

Battery Circular Economy Initiative Dashboard:

US Supply Chain

User Guide

This user guide provides an overview of the dashboard outputs' user control parameters, references and data sources, and key assumptions and uncertainties.

A resilient and responsible battery supply chain is a critical enabler of transportation electrification, and circularity of battery materials plays a key role in developing such a supply chain. In a circular battery economy, EV batteries are reused again in EVs or repurposed for energy storage applications, before being eventually recycled, meaning raw materials are extracted to be used in another product.

RMI's Battery Circular Economy Initiative (BCEI) Dashboard: US Supply Chain aggregates and synthesizes current, publicly available information related to electric vehicle battery (EVB) manufacturing and recycling capacity in the United States. Its purpose is to:

- Project likely gaps between EVB supply and demand and highlight how a circular battery economy can benefit the EVB supply chain;
- Provide data-driven insights that can inform the development and implementation of policy, corporate near- and long-term planning, and other levers that will advance a circular battery economy; and,
- Provide a robust, replicable analytical framework that policymakers, academics, industry players, and other stakeholders can use in other regions of the world to interpret information related to manufacturing demand and to understand the advantages of recycling EOL EVBs.

Exhibit 1: Annual Battery Demand

The EVB demand projection forms the basis of nearly all other outputs on this dashboard. Pre-defined, default scenario values are for the United States' private passenger vehicle EV demand and medium- and heavy-duty EV demand.

- Private passenger segment EVB demand projections are based on RMI's analysis that examines the impact of the Inflation Reduction Act (IRA) on EV adoption, with battery chemistry market share taken from the BloombergNEF (BNEF) Long-term EV Outlook 2022.
- Medium- and heavy-duty segment EVB demand projections are based on sales projections from the National Renewable Energy Laboratory (NREL) and battery size inputs from NREL's Annual Technology Baseline 2024. These EV sales projections are based on total cost of ownership (TCO) estimates, which depend on fuel price and technology advancement scenarios. The NREL EV sales scenario selected to define the Low, Medium, and High EVB demand were Constant, Central, and Advanced Electricity Price respectively.
- Additionally, batteries in medium- and heavy-duty EVs might retire before the EV reaches end of life, given the higher mileage for this segment. A second source of battery demand arises if a battery replacement is needed before the vehicle reaches end of life.

User control parameters

Users can insert their own EVB demand estimate for the target year 2030 or select from a menu of RMI's pre-defined scenarios. If users choose to insert their own estimates:

- For private passenger EVB demand in 2030, they may insert a value between 500 and 1500 GWh. The lower bound is based on the lowest private passenger segment EV demand projection evidenced in research. The upper bound adds a ~50% margin to RMI's highest EVB demand projection allowing users to accommodate alternate or additional EVB demand (e.g., demand from micromobility). We chose the year 2030 for the supply gap analysis to illustrate medium-term gaps between supply and demand for key EVB materials.
- For medium- and heavy-duty EVB demand in 2030, users can input a value between 0 and 100 GWh. A lower bound of 0 enables analysis without the medium- and heavy-duty segment (i.e., focused solely on the private passenger vehicle segment). The upper bound, rounded to the nearest hundred, captures the high end of preset EVB scenarios with additional margin.

References and data sources

- EVB demand projections:
 - [How Policy Actions Can Spur EV Adoption in the United States](#), RMI
 - [Energy Policy Simulator](#), Energy Innovation
- Battery chemistry market share projections for passenger vehicles in the United States:
 - [Electric Vehicle Outlook 2022](#), BloombergNEF (BNEF)
- Battery chemistry market share projections for commercial vehicles globally:
 - [Electric Vehicle Outlook 2024](#), BloombergNEF (BNEF)
- Medium and heavy-duty EV sales projections:
 - [Assessing Total Cost of Driving Competitiveness of Zero-Emission Trucks](#), National Renewable Energy Laboratory (NREL)
- Battery size for medium- and heavy-duty EVs:
 - [Annual Technology Baseline 2024](#), NREL
- Battery lifetime for medium- and heavy-duty EVs:
 - [Lithium-ion Battery Recycling Analysis \(LIBRA\)](#), BNEF
 - [Tracking Flows of End-of-life Battery Materials and Manufacturing Scrap](#), Gaines et al.
- Vehicle lifetime for medium- and heavy-duty EVs:
 - [Transportation Energy Data Book, Edition 40](#) (Table 3.15 and 3.16), Oak Ridge National Laboratory
- Retirement curve (based on average vehicle lifetimes) for medium- and heavy-duty EVs:
 - [Washington Transportation Electrification Strategy](#), Washington's Interagency Electric Vehicle Coordinating Council

Key assumptions

Our private passenger EVB demand projections are derived from another RMI model, for which key assumptions are listed below. All assumptions and areas of uncertainty are dependent on the effects of the IRA and consumer behavior.

- The dashboard only considers battery electric vehicles (BEVs), as sales and use of plug-in hybrid electric vehicles (PHEVs) are projected to [gain an insignificant market share outside](#)

[Europe and peak by 2026](#). Battery prices will influence EV cost parity with internal combustion engine (ICE) vehicles, which in turn will heavily influence EV demand. Battery prices will likely decrease, in line with BNEF battery price projections.

- The demand forecast uses BNEF's charger cost trajectory. The forecast also assumes mild vehicle efficiency gains in the future. No assumptions are made regarding significant changes in either battery or vehicle technology.

Key areas of uncertainty

- Demand projections do not fully account for factors that might accelerate adoption, such as reduced electricity cost from renewables, increased range, faster charging, inductive charging, or fewer gas stations.
- Similarly, demand projections do not fully account for factors that may impede adoption like charging and/or grid infrastructure constraints, material scarcity, electricity shortages, or significant changes to the IRA. Actual demand may vary significantly from the default demand scenarios. RMI will update the tool following significant changes and developments.

Exhibit 2: Projected EV Battery Supply Chain Gaps in 2030

From the total battery demand estimated above, demand is broken down for upstream and midstream products across the supply chain, such as cells and cell components (e.g., electrodes, electrolytes, separators) and constituent materials (e.g., precursors, critical minerals) using an input-output model. (Refer to the material flow diagram on the dashboard.)

Supply from existing and announced manufacturing capacity is based on publicly available data about North American facilities.

The demand estimates can be dynamically updated by changing user input parameters, while the North American supply is static information which is uploaded to this model. By subtracting the supply data from the demand gap projections, we arrive at the supply gap. **This supply gap estimate considers the United States' EVB demand for private passenger and medium- and heavy-duty vehicles, compared to North American manufacturing capacity. It does not account for imports of battery materials.**

A detailed methodology for our supply gap assessment is provided in RMI's report, *Measuring Gaps in Supply and Demand for EV Battery Material in the United States*, linked in the references and data sources section below.

User control parameters

- None

References and data sources

- Supply gap assessment methodology:

- [Measuring Gaps in Supply and Demand for EV Battery Materials in the United States](#), RMI
- Bill-of-Materials (BOM) for individual supply chain component demand data:
 - [GREET 2020](#), Argonne National Lab (ANL)
 - [EverBatt](#), ANL
- Domestic supply data:
 - [NAATBatt Lithium-Ion Supply Chain Database](#), NREL
 - [EV Supply Chain Database](#), Charged

Key assumptions

A detailed list of assumptions and uncertainties in the methodology can be found in the supply gap assessment report mentioned under references. Key assumptions include:

- We use BNEF chemistry projections for US passenger BEVs with some simplifying assumptions.
 - There are 9 NMC chemistry formulations in the BNEF analysis. NMC532 is used to represent cobalt rich NMC formulations (NMC111, NMC532, NMC622). NMC811 is used to represent all nickel-rich formulations (NMC721, NMC811, NMC955, NMC96i, LMR-NMC, NMCA). Such simplification reduces the computational intensity and is also necessary because a bill-of-materials (BOM) is not available for every formulation.
 - Additionally, in the absence of a BOM for LNO and LNMO chemistries, their shares in chemistry projections are assigned to NMC811. These chemistries constitute a relatively smaller share of the demand.
- We use BNEF's chemistry projections for global commercial vehicles with some simplifying assumptions for evaluating medium- and heavy-duty EVB demand by chemistry.
 - Given that chemistry projections did not vary considerably through the years, battery chemistry distribution is maintained at constant levels (76% LFP, 20% NMC811, and 4% NMC532). This simplifies calculations for medium- and heavy-duty battery demand attributed to battery replacements.
- Given that announced capacity timelines are uncertain, we assume remaining years in this decade to build all announced capacity, which is why the supply is assessed in 2030. It is then compared with demand for the same year to arrive at the supply gap assessment for 2030.
- We assume that 100% of announced recycling output capacity translates into an equivalent supply of battery grade metal/metal sulfates/precursor cathode active material (pCAM)/cathode active material (CAM).
- In the absence of cathode production information from the NAATBatt database, we assume any reported pCAM/CAM production will be consumed domestically for cathode and cell production, therefore avoiding under-reporting that might occur due to vertical integration.

Key areas of uncertainty

- Projected battery chemistry market shares from BNEF are used to determine the amount of individual constituents required (e.g., Li, Co, Ni, etc.), and can vary significantly with newer chemistries, regulations, market conditions, etc.
- Depending on the battery chemistry, lithium carbonate or lithium hydroxide will be required for CAM production for lithium-ion batteries. Based on our interpretation of the Argonne

National Laboratory (ANL) EverBatt model, we assume lithium hydroxide is used in its anhydrous form to derive raw lithium demand. If other forms of lithium hydroxide, such as monohydrate, are used – it will make a significant difference to the raw lithium demand.

- While industry reports indicate that LFP chemistries use lithium carbonate in CAM production, ANL’s EverBatt model specifies that lithium hydroxide is used in LFP batteries. The EverBatt model’s BOM forms the basis of these demand projections, and thus raw and battery-grade lithium demand projections could vary due to this difference.
- Supply projections should be considered optimistic estimates. Projections for 2030 are based on existing and announced capacity and come with inherent execution risk. Projects for ore extraction, refining and processing into metal salts carry significant execution risk, given their long development lead times and associated environmental and social impacts.
- The supply gap related to raw lithium and lithium compounds (carbonates, hydroxide) has several sources of uncertainty, as explained above in the main section.

Exhibit 3: End-of-life (EOL) EVB Recycling Volumes

This measurement refers to the volume of batteries that will be discarded from vehicles and require recycling and describes the scale of buildout needed for a circular supply chain. The battery recycling volumes are calculated using historical battery volumes until 2021, projected battery demand from 2023 onwards, and the user input value for battery life. By default, we assume battery life to be 12 years.

The model’s recycling volume estimates do not include battery production scrap. Since manufacturing scrap is not considered in the raw material demand projections, material recovered from recycled scrap cannot be counted toward meeting demand.

User control parameters

The user can specify battery life to be between 10 and 20 years for passenger vehicles and between 6 and 20 years for medium- and heavy-duty vehicles.

References and data sources

- Historical battery volumes:
 - [Assessment of Light-Duty Plug-in Electric Vehicles in the United States](#), ANL
- Battery lifetime estimates for private passenger EVs:
 - [Machine-Learning Assisted Identification of Accurate Battery Lifetime Models with Uncertainty](#), NREL
- Battery lifetime for medium- and heavy- duty EVs:
 - [Lithium-ion Battery Recycling Analysis \(LIBRA\)](#), BNEF
 - [Tracking Flows of End-of-life Battery Materials and Manufacturing Scrap](#), Gaines et al.
- Vehicle lifetime for medium- and heavy-duty EVs:
 - [Transportation Energy Data Book, Edition 40](#) (Table 3.15 and 3.16), Oak Ridge National Laboratory
- Retirement curve (based on average vehicle lifetimes) for medium- and heavy-duty EVs:
 - [Washington Transportation Electrification Strategy](#), Washington’s Interagency Electric Vehicle Coordinating Council

Key assumptions

- Battery lifetimes for passenger EVs range between 10 and 20 years and are considered to reach EOL at 80% remaining capacity.
- Battery lifetimes for medium- and heavy-duty EVs are assumed to be fixed in years, not in miles/cycles, due to data limitations. In reality, long-haul vehicles may need battery replacements sooner than last-mile delivery vehicles. This combination of distributed retirements of vehicles but fixed schedules of replacing batteries creates a source of uncertainty, in addition to the existing uncertainty around battery lifetimes. For example, it is unclear when fleet operators will opt to replace a battery, retire the vehicle, or downgrade the vehicle to a different duty cycle.
- Default estimates of battery life for passenger EVs do not consider extended life from reuse or repurposing. The stock of EOL EVBs is highly dependent on their lifetime.
- In addition to the assumptions above, assumptions listed in the [Annual Battery Demand](#) section of this document apply here.

Key areas of uncertainty

- Battery lifetimes continue to improve with technological gains. Extended battery life may thus delay retirements and reduce EOL recycling feedstock. Delayed EV retirements might also reduce demand.
- Actual collection rates of EOL batteries may be significantly below 100%. Lower collection rates decrease feedstock supply.
- In addition to the bullet points above, uncertainties listed in the [Annual Battery Demand](#) section of this document apply here.

Exhibit 4: Percentage of Demand That Can Be Met by Recycled Content

This output builds on the [End-of-life \(EOL\) EVB Recycling Volumes](#) and represents the theoretical maximum recoverable mineral content available from EOL EVBs. In this ideal scenario, all EOL batteries would find their way to recyclers, there would be enough recyclers to process these materials, and recyclers would use the best currently available technology (hydrometallurgy) to recover the battery minerals.

The output represents the maximum extent to which we can reduce our dependence on mined sources for EVB raw materials.

User control parameters

The user can specify battery life to be between 10 and 20 years for passenger vehicles and between 6 and 20 years for medium- and heavy-duty vehicles.

References and data sources

- Recoverable material content in lithium-ion battery by chemistry type:
 - [GREET 2020](#), ANL
 - [EverBatt](#), ANL
- Data sources listed in the [EOL EVB Recycling Volumes](#) section of this document apply here.

Key assumptions

- In the absence of data for historical battery volumes by chemistry for passenger EVs, we used the chemistry breakdown from the starting year of BNEF chemistry market share analysis (i.e., from 2020) to model the battery chemistry composition of historical battery volumes (i.e., from 2011 through 2019).
- Assumptions listed in the [EOL EVB Recycling Volumes](#) section of this document apply here.

Key areas of uncertainty

- EOL EVB chemistry market share assumptions drive the EOL stock of each battery chemistry, which in turn determines the maximum recoverable content, as material recovery rates depend on chemistry type. For instance, an increase in the assumed historical share of the LFP battery chemistry would reduce the maximum recoverable nickel and cobalt since LFP does not yield those elements.
- In addition to the bullet points above, uncertainties listed in the [EOL EVB Recycling Volumes](#) section of this document apply here.

Exhibit 5: Emissions Benefit from Recycling

This analysis extends the [EOL EVB Recycling Volumes](#) section to illustrate the net emissions benefit of recycling by comparing the process emissions of greenhouse gas equivalents from hydrometallurgical battery recycling and the emissions reduction resulting from decreased need for virgin materials.

User control parameters

- None

References and data sources

- Recycling process emissions estimates per battery chemistry for hydrometallurgical recycling:
 - [EverBatt](#), ANL
- Counterfactual lifecycle emissions from the equivalent virgin materials from mined versus recycled content:
 - [GREET 2020](#), ANL
- Emissions in kg of CO₂ equivalent/kWh per supply chain tier of a US versus non-US made battery:
 - [To Decarbonize Transportation, We Must Invest in the US EV Battery Supply Chain](#), RMI

Key assumptions

- The entire recycling process occurs in the United States.
- Recycling processes are modelled at the cell level due to limited information on the recycling of other battery pack components.

- Calculation of emissions avoided by using recycled content instead of mined content assumes that the extraction of minerals would have occurred in the United States. Therefore, it does not consider emissions avoided as a result of not having to transport raw materials from other parts of the world into the United States.

Key areas of uncertainty

- The material and energy use assumptions per recycling facility depend on specific technological capabilities. Variations in the hydrometallurgical process may produce different emission outcomes.
- Both recycling process emissions and avoided emissions are dependent on the electricity grid mix. An electricity grid with a higher portion of clean sources of energy such as solar or wind results in lower recycling process emissions. Consequently, process and avoided emissions will vary regionally.

Exhibit 6: Value of Materials Recovered from Recycling

This output illustrates the market value of the theoretically maximum recoverable amount of critical minerals and other materials such as graphite and steel from the recycling of EOL EVBs. Given current prices and known recycling outputs, the economic benefit of recycling shows the value that recyclers would obtain for the recycling output in current market conditions.

User control parameters

- None

References and data sources

- Manganese prices:
 - Average manganese metal prices 2018-2022, [Mineral Commodity Summaries](#), United States Geological Survey
- Nickel and cobalt prices:
 - [Average cash price of nickel and cobalt, 2018-2022](#), London Metal Exchange
- Lithium prices:
 - [Average cash price of lithium chemicals \(lithium carbonate and lithium hydroxide products\) in lithium carbonate equivalent \(LCE\), 2020-2022](#), S&P Global Market Intelligence

Key assumptions

- Forward-looking economic value calculations are made using static prices (2019-2022 averages). We have not attempted to develop price forecasts.
- Recovery rates of recycling output are constant throughout the forecasting period.
- Our projections are based on United States and European metal prices. Global variations are not accounted for.

Key areas of uncertainty

- Commodity metal prices are subject to significant fluctuations caused by a wide range of economic, geopolitical, technological, and environmental factors. Therefore, the economic value of recycling outputs may vary significantly from what the dashboard shows.
- The economic benefit output only illustrates the economic value of recycling output from currently known hydrometallurgical processes and does not reflect recycling output from more technologically advanced recycling processes such as direct recycling.

Exhibit 7: Circularity Index

Reaping the emissions-reduction and economic benefits of recycling will require a robust and circular battery economy. Because the recycling industry is nascent, and because there is a dearth of data regarding its processes, it is difficult to determine what fraction of benefits can be realized, and where the key losses are happening in supply chain.

The Circularity Index presented here serves as a simulator that lets users insert educated assumptions and understand the cumulative effect of three portions of EOL battery management systems: collection efficiency, recycling capacity, and the recovery rates of individual minerals. The recovery rate is more nuanced than individual recycling facilities' efficiency. It represents the industry-wide recovery rate of a given mineral in a region, and thus should reference the overall system's technological process efficiency gains, which can happen by setting up new facilities or updating existing facilities with the latest recycling technology. These gains can boost the overall circularity of the system. The Circularity Index is similar to the recycling efficiency and recovery rates the [European Union](#) (EU) is tracking under its battery regulation, albeit more comprehensive by combining these separate metrics into one metric.

While such an index would provide a clear-eyed picture of how circular the EVB supply chain is, the inputs required to inform the Circularity Index are hard to find given that today's EOL EVB volumes are low and do not provide any indication of what collection and recycling will look like in the future. The Circularity Index allows decision makers to insert their own assumptions, get a sense of the wide range of possible outcomes, and inform investments and policy action.

To inform their inputs, users can consider parallels from the [lead-acid automotive battery recycling](#) and [consumer electronics battery recycling](#) as the best- and worst-case scenarios, respectively. With policy drivers such as extended producer responsibility (EPR), and economically viable and well-developed business models, the lead-acid battery industry has reached a highly circular state in the United States with 99% of lead-acid batteries being recycled today. In contrast, EOL consumer electronics — which use lithium-ion battery chemistries similar to those used in EVs — are sitting in junk drawers or being thrown away; some [estimate that only 5% of lithium-ion batteries](#) (mostly from consumer electronics) are being recycled today in the United States. However, the methodology for evaluating the recycling rate is unclear and depending on the approach used, [the recycling rate may vary significantly](#). While the picture may not be as dismal for EOL EVBs, without policy and market drivers, it is unlikely that they will achieve the same high recycling rates as lead-acid automotive batteries.

User control parameters

The user provides inputs for:

- Collection efficiency (between 0 and 100%): This value represents the ratio of EOL EVBs being collected compared to EOL EVBs being retired.
- Recycling capacity (between 0 and 100%): This value represents the ratio of recycling capacity of existing facilities versus recycling feedstock collected. If recycling capacity exceeds need, recycling capacity is capped at 100%. If the recycling intermediate product is exported out of country as black mass, it results in mineral recovery outside of North America, meaning that recycling capacity is 0% in this model.
- Recovery rates for individual minerals (between 0 to 100%): Typically, individual recyclers disclose their recycling efficiencies in terms of percentage of minerals recovered from EOL EVBs. However, not all recyclers recover every available mineral. Depending on the facility setup, they may not recover certain minerals. The recovery rate of the system represents an average estimate of these individual recyclers' recovery rates for every mineral.

Key assumptions

The default values correspond to an artificial scenario where:

- The collection rates of EOL EVBs are similar [to lead-acid battery collection and recycling rates in the United States](#).
- The recycling capacity is assumed to be 95% based on the sheer volume of recycling startups in the US industry today.
- Recovery rate estimates that are representative of the whole industry are hard to come by, and so defaults are based on target recovery rates under [EU Battery Regulation](#).

Key areas of uncertainty

- Recovery rates contain the greatest uncertainty. Most of today's recycling scrap gets sent to facilities that use pyrometallurgy, and certain minerals such as lithium or graphite may never be recovered. Going forward, the recycling feedstock is likely to be handled by [newer, more efficient hydrometallurgical facilities](#).
- Robust local midstream production capacity is critical to advancing recycling. Without a domestic marketplace for using recovered minerals or intermediates, recycling companies will not thrive. This lack of a marketplace is why most recycling facilities today are in regions which have the midstream EVB facilities.
- The economic viability of recycling business models is directly tied to mineral prices. Lower metal prices without a proportionate decrease in recycling costs result in lower profit margins for recyclers, or even unviable business models.