life users (grid operators, businesses, hospitals, etc.)
WHAT IS BATTERY SECOND-LIFE?

- **Second-life** is the use of a LIB in an application that occurs after its initial use that is a **different LIB application** than the original for which it was used.

- **Refurbished** or **Remanufactured** batteries are LIB that have come out of service, been **evaluated** and **repaired** if needed, graded as meeting application specifications, and made available to the **original LIB application**.
WHAT ARE THE POTENTIAL SECOND-LIFE APPLICATIONS?

- Residential energy storage service
  - Solar, backup, off-grid, etc.
- Utility energy storage service
  - Supply side for frequency regulation, peak shaving, etc.
- Telecom
  - Backup power support
- EV charging
  - Provide charging points for EVs
- Other EV
  - Low power applications (golf cart sized vehicles)
- Pb-Acid replacement
  - Viable in place of lead acid batteries

Hans Eric Melin, Circular Energy Storage Research and Consulting

https://www.greentechmedia.com/articles/read/bmw-is-turning-used-i3-batteries-into-home-energy-storage-units#gs.0zS=4
COLLECTION APPROACHES

How are OEMs thinking about collection (if they are at all)?

- The 4R mantra
  - Reuse, resell, refabricate, recycle (Nissan)
  - Repair, remanufacturing, refurbishing and repurposing (SNT)

- US OEM mostly let batteries to go to salvagers to allow them to leverage expertise for second-life market

- Foreign OEMS seem to partner with a group to define the second-life
  - May relate to take-back laws in other countries

https://www.nissan-global.com/EN/ZEROEMISSION/APPROACH/COMPREHENSIVE/4RBUSINESS/
TRYING TO UNDERSTAND WORLDWIDE INDUSTRY RESPONSE TO 2ND LIFE USES

Know what’s on the market to know what will be available

- Monthly PEV sales data combined with vehicle attributes allows insight into available second-life market

Source: David Gohlke (ANL) compilation of numerous PEV data sets
**CHALLENGES TO SECOND-LIFE MARKET**

- **Transportation challenges:**
  - LIB classified as a class 9 hazardous material

- **The battery management system (BMS) issues:**
  - BMS is the brain of the LIB, it monitors and regulates LIB for safety in their designed application
  - BMS is application specific

- **Battery module variability:**
  - Battery modules vary in form factor, dimensions, chemistry, etc.
  - Mixing modules adds complexity

- **Refurbishment applications may limit second-life application**
  - LIB modules may degrade at different rates within a pack
  - Some used modules may still meet OEM specifications
  - LIB are currently most valuable within original application
LIFE CYCLE ANALYSIS OF LIB
LIFECYCLE ANALYSIS EVALUATES PROCESS IMPACTS

of a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling, and final disposal if any.
COBALT SUPPLY COULD BE A CONSTRAINT

- Co is a key element in the cathode
  - Battery usage being reduced
- Half of the world’s Co is in Congo
  - Political issues
  - Human rights issues
- Co price is volatile
- Current recycling efforts focus on Co

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<th>Element</th>
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<th>USGS Reserves (1000 tons)</th>
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<td>If all NMC is hi-Co (111)</td>
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<tr>
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Lithium

Cobalt

Nickel
LI-ION BATTERY CONTRIBUTION TO LIFE-CYCLE GHG IS SMALL BUT SIGNIFICANT FOR SO$_x$ EMISSIONS

**Life Cycle Energy Consumption**

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<th>NMC111</th>
<th>NCA</th>
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<td>BEV300 (US Grid)</td>
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<th>Total Energy (MJ/km)</th>
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**Life Cycle SO$_x$ Emissions**

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<th>SO$_x$ Emissions (g SO$_x$/km)</th>
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- **Vehicle Cycle: Battery**
- **Vehicle Cycle: Car Less Battery**
- **Fuel Cycle: Well-to-Pump**
- **Fuel Cycle: Pump-to-Wheels**
SULFUR EMISSIONS CAUSE ENVIRONMENTAL DAMAGE

Source: NASA poster NW 2011-10-093-GSFC
Second Use Further Delays Material Return

- Discarded automotive LIB may retain 80% capacity
- Suitable for utility and short range application
- Impacts and cost per use are reduced
- Several companies refurbish and resell used BEV/HEV batteries
- Extensive and expensive texting needed for high reliability
- LIB eventually unsuitable for reuse and can then be recycled
  - Reuse will delay material return
  - Reuse could degrade material quality
BATTERIES MUST BE COLLECTED & TRANSPORTED

Who is responsible?

- Consumer electronics batteries are not collected efficiently
- Pb-acid SLI batteries are larger and returned when replaced
  - Backhaul uses same truck as delivery
  - Almost 100% come back for recycling
- Electric vehicle packs are large and potentially valuable
- Dealers and junk yards will collect for reuse and recycling
- Packs need to be discharged for safe transport
- Transport may be regulated and expensive
SORTING AND DISASSEMBLY MAY BE NEEDED

- There is a variety of:
  - Pack sizes and shapes
  - Fastening mechanisms
  - Cell sizes and shapes
  - Material compositions

- That makes robotic disassembly impractical
- SAE Recycling Committee has recommended labels
- Standardization and design for recycling could reduce EOL costs
ARGONNE’S NEW RECYCLING MODEL

RECYCLING MODEL

BATTERY COMPONENTS & VIRGIN FEEDSTOCKS

BATTERY MANUFACTURING

COLLECTION, PRETREATMENT

MATERIAL CONVERSION

RECYCLE PROCESS

CATHODE PRODUCTION

BATTERY USE

Direct cathode recycling

Feedstock recovery

Recycled feedstock

Metal salt recovery

COST, EMISSIONS, ENERGY, THROUGHPUT, WATER CONSUMPTION, COMMODITY RECOVERY, REVENUE, WASTE TO ENERGY, ...

Contact: J. Spangenburger
LI-ION RECYCLING PROCESSES DISPLACE MATERIALS AT DIFFERENT PRODUCTION STAGES

The more process steps that can be avoided, the more energy is saved.
CATHODE VIABILITY IS KEY TO ECONOMICS FOR CATHODES WITH LOW ELEMENTAL VALUES

Cathode materials are valuable, even if constituent elements aren’t

![Graph showing estimated cathode cost vs. constituent cost for different cathode types: LCO, NMC, NCA, LMO, LFP. The graph compares element value and cathode cost for each type.](image-url)
SUMMARY

- Used PEV can both extend the life of LIB and improve mobility for low-income households
- 2nd life applications can (further) extend the life of LIB, providing increased value to users
- LIB provide opportunities for reducing vehicle emissions
- LIB and their materials must be managed thoughtfully to ensure that they do not have unintended consequences
- Recycling is still in its nascent stages for LIB, but has the potential to drastically improve environmental performance
THANKS!
QUESTIONS?

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https://cleancities.energy.gov/webinars#26476
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