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

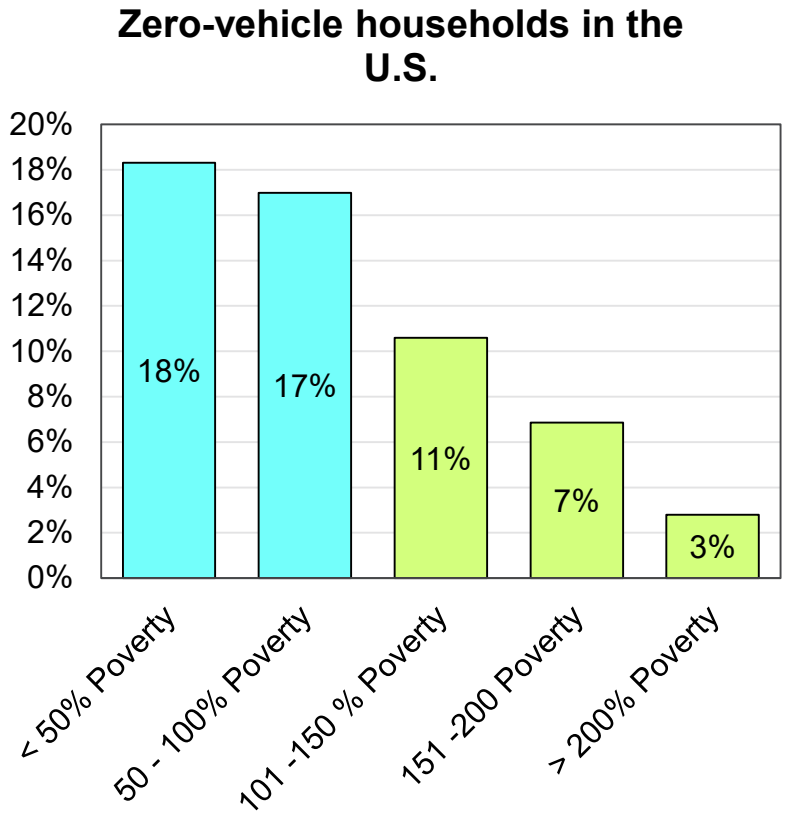
USED PEV: RESEARCH QUESTIONS

- 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

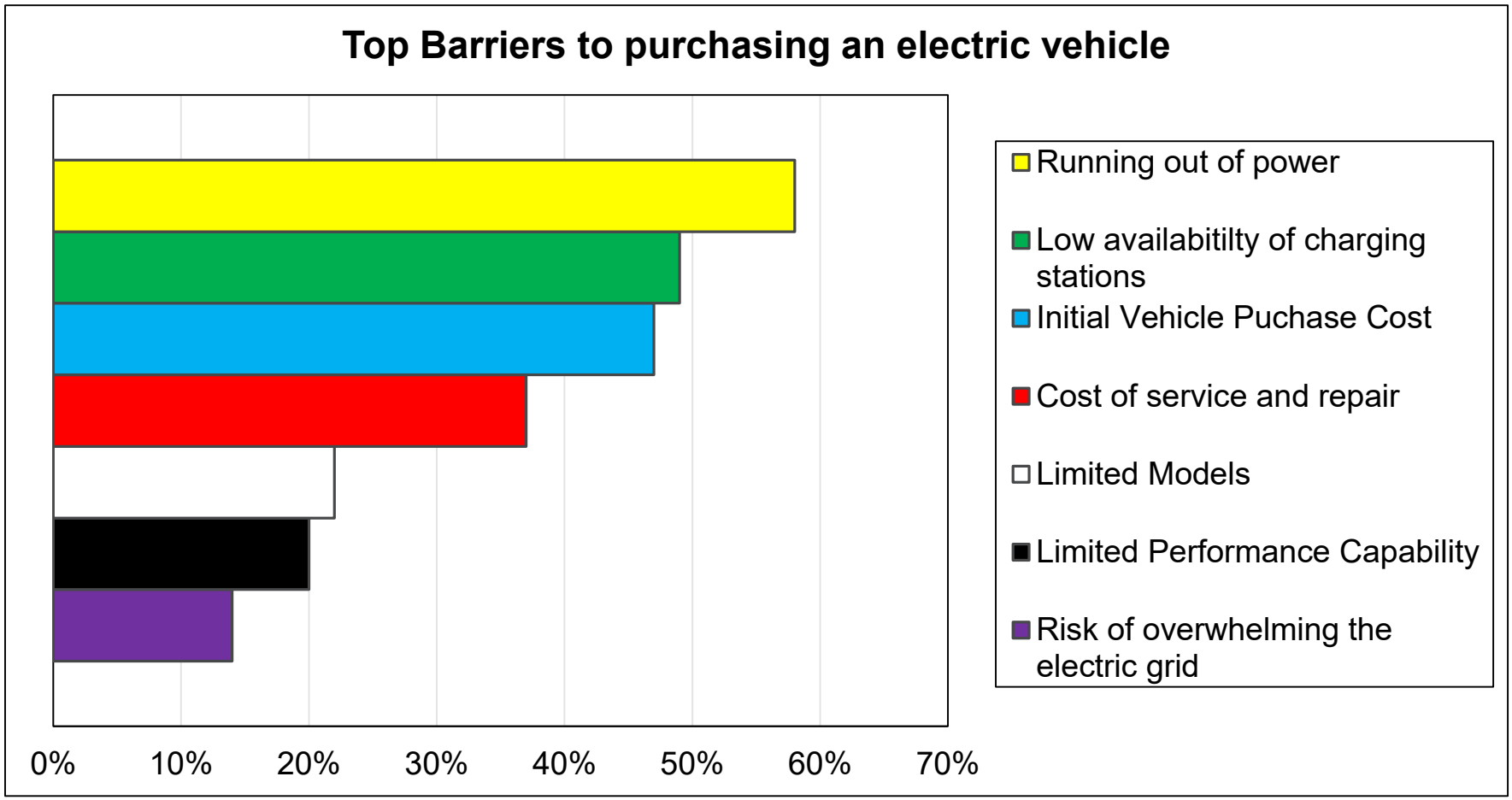
- Low-income households have the highest percentage of zero-vehicle households
- Reliable transportation is crucial for access to services and amenities
- Operation and Maintenance costs of PEV are lower than ICEV:
  - $485 vs $1,117annually[1]



Tomer, Adie. *Transit access and zero-vehicle households*. Metropolitan Policy Program at Brookings, 2011

1. Sivak, Michael, and Brandon Schoettle. "Relative Costs of Driving Electric and Gasoline Vehicles in the Individual US States." *University of Michigan, Report No. SWT-2018-1.*

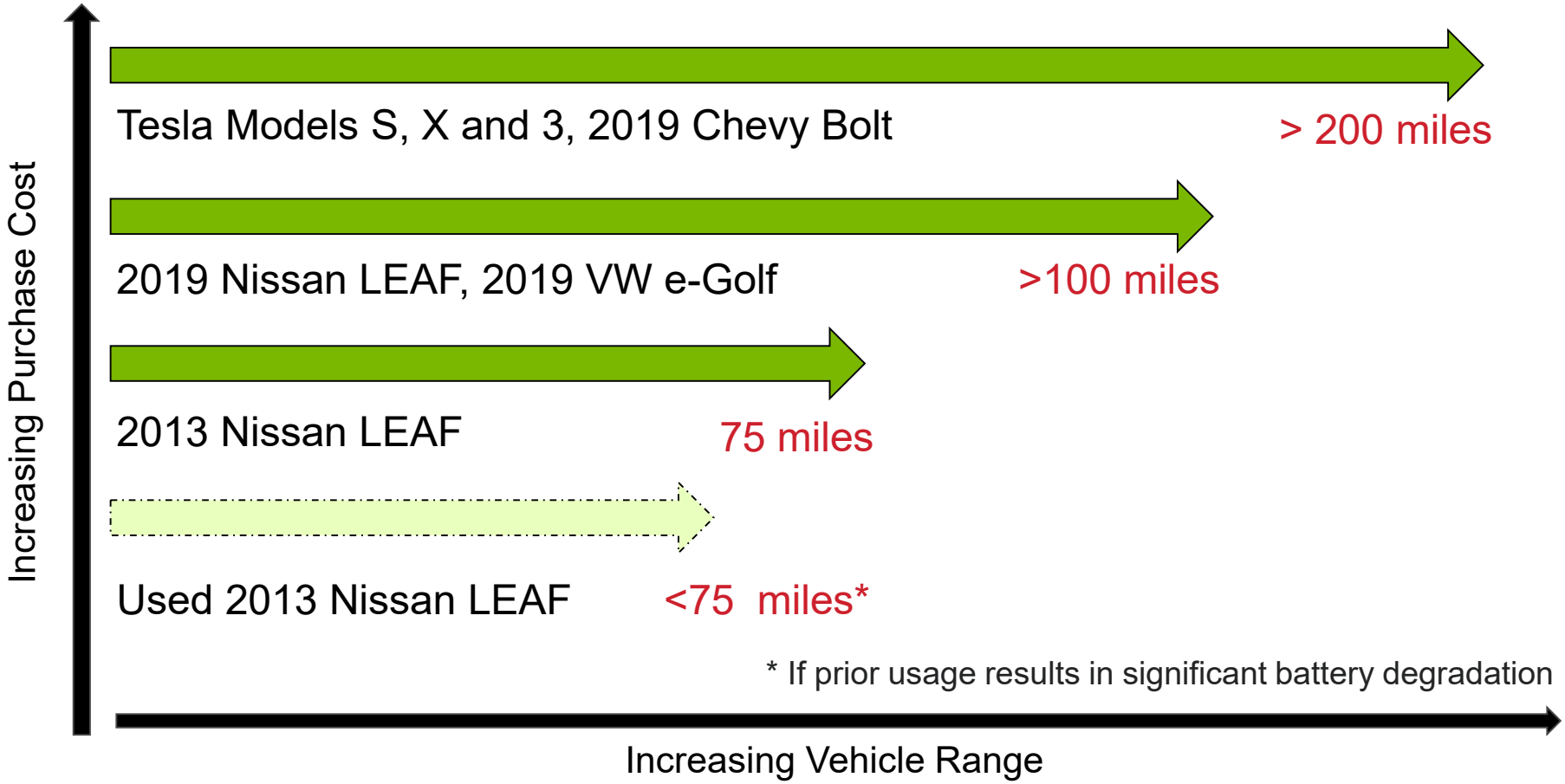
PRIMARY BARRIERS TO PEV ADOPTION



https://evadoption.com/more-charging-stations-biggest-factor-to-increase-ev-purchases-volvo-car-usa-the-harris-poll/.

PRIMARY BARRIERS TO PEV ADOPTION

"Running out of power" / Range anxiety



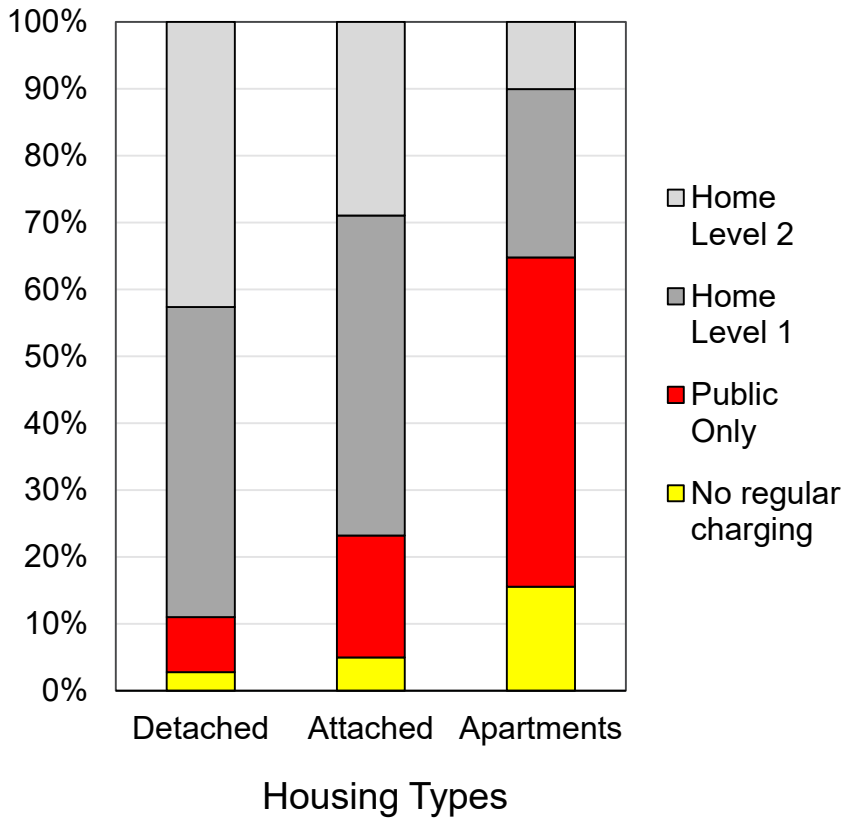
- Vehicle ranges have increased, but used BEV will have some range reduction

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

State	Public charging outlets (#)
California	21,604
New York	3,552
Florida	3,321
Texas	3,284
Washington	2,539
Colorado	2,095



Nicholas, Michael, Dale Hall, and Nic Lutsey. "Quantifying the electric vehicle charging infrastructure gap across US Markets." The International Council on Clean Transportation (2019): 4-14

PROGRAMS TO ASSIST USED PEV ADOPTION

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.ol2bS=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/

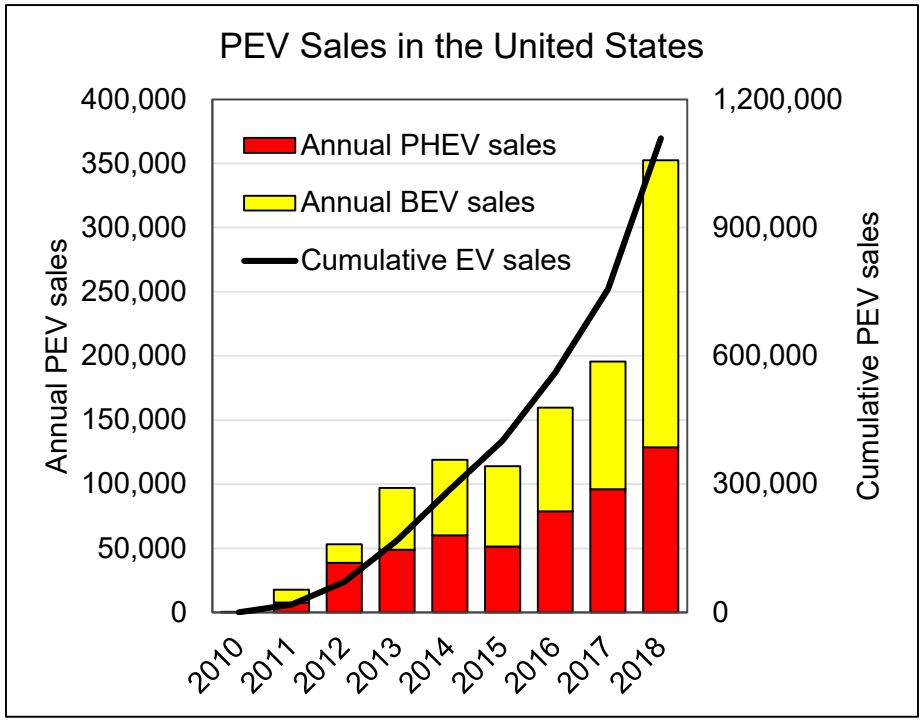
TRYING TO UNDERSTAND WORLDWIDE INDUSTRY RESPONSE TO 2ND LIFE USES

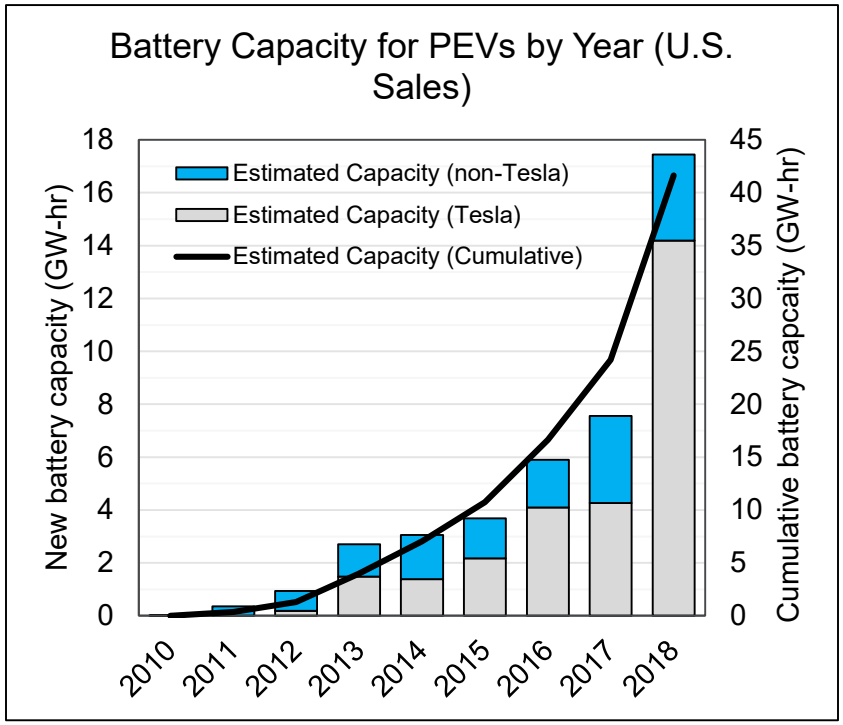
https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire

U.S. QUANTITY OF PEV BATTERIES

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

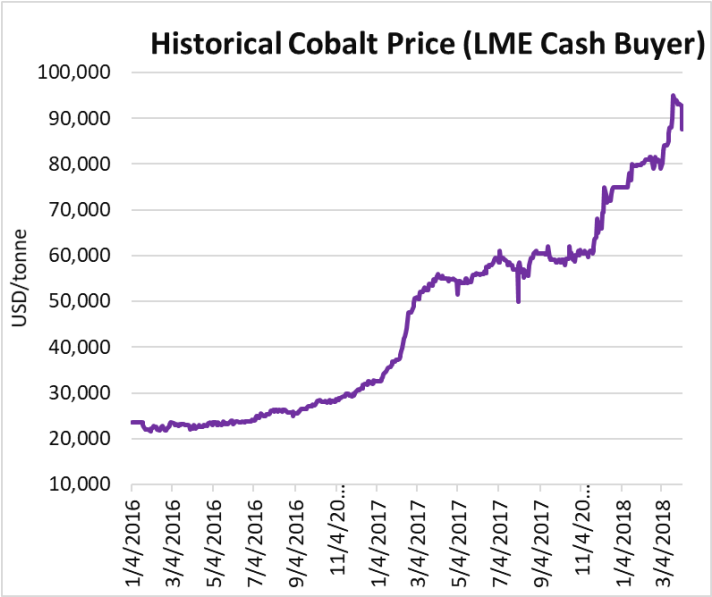
LIFECYCLE ANALYSIS EVALUATES PROCESS IMPACTS

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

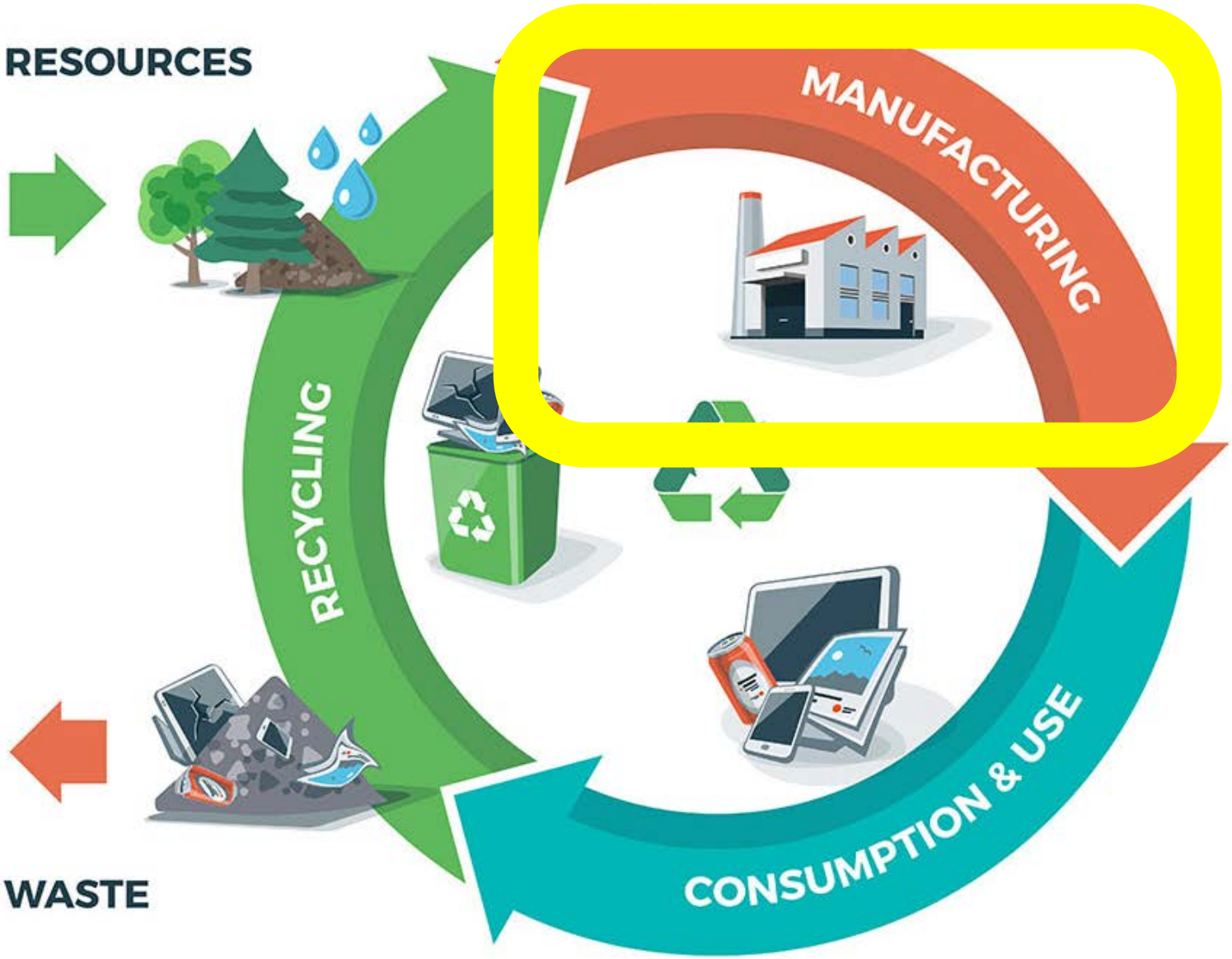

RESOURCES
MANUFACTURING
CONSUMPTION & USE
WASTE

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



Element	Projected Demand to 2025 (1000 tons)		USGS Reserves (1000 tons)
	If all NMC is low-Co (811)	If all NMC is hi-Co (111)	
Lithium	230	230	14,000
Cobalt	790	910	7,000
Nickel	580	340	78,000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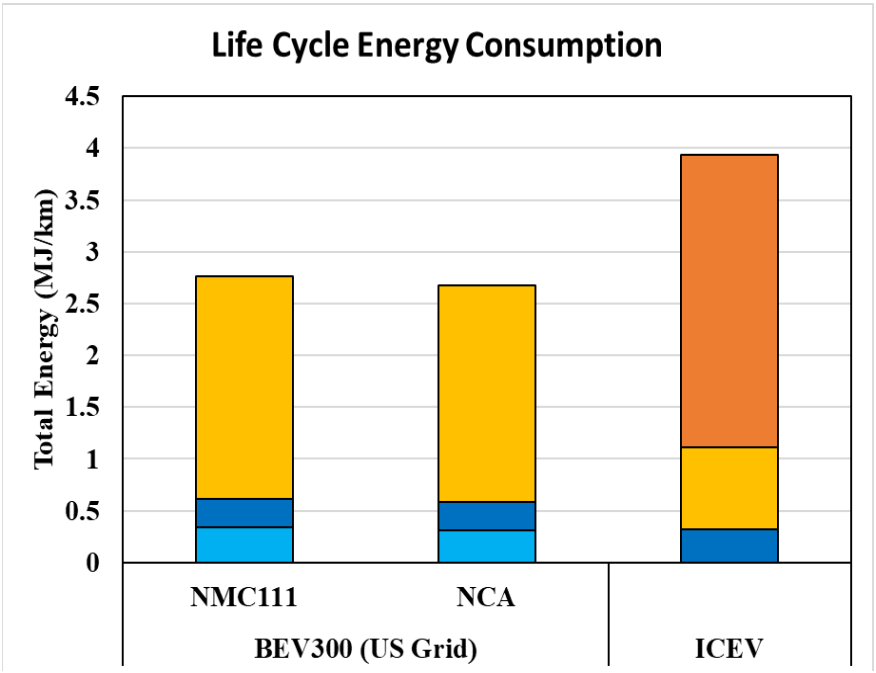
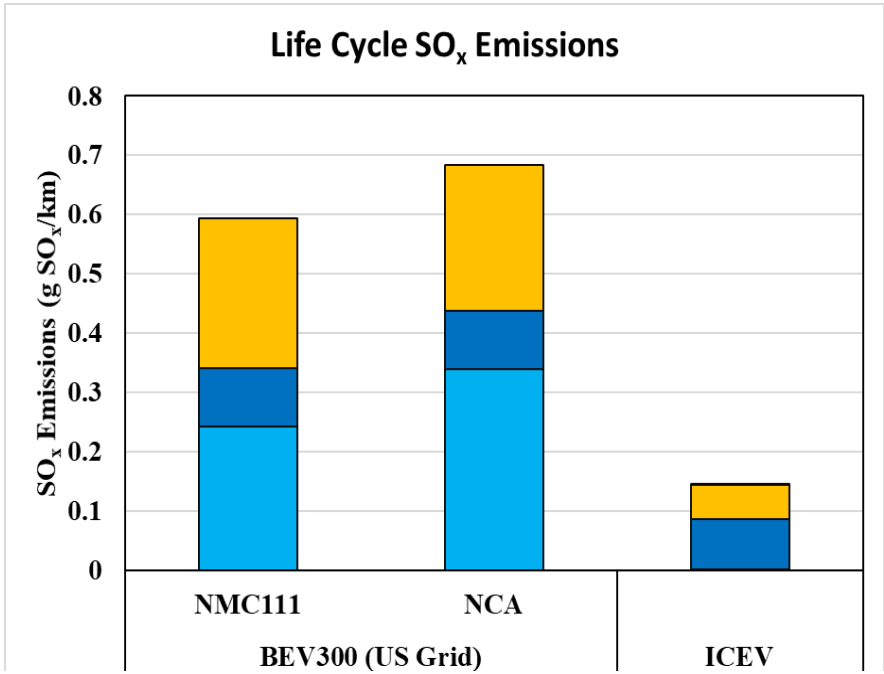
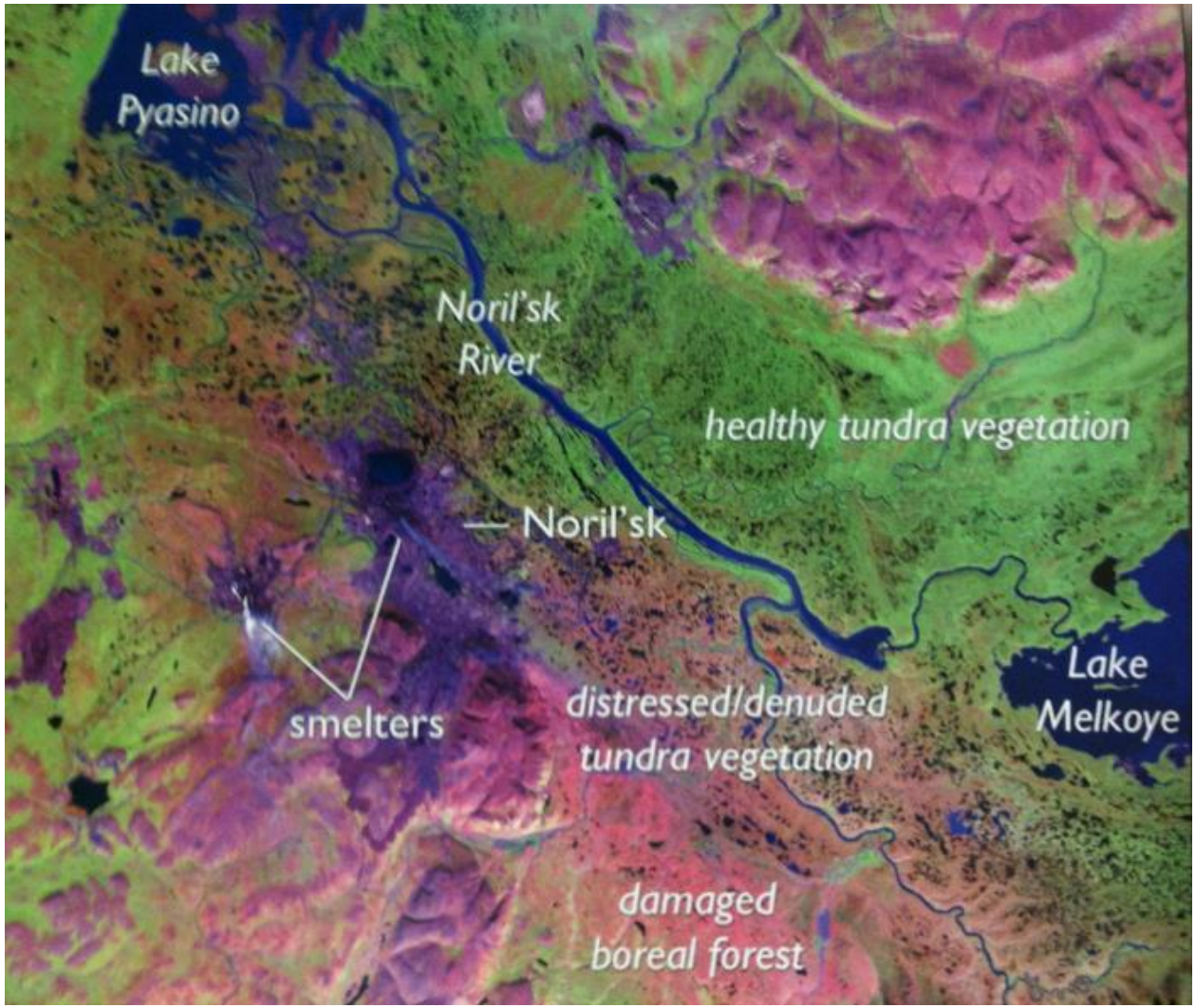
LI-ION BATTERY CONTRIBUTION TO LIFE-CYCLE GHG IS SMALL BUT SIGNIFICANT FOR SO_X EMISSIONS



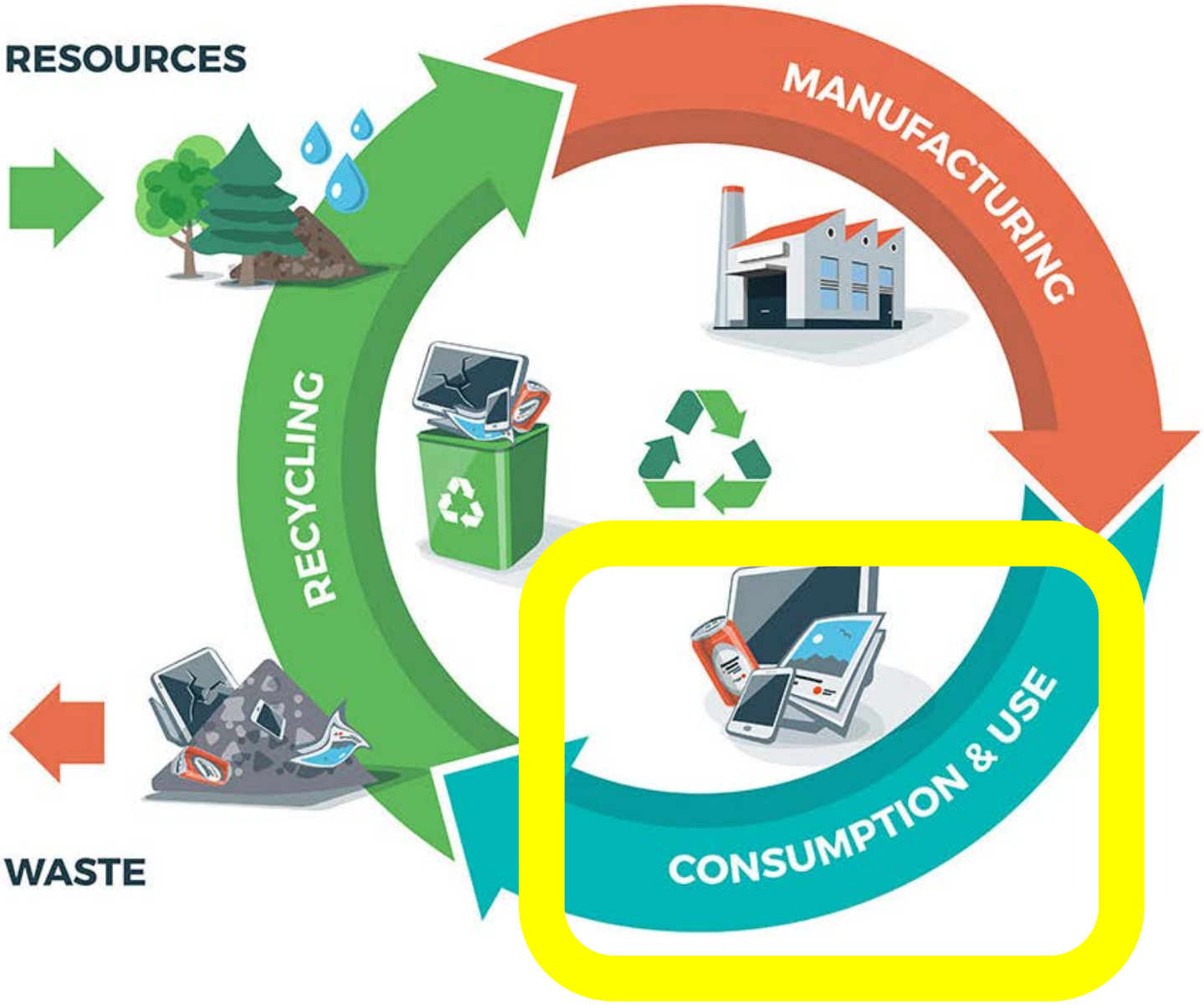


Vehicle Cycle: Battery
Vehicle Cycle: Car Less Battery
Fuel Cycle: Well-to-Pump
Fuel Cycle: Pump-to-Wheels

SULFUR EMISSIONS CAUSE ENVIRONMENTAL DAMAGE



Source: NASA poster NW 2011-10-093-GSFC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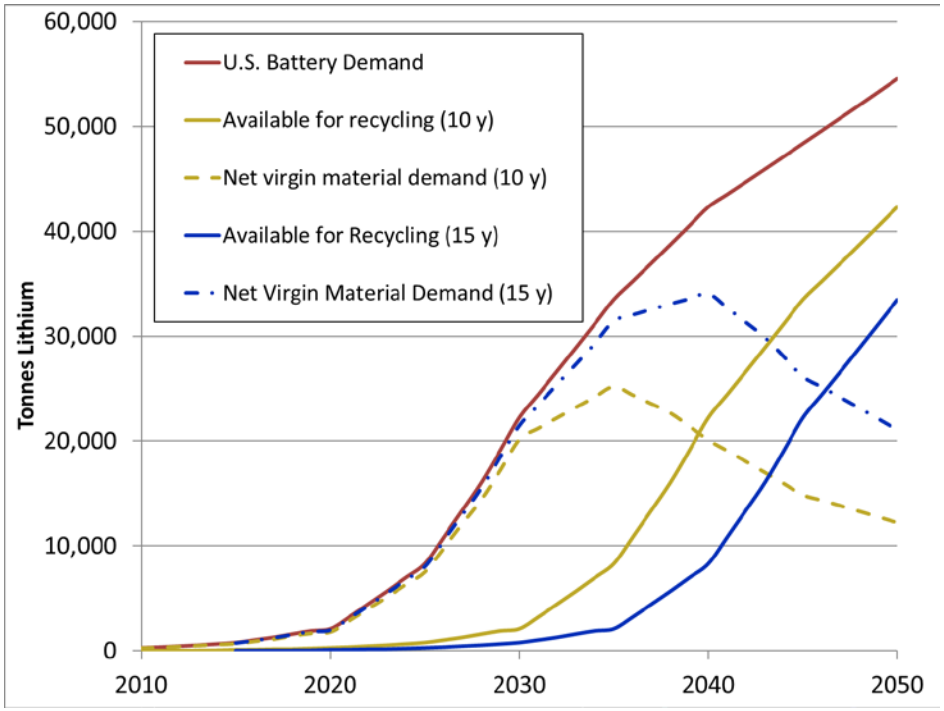
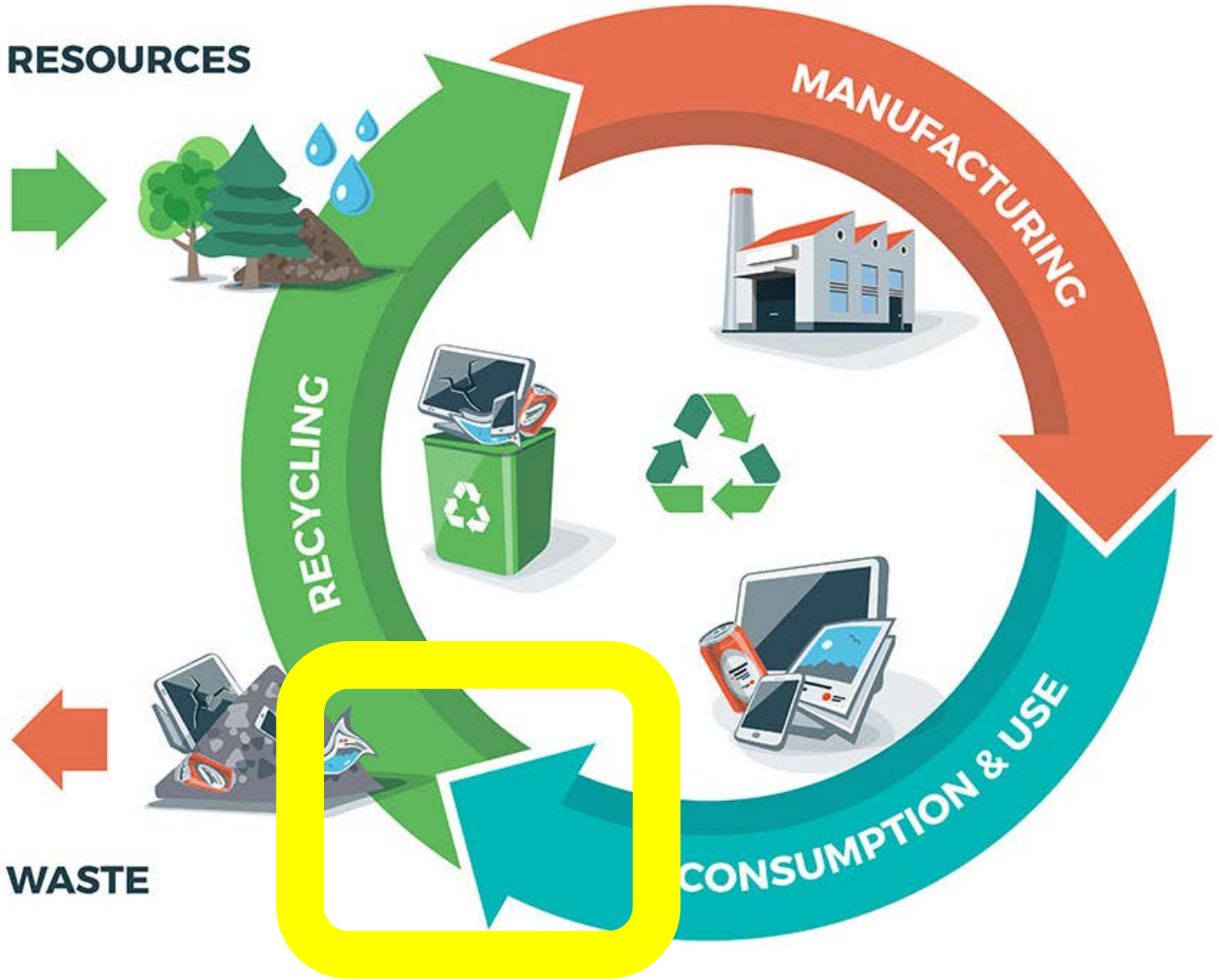
SECOND USE FURTHER DELAYS MATERIAL RETURN

- 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

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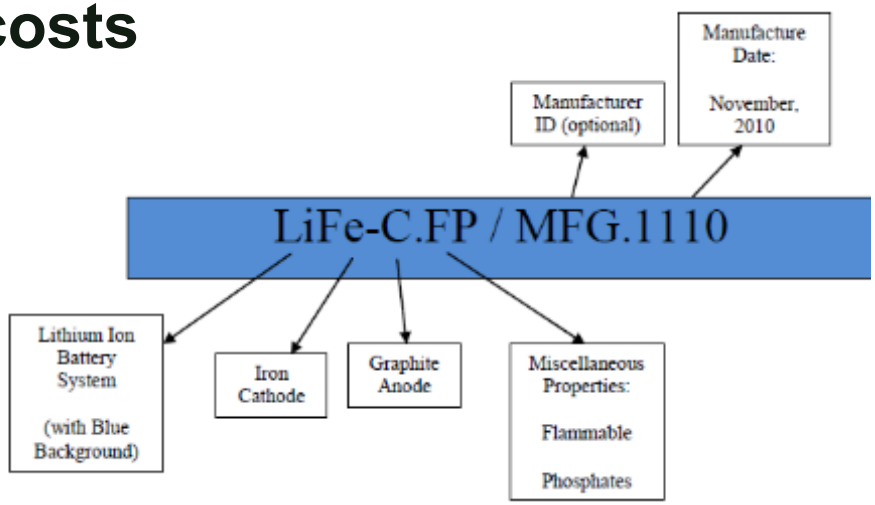
BATTERIES MUST BE COLLECTED & TRANSPORTED

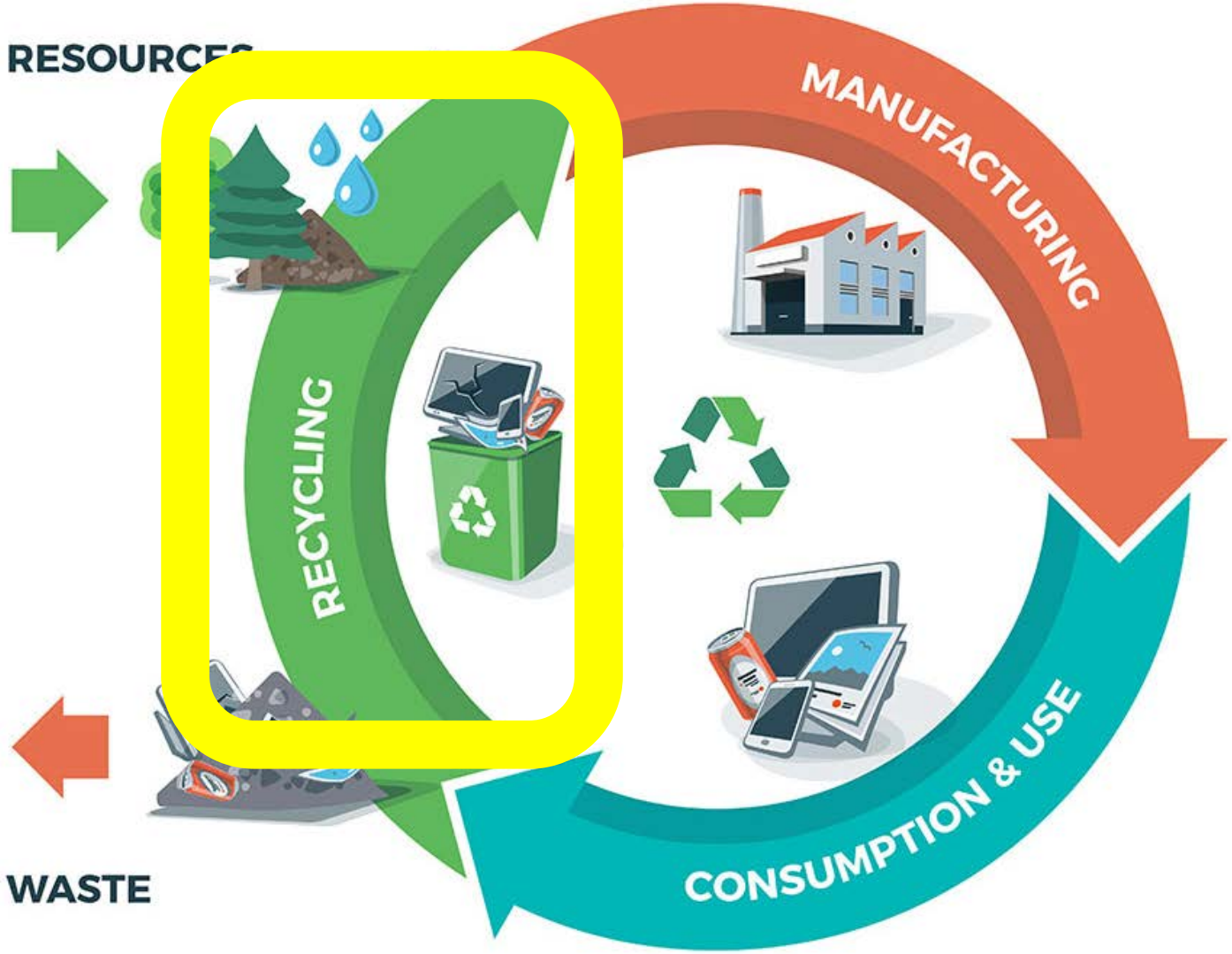
Who is responsible?

- 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**

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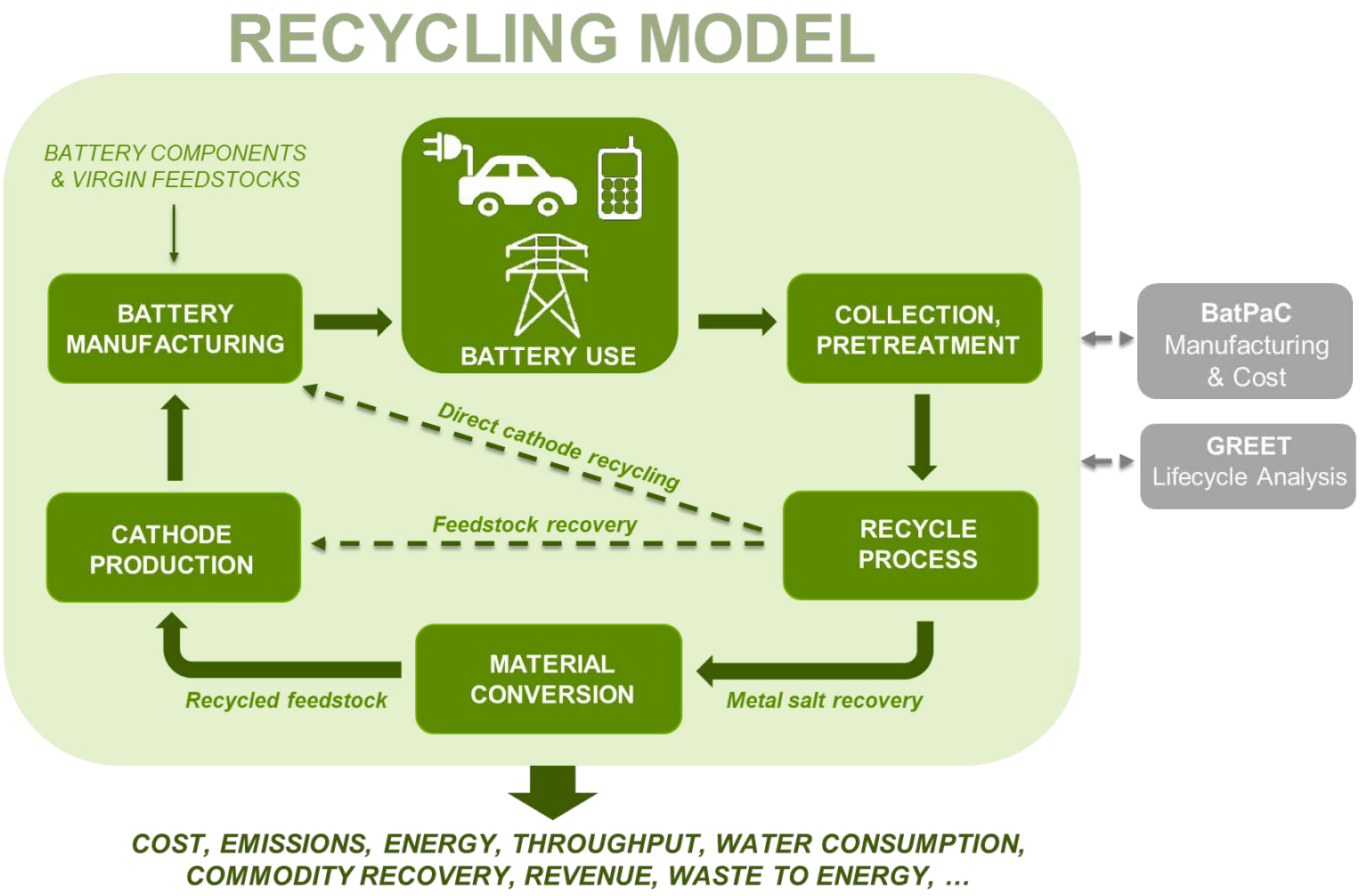
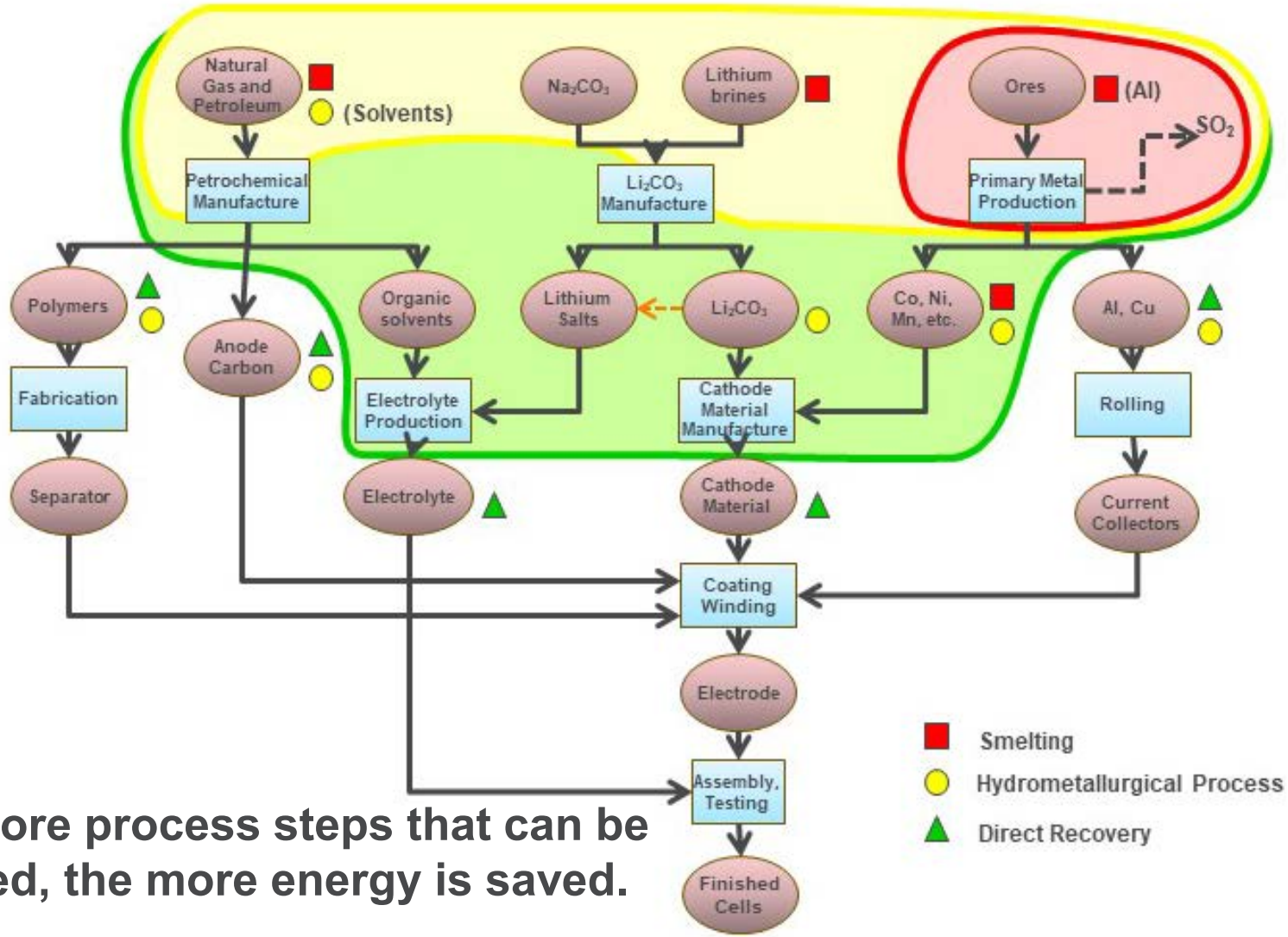
ARGONNE'S NEW RECYCLING MODEL



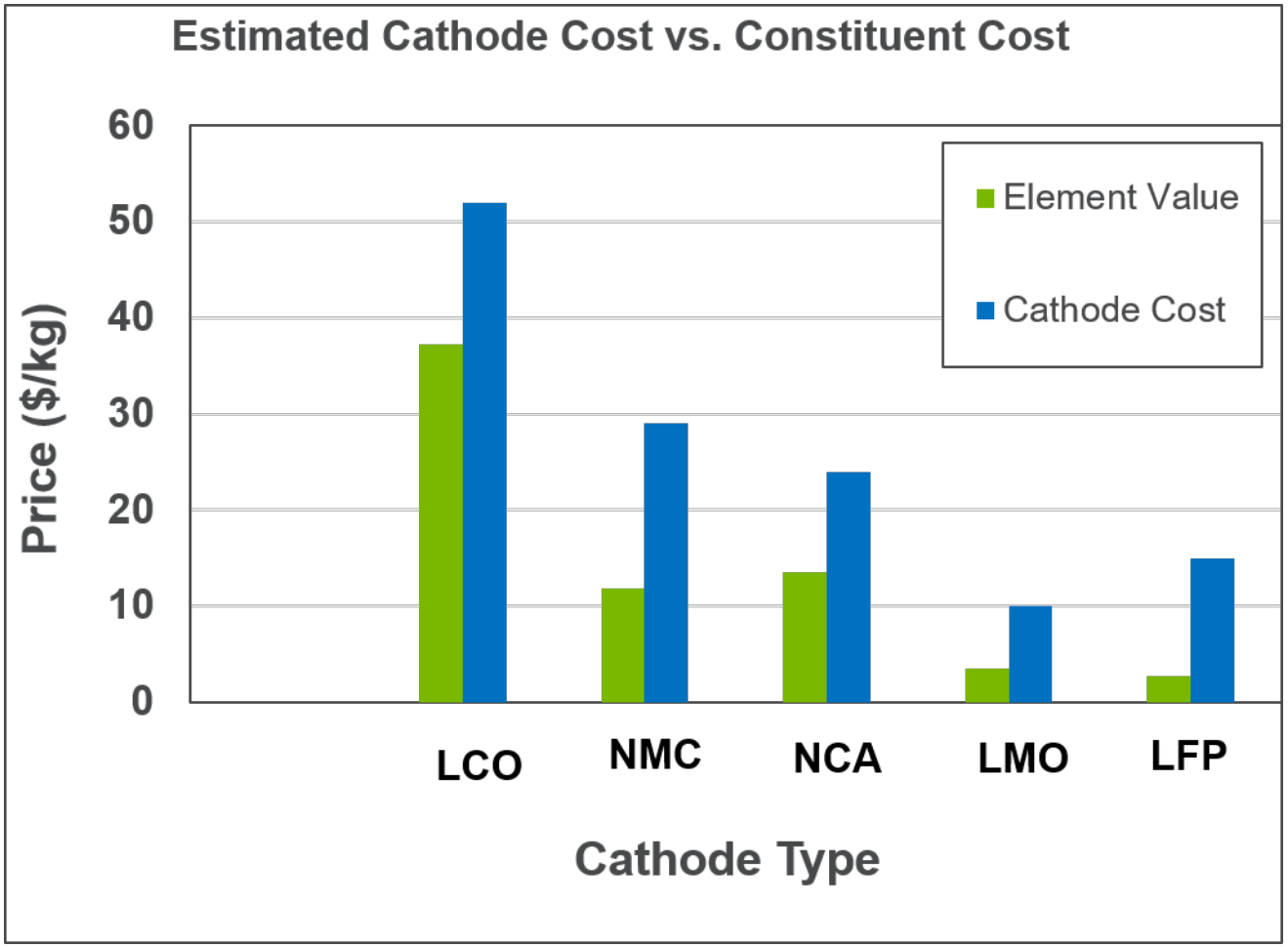
LI-ION RECYCLING PROCESSES DISPLACE MATERIALS AT DIFFERENT PRODUCTION STAGES



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



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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