California Lithium-ion Car Battery Recycling Advisory Group

January 27, 2020 Meeting Minutes

1. Call to Order, Roll Call, and Establishment of Quorum (Caroline Godkin)

- Present:
  - Caroline Godkin
  - Teresa Bui
  - Mohammed Omer
  - Mark Caffarey
  - Dan Bowerson
  - Todd Coy
  - Perry Gottesfeld
  - Steve Henderson
  - George Kerchner
  - Bernie Kotlier
  - Jennifer Krill
  - Nick Lapis
  - Alison Linder
  - Geoff Niswander
  - Lou Ramondetta
  - Alisa Reinhardt
  - Jon Weisman
- Absent:
  - Terry Adams

2. Interim Updates – Mohammed Omer
   - Thanks to everyone for their time
   - Administrative items
     - Meetings are video recorded, CC'd, available on CalEPA page
     - Draft minutes have been uploaded
     - There will be several opportunities to participate and ask questions
       - Email is sierrarm@calepa.ca.
     - We will skip over a few agenda items
   - Examples of global interest in EV battery recycling/supply
     - LIBs a theme at World Economic Forum
     - Invited panelists to share updates or news of other involvement
   - For discussion today, MO and HA created a framework, schedule of meetings and associated topics for the advisory group

3. Presentation: Dr. Hanjiro Ambrose, UC Davis
    - Comments on global interest and momentum
        - WEF: Global Battery Passport program highlighted (re: data tracking for battery value chain)
        - UNEP, IEA, also increasingly engaging in this issue, looks forward to bringing more groups and outside experts into the conversation
    - Goal of first presentation is to provide common background, framing, terms re: battery development, trends, materials, design, recycling. Panel is comprised of people with diverse backgrounds
    - Second presentation is to set a course for later topics and guest speakers to inform AG
    - Before beginning, emphasized that EV battery sustainability fits into larger effort to decarbonize transportation, key to meeting climate change goals—goal is to make the tech as sustainable as possible, not to argue *against* battery deployment

- "Reuse and Recycling of Lithium-ion Batteries for Motor Vehicles"
    - Key points
        - There is a time-based motivation for recommendations
        - Infrastructure, logistics, knowledge-sharing throughout supply chain will be key topics for this group
        - We as California have an important role to play avoiding environmental/equity issues that have historically been associated with e-waste and batteries
        - Reuse – need to think about role of reuse in eventual recycling; reuse is a stopgap not a final solution, and it's complicated for material recovery because they filter more widely into global value chains.
    - LIB Big Picture Trends
        - Became the dominant electrochemical storage technology on the market within three decades
        - Enabling development of innovative technologies in diverse markets bc of falling price
        - Size increasing across various applications
    - Deployment Trends
        - Shift towards larger, premium EVs
        - Increase in battery size in EVs (now around 60-100 kWh)
    - Deployment trends 2
        - Shift towards larger battery format
        - Diversity in modules + diversity in battery chemistry
    - QUESTION, Perry Gottesfeld: are hybrid vehicles included? No, just battery electric vehicles (BEV). Hybrids don't typically use LIBs, they're NiMH
        - A BEV is a vehicle without any internal combustion engine that charges primarily from grid electric power. A "pure electric vehicle."

- Cathode chemistry
    - High performance offered by cobalt crystalline structures will continue to dominate the market; skeptical of no-cobalt chemistries
- Deployment trends 3
    - More manufacturers are ramping their capacity on nickelate lines
    - Greater power density; minimizes deformation of cathode
- Global LIB production in 2018
    - Forecast by Benchmark Minerals illustrates dominance of a small handful of Tier 1 producers in the US market (40% of market = 4 producers)
    - Tier 1 refers to producers who are the most established with ability to control price point
- LIB design
    - A battery pack is comprised of modules equipped with thermal management and software that manages performance (BMS)
    - Different formats; cylindrical (more common in consumer electronics) and larger-format prismatic pouch cells
    - Prismatic and pouch-type cells can be packed into a smaller volume but harder to regulate temperature
    - Cylindrical = easier to regulate temperature but more packaging required
    - Tradeoffs between pouch/cylindrical do not point to an obvious favorite
- Evolving batteries
    - Batteries in five years may not look the same as they do today
    - Need to think flexibly about future of battery development
- Degradation
    - Cell phone analogy: batteries in an EV are similar to an iPhone in that as it ages, the battery starts dying quicker. However, the performance requirements are different for an EV, which means degradation looks different than for cell phones
    - DoD isn't about how close you keep battery to fully charged, it's about how close it is to the center of the range; battery degrades further if it's operating close to zero or fully charged
    - Natural temperature & time also degrade battery even if it's not being operated
    - Larger batteries are likely to last longer
        - Easier to limit charge/discharge rate and avoid using the extremes of the battery
- Non-catastrophic vs. catastrophic failures
    - Solids form in the electrodes that can puncture the battery and cause thermal runaway
    - Non-catastrophic failure means the battery may drain quickly or not start. Catastrophic failure may mean there is an explosion.

        - Think about catastrophic failure as it relates to logistics
    - Battery lifetime improving
        - Batteries in the future may be in the vehicle longer than guaranteed by warranty
        - Batteries typically warrantied up to 80% of capacity
        - QUESTION, Lou Ramondetta: is 80% a threshold? Is there a reason they couldn't go to 50%?
        - ANSWER: 80% is not a hard threshold, it's ultimately dependent on user preferences. Performance of EV is affected by battery degradation more noticeably than range. But there is room to think creatively about degrading range (e.g. lower-range vehicles might be useful for high schoolers).
        - Range also depends on temperature, auxiliary load (i.e. charging cell phone, AC, etc.)
    - Materials
        - Batteries rely on small subset of constrained materials, geographically concentrated in deposits, environmental impacts
        - Key materials for LIBs are nickel, cobalt, and lithium
    - Key terms
        - Resources = everything in the lithosphere that exists
        - Reserves= resources that are economically recoverable *today*
        - Over time, there is an interchange between reserves/resources (demand increases price, which makes more resources economically recoverable + stimulates exploration to discover currently unknown deposits)
        - Short-term, there are enough materials to meet demand BUT there are still supply risks and equity concerns
    - Supply risks
        - Focus on Lithium, Nickel, Cobalt. Other materials may be present in LIBs in significant quantities but are not included (e.g. aluminum bc demand from batteries is small percentage of global demand for aluminum)
        - Lithium
            - Deposits are widely distributed globally, though high-quality deposits are concentrated
            - Mostly from Chile and Australia
        - Nickel
            - Forecast increase in demand for *high-grade nickel*
            - Mostly from Russia, Asia
        - Cobalt
            - Mostly from Africa; production concentrated in DRC (increased from 40-60%)

- Supply risk: we think about it in terms of Static supply index and geographic concentration. If a mineral is highly concentrated, it's considered riskier because it's more vulnerable to disruption. Static supply is the total known reserves divided by the annual production
    - Environmental impact; highest from nickel and cobalt, so these chemistries have the highest life-cycle impact
- Lithium resources
    - Globally deposited but high-quality deposits (with economically recoverable *reserves*) are limited
    - Resources in the US include the Salton Sea, which people are exploring
    - Produced from pegmatite and brine.
    - It will be difficult for production in more developed areas to compete with cost-structure.
    - Static reserve index = 67 years, meaning that at current consumption/production rates + prices, it would take 67 years to mine all the lithium
- Cobalt
    - Greater percentage of cobalt resources are economically recoverable today, meaning we're closer to the ceiling of the Earth's capacity to provide it
    - Significant negative impact on local community and workers,
- QUESTION, GOTTESFELD: Does this suggest that all refining occurs in China?
    - HA: most refining is in China, board members may have more current information
- In-use stocks
    - How can we make sure that cobalt in-use today (in EVs and consumer electronics) come back into the supply chain and displace the need for primary materials?
- QUESTION, RAMONDETTA: High costs are associated with breaking down + separating parts. Will you talk about economic models that make it feasible? People
    - HA: Commercial recycling of LIBs exists in the US, some industry members are on this board. I think there are there are models from a business and from a technical standpoint as far as assessing the trade-offs, and part of the work we're doing to refine and develop some of those me.
- Recovery value
    - Value of constituent materials insufficient to
    - Other barriers exist—logistics, testing, disassembly
    - Importance of optimizing the environmental benefit of recovering materials; there's a tradeoff between only recovering the easiest, most

economical materials and recovering more materials at a better environmental outcome. If you try to recover every mineral, eventually you may get to a point where it's not worth the cost
        - How will policy mechanisms influence costs for businesses in this market?
- Pathways
    - There are commercial LIB recyclers
    - Three main pathways are talked about a lot: pyrometallurgical, hydrometallurgical, direct recovery (i.e. refunctionalization)
    - PM is the most common (i.e. smelting)
        - Some constituent materials are recovered (cobalt, nickel); others lost in slag
    - Hydrometallurgical
        - Use leaching agents to remove chemical components and break up the cathode; potential to be more targeted. Economical tradeoffs; more expensive but potential to recover refined higher value materials
    - "Direct recycling"
        - Use mechanical + HM techniques to recover cathode compound, avoid need for resynthesis
    - RAMONDETTA: Pyrometallurgical is being practiced now commercially, how about hydro and direct cathode recycling?
        - HA: most are pyrometallurgical ??? but it's hard to to get information about scale
    - Mixed waste stream is another barrier; we don't have examples of an aggregate recycling
    - COMMENT Caffarey: Issue isn't that you can't mix chemistries. Issue is that the *value* you get out of chemistries are very different so you wouldn't want to incorporate LFP batteries into the stream because you wouldn't break even for the entire process
    - LINDER: Where does replacing individual cells fit into EOL system? Could that fit into the recycling diagram?
        - HA: refurbishing/remanufacturing would be considered during battery use phase (for a battery that would go back into an EV) or for reuse. Batteries are usually soldered so it's difficult to replace individual cells; research today is directed towards finding ways to better identify cell failure and isolate
    - LINDER: Does every cell have a cathode?
        - HA: Yes, every cell is basically identical. Cathode active materials look like graphite powder, they are synthesized then shipped to the manufacturer which applies it to the foils that are inside the collector electrodes in the battery

        - GOTTESFELD: Isn't most experience we have from consumer electronics recycling and isn't that the process that we're modeling this on?
            - HA: consumer electronics are a good analogy to learn lessons from but there isn't good data on consumer electronic recycling either
- Recovery costs/impacts
    - Research is comparing economic, environmental costs/benefits. Direct recycling (refunctionalization) is promising but still in the early stages
- Design for recycling/remanufacturing/reuse
    - There's a spectrum of simpler → innovative solutions
        - Ex) Labeling, using certain colors → specified tooling; open access BMS
    - Example: flush out the degraded/deformed electrolyte to rejuvenate the battery
- Reuse
    - Power demands for other applications are order(s) of magnitude less than for a vehicle, so the battery can be used in other applications with different performance requirements
    - Interest in reuse increased by the low value of recovered materials + need for stationary storage in electric grid
- Key questions
    - When a battery comes off the road, you know very little about it
    - Cost of new batteries is falling rapidly
- RAMONDETTA: Are you saying there's a theoretical model where my Tesla battery could be used in my house paired with a solar system when the range has fallen?
- NISWANDER: Can confirm that this is already happening, someone (a rate payer) used an old EV battery at their off-grid home, but it failed and cost their HHWCF over $1000 to dispose of (how did they dispose of it?)
- Parallel examples
    - Consumer electronics, PV, CRT are all good examples
    - People are always talking about lead-acid. It's a good example because the collection and recycling rates in the US are a success story. But we still export millions of used batteries globally which end up in informal recycling sites and there is a legacy of contamination from lead recycling in LA (Exide battery recycling)
- Important to consider keeping batteries + constituent materials where we can see them; equity issues in global value chain are a strong motivator for keeping recycling domestic

Questions

- BOWERSON: You touched on cobalt and lithium; what about a potential nickel shortage?
  - HA: Nickel is usually a coproduct, often a by-product of copper production. But we're seeing a large ramp up of nickel production, we're seeing chemistries shift towards higher nickel concentration. Not as much of an issue with geographic concentration but potential for price spikes.

- CAFFAREY: Cobalt is also primarily a by-product; there are no cobalt-only mines. It's a by-product of copper (DRC) or nickel production (Canada, Russia, Cuba, Australia). EVs will need more copper for motors, so don't you think demanding more copper will increase the availability and production of cobalt?
  - HA: Need to evaluate it further. You're right, also value of cobalt could also be high enough to drive production.

- NISWANDER: To expand on Pb-acid example, it seems like LIBs will be this generation's version of changing your own oil. So don't we already have an example?
  - HA: battery systems are likely to outlast the lifetime of the vehicle, not like oil. Performance of LIBs continues to exceed rather than fall short of expectation, degradation has decreased since they were first introduced in the early Nissan Leafs.

- RAMONDETTA: You mentioned the Davos conference, are there best practices from other countries even though we are the largest consumer?
  - HA: China's market for EV is 3-4x that of the US. There are value-chain tracking mechanisms, labeling, take-back programs, design-for-remanufacturing. Using blockchain to increase transparency is another innovative strategy; there are also existing tried-and-true strategies that could be implemented.

- LINDER: Earlier you mentioned that there are different battery chemistries and different types of electric vehicle batteries that we need to figure out how to recycle. Are there certain chemistries we should be focusing on? Should we discuss how to recycle all of them plus future unknowns or just the top three?
  - HA: We've consolidated around a few chemistries in the US. LMO only is fading out, the market is trending towards nickelate and cobalt-containing chemistries (NMC, NCA), so that would be a good place to focus. But other battery manufacturers are using other chemistries—for example, BYD manufactures LFP batteries.

- LAPIS: In your report you mention the EU and their extended producer responsibility policies, can you tell us more about that?

- EU adopted WEEE (?) program in the late 90s
- Happy to talk about this more when we discuss policy examples

- OMER:
  - Questions in the audience?
  - No

- KERCHNER
  - EU member states have better data on recycling rates. We work a lot with battery associations in Europe and they have a "treasure trove" of information
  - European Battery Directive is a good example for this group to follow
  - Hanjiro: Those are good points and we should spend an entire discussion talking about policies and examples from EU

- GOTTESFELD: Great presentation, and circling back to discussion of chemistries; do producers actually put out information on percentages of metals in their batteries?
  - HA: It's difficult to get down to cathode formulation level; it's easy to tell cathode type (e.g. NMC) but difficult to get information about stoichiometry (I.e. NMC 111 vs. NMC 622) There is no reporting on exact cathode chemistries
  - GOTTESFELD: Do they at least disclose chemistries?
  - HA: There is no formal disclosure
  - COY: The information is kept close to the chest, but you can suss it out from SDCs
  - HA: data and information sharing are one of the greatest challenges

- KERCHNER: SAE standard requires chemistry to be color coded and marked on EV batteries. There is already a voluntary standard, it doesn't need to be regulated.
  - HA: This is important and there is room for industry to move the needle forward, but doesn't policy doesn't also have an important role.

30-minute break

4. Discussion on Proposed Meeting Schedule and Topics for Technical Presentations (Mohammed Omer)

- OMER: Before we move onto discussing future topics, we're going to begin by talking about meeting dates.
  - April: Last time we met, the 13th and 20th were ruled out; now we're looking at April 6th and April 27th.

        - Lou Ramondetta, Jennifer Krill unavailable April 27th; Nick Lapis unavailable on Mondays in April
        - April 6th is the better date
        - GOTTESFELD: Can we move meetings earlier to avoid Bay Area traffic?
        - BOWERSON & HENDERSON: Travelling from out of state, support current time because of flight availability
        - KOTLIER: Coming from San Jose; he'd hit traffic more traffic if he left later
    - July:
        - COY: unavailable July 6
        - July 13: No objections
        - July 20: Dan Bowerson unavailable
        - July 27: George Kerchner

Comment from public on earlier presentation

- Dr. James Blair, California State Polytechnic University
- Objects to discussion of brine extraction as sustainable method due to low energy inputs; neglects impact of water availability, neglects problem of exploitation of indigenous land with out free, prior, obtained consent; impact on high-desert ecosystem oases. Highlighted importance of recycling AND reducing single passenger vehicle travel
- HA responded by citing examples of lithium producers who are working to distribute wealth more fairly, but agrees that these are important points

5. Discussion on Developing Policy for Battery Recycling and a Plan for Technical Presentations (Dr. Hanjiro Ambrose)

- Goal is to map out content in order to bring in more expert presenters, discuss goal and scope of advisory group
- Goals
    - Clear that focus should be on large-format vehicle batteries
    - "Reuse or recycle" language is problematic; battery will still need to be reused after it is recycled. Reuse and recycling are not separate strategies.
    - "Life cycle considerations"
        - Colloquial and technical term; technically, LCA is a specific methodology but colloquially it's used to refer to supply chain
- Tentative schedule
    - Q2: Reuse; bring in outside companies who are working on this
    - Q3: recycling; follow up on discussion from earlier

    - Q4: logistics and infrastructure (gives time to talk about it with more information since it's developing quickly)
- Battery reuse
    - Scheduled for April 6th
    - Scale and magnitude of potential applications on the grid; talk about data from early examples
    - HA is in contact with NREL prize winners on work related to second life
    - Include global examples
    - Barriers
        - Are there existing policies acting as a barrier?
        - Technoeconomic challenges
    - KERCHNER: When you say policy, do you mean laws and regulations?
        - Yes
- Material recovery and recycling
    - Take a deeper dive into costs, environmental impacts
    - Design for recycling
- Logistics and infrastructure
    - Existing laws and regulation for hazardous waste material, global supply chain
    - Fire safety
        - Consider other relevant stakeholders, i.e. fire dept, CHP

6. Discussion on Additional Topics Relevant to Advisory Group

- OMER: We can always have more meetings if needed/desired, quarterly is a minimum. As an example, Everledger is visiting next meeting to discuss tracking value chain w blockchain
- GOTTESFELD: On battery reuse, I read an article about California startups reusing batteries, it would be interesting to learn more about their business models
    - HA: yes, if you can send us specific names, articles that would be helpful
- BOWERSON: Suggested bringing in someone from DOT during logistics session; would also like to hear from other committee members on recycling/recovery
- HENDERSON: Tracking seems important, which session would this fit in?
    - HA: data tracking transects all sections. Barrier for reuse, necessary condition for logistics, also blends into mechanisms + enforcement
- COY: Expertise from permitting in DTSC would be helpful during logistics
    - Mohammed can set this up
- KOTLIER: Include best practices from other nations. Specifically, someone from the EU who has been involved in their process and can share lessons learned
- BUI: Also include examples from China + financing options for infrastructure

- Goal is to lay groundwork on technical information, ecosystem and supply chain; then focus in on policy tools and what's been done by others
- NISWANDER: Consider speaking to MRF (Material Recovery Facility), operators who have to had to deal with landfill fires from consumer electronics
- KRILL: Economic modeling expertise on different pathways. More information on cost/benefit of low + high impact recycling
- LINDER: Use economic cost-benefit as a metric; we should also use GHG impacts as a metric
- KERCHNER: Getting back to scope; circled back to a topic we discussed at the last meeting. Motor vehicle can also be defined as a scooter or e-bike; are we all decided that we are limiting our scope to motor passenger vehicles?
    - GODKIN: This will be discussed at the next committee meeting
    - Hanjiro agrees
- LAPIS: He sponsored the bill; intent was definitely for car batteries, unsure why a broader code was cited
- GOTTESFELD: All these batteries are modulized, they're just larger and smaller versions of the same material, we should look at this holistically since the range of issues will be the same
- KOTLIER: hopeful that it will also include ZEV buses + trucks given recent mandate
- Hanjiro: buses may outpace personal vehicles, should be included. Hanjiro is thinking about batteries that operate at a high voltage, are in a pack, are greater than 15 kWh (this differentiates vehicle batteries from personal consumer batteries and scooters)
- OMER: We will consider ourselves to be limiting focus to vehicles (i.e. cars) until we receive further clarification from Senator Dahle's office
- COY: Lithium ion starter batteries as a future waste stream; core charges/deposits at time of purchase?
- HA: Differentiating based on traction batteries, meaning battery is being used as a motor
- HENDERSON: Do we envision having a storage capacity cut-off or will it be more in the realm of function?
- HA: Defining metrics is key to this scope; it's difficult to choose one metric to describe batteries. Life-cycle analysis uses a functional unit; functionality is a good way to define metrics (i.e. kWh in a vehicle, years in a vehicle…). A broader range of applications will make it harder to optimize
- COY: Agreed—good to pare things down and be efficient and effective—but we also don't want to realize we missed something later.
- HA: Important for committee to understand how any subset of LIB applications fits within the broader world of LIB uses.

- NISWANDER: Is there a point where these batteries will “fall off” and no longer qualify for the law? For example if they are reused in a grid service application for X years does the law still apply to them?
- LAPIS: Key issue for introducers of bill is they want to see extended producer responsibility for vehicle batteries; they’re working on a bill for other battery applications.
    - Clarification—defines producer responsibility as the cost of recycling being incorporated into the product/born by the manufacturer
    - KOTLIER: policy vs. enforcement; how can the policy improve the enforcement?
    - Issues w producer responsibility not preventing some of the other challenges (global equity, exporting e-waste, etc.)
- OMER: Action item to get in touch with Senator Dahle ‘s office
- KOTLIER: We should take advantage of location in Sacramento to include state fire marshall’s office

SUMMARY

- OMER: Record attendance, reviewed administrative items, great presentation by Dr. Ambrose + Q&A, break, discussion of future meeting dates, discussion of technical presentation topics and potential speakers…
- GODKIN: Thanks, be in touch about any suggestions for speakers, site visits, public meeting locations.
- Slides will be made available to the group