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INVESTIGATING THE U.S. BATTERY SUPPLY CHAIN AND ITS IMPACT ON ELECTRIC VEHICLE COSTS THROUGH 2032

Chang Shen, Peter Slowik, Andrew Beach

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Editor: Amy Smorodin

International Council on Clean Transportation
1500 K Street NW, Suite 650
Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

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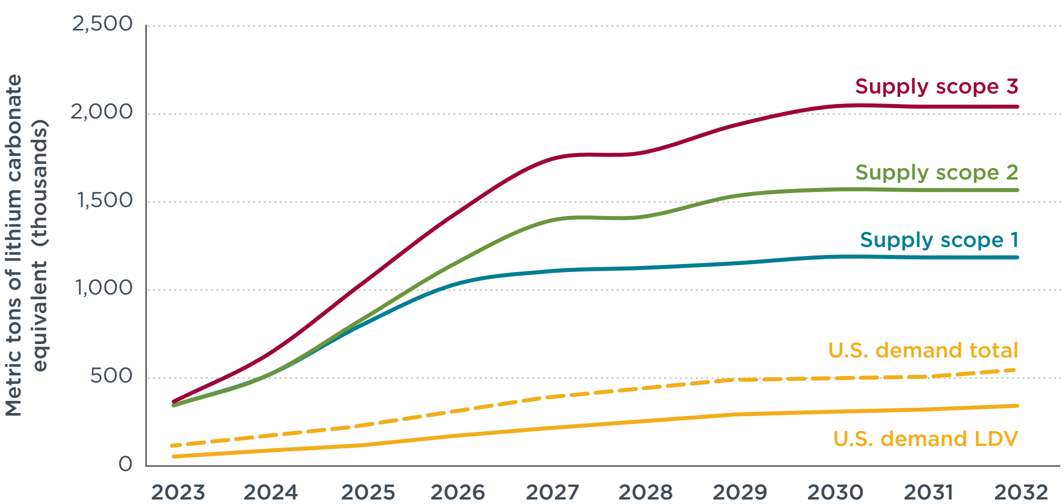
EXECUTIVE SUMMARY

The global shift toward zero-emission vehicles is rapidly advancing, and many countries are setting ambitious decarbonization targets. In this context, the United States, through the U.S. Environmental Protection Agency's (EPA) recent standards proposal, aims to lead global efforts to reduce light-duty vehicle pollution. However, a pivotal research question arises: Can the United States ensure a reliable supply of essential minerals to produce affordable battery electric vehicles (BEVs), especially given fluctuating raw material prices and evolving battery technologies?

This study addresses that question by analyzing the development of the U.S. battery supply chain and its impact on BEV costs from 2023–2032. It explores the feasibility of the United States securing a reliable lithium supply chain with the minerals eligible for tax credits and generates hypothetical prices scenarios of three key battery materials (lithium, cobalt, and nickel) from 2023–2032. It then develops a bottom-up battery cost analysis to identify the impact of changing raw material prices on battery pack-level costs and applies those battery cost estimates to assess the impact on new BEV prices through 2032.

Figure ES1 illustrates a key finding of this work—that new lithium supply may far exceed lithium demand from new U.S. light-duty BEVs through 2032. The three potential scopes of new lithium supply are based a detailed assessment of new projects within the United States and in countries with which the United States has existing or potential future Free Trade Agreements (FTA) or Critical Mineral Agreements (CMA). Lithium demand from new U.S. BEVs is based on a scenario aligned with EPA's proposed 2027–2032 multipollutant standards, such that the BEV share of new sales increases from about 7% in 2023 to 67% in 2032. Also shown are estimates of additional lithium demand from heavy-duty vehicles, grid battery storage, and consumer electronics.



Scope 1 includes lithium supply from the United States and its existing FTA and CMA partners in battery minerals, and excludes facilities owned by a Foreign Entity of Concern and all prospective projects. Scope 2 includes supply from current FTA and CMA partners and all prospective projects. Scope 3 further includes countries that are potential FTA and CMA partners as well as all prospective projects, without exclusions based on ownership.

Figure ES1. Three scopes of announced lithium supply from United States and its existing and potential FTA and CMA partners compared to lithium demand from new U.S. light-duty BEV sales through 2032.

Figure ES1 shows that by 2032, the United States is projected to need around 540 thousand metric tons per annum (ktpa) of lithium carbonate equivalent (LCE). This demand would be about 26% to 46% of the amount of announced supply, which is estimated to range from about 1,190 ktpa (Scope 1, which includes plants that are already in operation or under construction in the United States and its existing FTA and CMA partner) to about 2,000 ktpa (Scope 3, which includes additional prospective projects and potential FTA partnerships). When considering additional lithium demand from existing FTA and CMA partners, we find that announced supply would still equal or exceed demand for each supply scope.

Our analysis leads to four high-level conclusions:

More than 100 lithium mining and refining projects are underway in the United States and its existing and potential future FTA and CMA partners as of 2023. Together, these facilities are projected to amount to a lithium extraction capacity of 1,310 ktpa LCE and a refining capacity of 1,030 ktpa LCE in 2025. By 2032, extraction capacity is projected to increase to 2,170 ktpa, and the refining capacity to 2,040 ktpa. By 2032, the United States would account for approximately 17% of this mining capacity and 27% of this refining capacity. Countries with existing FTAs and CMAs like Australia, Canada, Chile, and Peru would account for 56% in mining and 47% in refining capacity. Potential countries for future CMAs such as Argentina would account for 28% of mining and 21% of refining capacities considered in this analysis.

The United States has potential to secure a lithium supply that far exceeds the lithium demand from new light-duty BEV sales. This analysis projects U.S. lithium demand for light-duty BEVs production to be approximately 340 ktpa LCE in 2032, which is based on a 67% new sales share in 2032 and an average BEV range of 300-miles. This value represents about 17%–33% of the announced supply in the United States and its existing FTA and CMA partners by 2032. When accounting for additional U.S. lithium demand beyond light-duty vehicles, we estimate that demand could increase from 340 ktpa LCE to 540 ktpa LCE in 2032, which is less than 50% of the announced supply from our most conservative estimates that exclude projects not yet under construction. When considering increased lithium demand outside of the United States from its FTA and CMA partners, announced lithium supply would still equal or exceed demand. From a global perspective, the limited literature suggest that global lithium supply may approximately align with global demand by 2030, indicating that any additional new and expanded mining and refining capacity could further ensure supply would meet demand.

Battery pack and BEV costs are linked to raw material prices, but substantial continued battery and BEV cost reductions are expected under most raw material price scenarios. Based on our “mid” raw material price scenario for lithium, nickel, and cobalt, which corresponds to a 50th percentile of historic prices, we find that battery pack costs decline from about $122/kwh in 2023, to about $91/kWh in 2027, and $67/kWh in 2032. Under our 25th percentile “low” raw material price scenario, pack-level costs are reduced to $60/kWh in 2032, whereas under our 75th and 95th percentile “high” and “extreme” raw material price scenarios pack-level costs are about $80/kWh and $115/kWh in 2032, respectively. Based on our “mid” raw material price scenario, we find that the upfront purchase prices of average new 300-mile range BEVs will be comparable to those of their gasoline counterparts in the 2028–2029 timeframe for cars, crossovers, SUVs, and pickup trucks without any government incentives. This is due in large part to technological advancements in BEV energy efficiency and battery-specific energy. Under a worst-case extreme raw material price scenario in which lithium, nickel, and cobalt increase to the 95th percentile of their historic prices by 2032, we find that the timing for when BEV purchase prices will be comparable to that of their gasoline counterparts could be delayed by about 2–3 years.

Incentives in the United States for battery production and BEV purchases accelerate the timing for purchase price parity by about 3 years. This study applies estimates of the average value of the Inflation Reduction Act Advanced Manufacturing Production Tax Credit (45X) for batteries and the Clean Vehicle Tax Credit (30D) for BEVs, which are estimated to be about $2,000 per vehicle for batteries and about $2,500 for new BEV purchases on average over the 2023–2032 timeframe. When both incentives are combined, they reduce the upfront BEV prices by up to $4,500 on average, which accelerates the timing for purchase price parity with conventional alternatives by about 3 years. The estimates of the Clean Vehicle Tax Credit incentive values assume that half of all new BEV sales comply with the new Foreign Entities of Concern (FEOC) provision, which disqualifies a new BEV from the tax credit if any of the battery components or materials are extracted, processed, or recycled by a FEOC starting in 2025. If relatively more or fewer new batteries and their components are sourced from FEOCs, the average incentive for new BEV purchases would be relatively greater or lesser than estimated here.

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INTRODUCTION

The global transition to zero emission vehicles continues to accelerate, and countries worldwide are setting targets for decarbonizing transportation and phasing out the sale of new internal combustion engine (ICE) vehicles. In the United States, new policies and investments have set the stage for rapid electric vehicle market growth. At the federal level, the U.S. Environmental Protection Agency (EPA) proposed a rule for the establishment of multipollutant standards for new light-duty vehicles sold from 2027–2032 that, by the agency's estimates, are projected to lead to about a 67% battery electric vehicle (BEV) market share by 2032 (U.S. EPA, 2023a).

Many batteries and battery materials will be needed to supply the increased sales volumes of BEVs in the United States, and the auto industry will need to secure a sufficient and affordable supply to manufacture and sell BEVs at prices comparable to their ICE counterparts. While it is well documented that there are more than enough battery minerals available for a global transition to BEVs (see e.g., Slowik, Lutsey, & Hsu, 2022), a key challenge is how to scale up investments in mining, refining, and battery production in the next 10 years. Annual global BEV sales have grown from about 2.2 million in 2020, to about 4.8 million in 2021, and to about 7.7 million in 2022 (EV-Volumes, 2023). Over this same timeframe, global prices of raw materials like lithium, nickel, and cobalt greatly increased temporarily before receding in 2023.

The Inflation Reduction Act (IRA) of 2022 incentivizes the scale-up of the electric vehicle industry and the related supply chain by allocating billions of dollars to climate and clean energy investments and expanding tax credits and incentives (Internal Revenue Service, 2022). The IRA provides Advanced Manufacturing Production Tax Credits for companies manufacturing battery cells and packs in the United States. It also provides a Clean Vehicle Tax Credit for consumers with eligibility restrictions based on where battery components and critical minerals are sourced. This directly incentivizes domestic raw material mining, refining, recycling, and battery production and supports resilient supply chains from select trade partners. Along with increased supply, continued technological advancements in batteries and shifts in lithium-ion battery chemistries can reduce the amount of the most expensive materials and help reduce total costs. Given these factors, a deeper investigation of battery and raw material industrial development in the United States and other countries is needed to understand potential imbalances in supply and demand and how these factors may influence raw material, battery, and BEV costs.

This study explores several questions related to the development of the battery supply chain for the U.S. BEV market and its impact on BEV costs through 2032. First, it catalogues lithium mining and refining capacity in the United States and its Free Trade Agreement (FTA) and Critical Minerals Agreement (CMA) markets as of 2023, and potential future CMA markets to quantify potential lithium supply. We next estimate the demand for batteries and the associated amount of lithium needed to supply the production of BEVs sold in the United States and compare that demand to the lithium supply capacities. We then develop hypothetical future price scenarios based on historical prices for lithium, nickel, and cobalt, and compare them with the available literature. Finally, we develop a bottom-up battery cost analysis and apply future lithium, nickel, and cobalt price scenarios to evaluate the effect of raw material prices and the IRA incentives on overall battery and BEV costs through 2032.

ASSESSMENT OF LITHIUM SUPPLY AND DEMAND

Securing a sufficient supply of batteries and their key minerals is a critical precursor to transitioning to BEVs. The U.S. Geological Survey (USGS) has identified five battery materials as critical due to potential supply disruptions driven by greatly increased demand: lithium, cobalt, manganese, nickel, and graphite (Congressional Research Service, 2022). This analysis focuses on lithium, nickel, and cobalt due to their importance to battery production, contributions to battery cost, recent global price volatility, data availability, and the cumulative raw material demand from the global BEV transition as a percentage of global reserves (Slowik et al., 2020).

Lithium is a component in all lithium-ion battery chemistries. Nickel and cobalt are key materials in several lithium-ion battery cathode materials, including lithium nickel manganese cobalt oxide (NMC) and lithium nickel cobalt aluminum oxide (NCA), which together made up about 70% of global battery market share in 2022 (IEA, 2023d). The global stock market prices of lithium, nickel, and cobalt have been volatile over the past few years, with prices increasing in the 2021–2022 timeframe before receding in 2023. As battery production and overhead costs are declining, the prices of raw materials have an increasingly high relative impact on the total pack-level cost. Although many studies express long-term confidence in a continued decline in battery costs regardless of raw material price developments (Mauler, Duffner, Zeier, & Leker, 2021; Rogers, Nair, & Pillai, 2021), the growing share of battery costs that raw materials represent warrants more detailed study of these relationships.

This analysis focuses particularly on lithium due to its indispensable role in battery production and substantial contribution to the overall battery cost. Subsequent sections of this analysis investigate lithium supply capacities in the United States, its FTA and CMA partners, and potential CMA countries, and compare that supply with demand from new U.S. light-duty BEV sales. We then analyze historical global prices of lithium, nickel, and cobalt, and develop hypothetical future price scenarios to analyze how battery and BEV prices may change as a result.

This analysis does not develop future price scenarios for manganese, graphite, or other battery materials. Manganese represents a very low share of total battery costs, and the price of battery-grade manganese sulfate has remained low since 2022 (Fastmarkets, 2022; Gordon, 2023). Graphite prices have also remained relatively stable, with a modest price increase of 3% from 2020–2022. A 2020 study found that the cumulative demand for manganese and graphite from global BEVs and PHEVs sales until 2050 is less than 1% and about 5% of known global reserves of cobalt and natural graphite, respectively (Slowik, et al., 2020). Considering that most BEV batteries today contain synthetic instead of natural graphite, the dependency on these reserves is even lower. Still, the global distribution of these raw material reserves varies greatly, and it is likely that the United States will rely on substantial imports of graphite to supply BEV demand. We address graphite further in the discussion section.

The battery material demand assessment and the battery cost projections developed in this analysis are based on technological improvements and innovations in lithium-ion batteries that do not require fundamental technological breakthroughs or nascent next-generation battery technologies such as solid-state or sodium ion batteries. Technological breakthroughs and commercialization of advanced technologies or alternative chemistries could potentially lead to a reduction in battery pack size and cost.

SCOPES OF LITHIUM SUPPLY CAPACITIES

The potential lithium supply capacities considered in this study were limited to projects which would meet IRA Clean Vehicle Tax Credit eligibility requirements and would be relatively more reliable compared to lithium that is sourced from outside of these markets. The Clean Vehicle Tax Credit consists of a battery component portion, for which a percentage of the value of the vehicle battery components needs to be manufactured or assembled in North America, and a critical mineral portion, for which a percentage of the value of the critical mineral in the battery must be extracted or processed domestically or in a country with which the United States has an FTA or recycled in North America (U.S. Department of Treasury, 2023). For the latter, countries that the United States has a more limited CMA with are expected to be eligible. Therefore, this analysis of lithium supply was limited to projects within the United States, its FTA and CMA partners as of 2023, and potential future CMA countries.

The USGS estimates that in 2022, the United States and existing FTA and CMA partners held 67% of the world's discovered lithium reserves, and the United States and FTA partners together made up over 78% of global lithium mine production (Congressional Research Service, 2022).[1] However, lithium refining capacity in the United States and these countries was comparatively low in 2022. For example, 96% of Australian lithium spodumene concentrate was exported to China for refining (Department of Industry, Science and Resources of Australia, 2023). As the U.S. BEV market grows, refining capacity will need to greatly expand if demand is to be met by production facilities within the United States, its FTA and CMA partners, and prospective future CMA countries.

We assembled a comprehensive database detailing lithium extraction and refining capacities in the United States, its FTA and CMA partners as of 2023, and potential future CMA countries. The data was gathered from public announcements related to individual mining and refining sites and includes information such as the country of origin of operating companies, ownership structure, current project status, and announced production capacities by year. All lithium extracting and refining capacities were converted to metric tons of lithium carbonate equivalent (LCE) per annum (tpa), which is the industry standard for benchmarking the lithium content since lithium is not sold in its pure elemental form in the market.

We evaluated each lithium mine or refining plant based on three attributes: location of the facility, ownership, and project status. We developed a three-tier system to categorize each facility: Tier 1 consists of mines and refining plants within the United States; Tier 2 includes mines and refining plants in countries that have an FTA or CMA with the United States as of 2023; and Tier 3 includes mines and refining plants in countries that are discussing CMAs with the United States. Detailed information about which markets have or are discussing FTAs or CMAs with the United States are provided in the appendix. Table 1 summarizes how lithium mining and refining facilities are categorized based on the location and project status attributes.

1 U.S. data is estimated since USGS withholds U.S. production data.

Table 1. Summary of lithium mining and refining facility attributes and categorization.

Attribute	Description
Location	Tier 1 = United States Tier 2 = Countries with existing FTA or CMA with the United States as of 2023 Tier 3 = Countries discussing potential CMA with the United States
Status	Existing: In operation Under construction: Commissioned and currently under construction Prospective: Have not yet begun construction and may be in the early stages of receiving permits
Ownership	Exclusion of facilities that are owned by a company likely to be classified by the U.S. government as a Foreign Entity of Concern

Information about the companies that own the mines and refining plants are important for determining potential IRA's Clean Vehicle Tax credit eligibility. Guidance proposed in April 2023 on Section 30D of the Inflation Reduction Act of 2022 states that starting from 2025, electric vehicles containing any critical minerals that were extracted, processed, or recycled by a company classified by the U.S. government as a Foreign Entity of Concern (FEOC) will not qualify for the credit (Internal Revenue Service, 2023). This term is defined in the Infrastructure Investment and Jobs Act as companies that are "owned by, controlled by, or subject to the jurisdiction or direction of a government of a foreign country" according to 10 U.S. Code § 4872 (Infrastructure Investment and Jobs Act, 2021; 10 U.S. Code § 4872, 2022). All lithium mines and refining plants owned by companies from these countries—China, Iran, Russia, and North Korea—are excluded from this analysis.

Within our database, some facilities are joint ventures with Chinese companies,[2] and there is uncertainty whether BEVs that contain lithium from these facilities may qualify for the mineral portion of the IRA's Clean Vehicle Tax credit (see Jack et al., 2023, and more information in the appendix). Furthermore, there is uncertainty about how much of the lithium production from these joint-venture plants might be available for the U.S. BEV market given the rising global competition for lithium supply. Thus, we include information about whether the facilities are joint ventures with companies in FEOC countries within our database.

Data on project status was also collected. Prospective projects are those that have not yet begun construction and are often still in the early stages of receiving permits. For projects that have announced the construction duration without providing details on the capacity increase schedule, we assumed that all capacity will come online in the year of announced completion. Existing projects are those currently in operation.

The compiled data for lithium mining and refining capacity in the United States (Tier 1), its FTA and CMA partners (Tier 2), and potential future CMA countries (Tier 3) are presented in Table A4 and Table A5 in the appendix. We identified 55 existing, new, or expanded mining projects and 54 existing, new, or expanded refining projects. Together, these facilities are projected to amount to a lithium extraction capacity of 1,310 ktpa LCE and a refining capacity of 1,030 ktpa LCE in 2025. By 2032, the extraction capacity is projected to increase to 2,170 ktpa, and the refining capacity to increase to 2,040 ktpa. By 2032, The United States (Tier 1) would account for approximately 17% of the mining capacity and 27% of refining capacity of all the three tiers. Countries with an FTA or CMA with the United States (Tier 2), like Australia,

2 For instance, certain mines in Australian like Greenbushes and Mount Marion are partially owned by Chinese companies.

Canada, Chile, and Peru, would account for 56% of mining and 47% of refining capacity. Countries currently discussing CMAs with the U.S. (Tier 3), such as Argentina and European Union Member States, would account for 28% of mining and 21% of refining capacities considered in this analysis.

We then developed three lithium supply scopes, summarized in Table 2, according to these classifications for lithium mining and refining capacities. As shown, Scope 1 includes facilities in operation and under construction in Tier 1 and Tier 2 countries, excluding facilities owned by an FEOC. Prospective projects that have been announced but are not currently under construction carry a degree of uncertainty regarding potential delays or cancellations and were thus not included in Scope 1. Scope 2 includes all prospective projects in Tier 1 and Tier 2 countries, and excludes plants owned by an FEOC. Scope 3 includes existing and prospective projects in Tier 1, Tier 2, and Tier 3 countries, and assumes 50% capacity for facilities owned by companies that are joint ventures with a headquarters in an FEOC. The colors and symbols used in the table correspond to figures of lithium supply used in the remainder of this paper. The dashed line represents the refining capacity of extracted raw materials and the solid line indicates the raw material mining capacity.

Table 2. Scope definition for lithium supply analysis.

Marker	Description
Scope 1	Tier 1 and 2 countries; excluding firms owned by an FEOC; including only existing and under construction projects and **excluding** all prospective projects.
Scope 2	Tier 1 and 2 countries; excluding firms owned by an FEOC; **including** projects of all status.
Scope 3	Tier 1, 2, and 3 countries; **including** projects of all status.
– – – **Dash**	Refining capacity measured in thousands of metric tons of LCE per annum.
——— **Solid**	Mining of raw materials measured in thousands of metric tons of LCE per annum.

Note: Tier 1 = United States, Tier 2 = Countries with FTA or CMA with the United States, Tier 3 = countries currently discussing CMAs with the United States.

The left panel in Figure 1 summarizes the lithium mining and refining capacity in the United States, its current FTA and CMA partners, and potential future CMA countries (Tier 1, 2, and 3 countries) according to the three scopes. As depicted in the figure, the initial mining capacities in 2023 are 503 ktpa, 503 ktpa, and 540 ktpa of LCE for Scope 1, Scope 2, and Scope 3, respectively. By 2032, these capacities grow to 1,190 ktpa, 1,570 ktpa, and 2,170 ktpa for each respective scope. Refining capacities range from 350 ktpa, 350 ktpa, and 370 ktpa of LCE for the Scopes 1, 2, and 3 in 2023, respectively, and expand to around 1,300 ktpa, 1,600 ktpa, and 2,040 ktpa, respectively, by 2032.

We then determined the lithium supply capacities for which both the lithium mining and lithium refining can be met in each scope. These supply capacities are limited by the mining or refining capacities. In the next few years, the overall lithium supply capacities are limited by refining capacities, while mining capacities limit the available volumes in the longer term. The overall lithium supply capacities in the United States, its current FTA and CMA partners, and potential future CMA countries is shown in the right panel in Figure 1. The initial production capacities in 2023 are 350 ktpa, 350 ktpa, and 370 ktpa of LCE for Scope 1, 2, and 3, respectively. By 2032, these capacities are projected to grow to around 1,190 ktpa, 1,570 ktpa, and 2,040 ktpa for each respective scope by 2032.

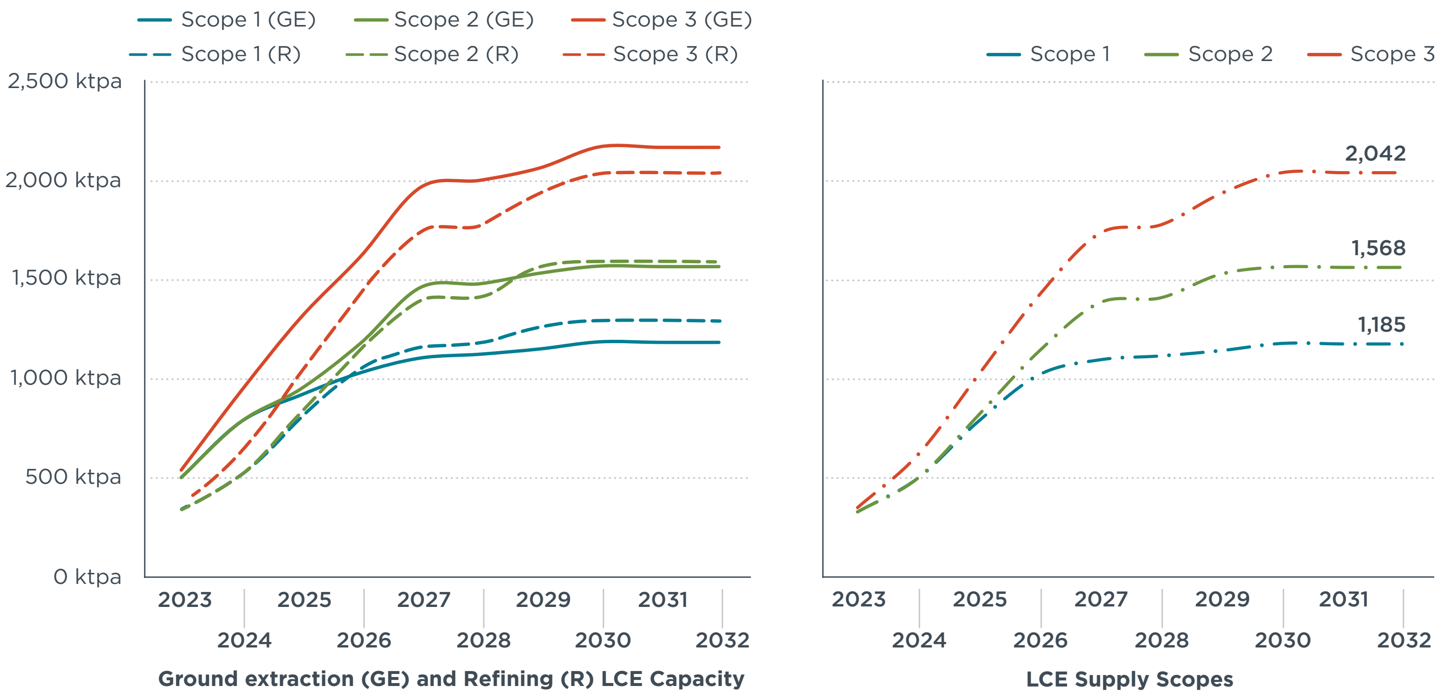

Figure 1. Scopes of lithium supply capacities in the United States and its current and potential future FTA and CMA countries, 2023–2032.

LITHIUM DEMAND FROM LIGHT-DUTY BEVS SOLD IN THE UNITED STATES

The analysis of lithium demand from light-duty BEVs sold in the United States through 2032 was based on annual BEV sales, BEV technical specifications such as electric range and battery size, new BEV sales by light-duty vehicle class (i.e., cars, crossovers, SUVs, and pickup trucks), the mix of various lithium-ion battery chemistries, and the amount of lithium per kilowatt-hour of each battery chemistry.

Annual U.S. light-duty BEV sales are based on the EPA's proposed 2027–2032 multipollutant standards, such that the share of new sales that are battery electric increases from about 7% in 2023 to about 17% in 2025, 36% in 2026, 60% in 2030, and 67% in 2032 (U.S. EPA, 2023a). The new BEV shares are shown in Figure 2 along with the absolute number of annual new BEV sales based on the International Council on Clean Transportation's (ICCT) 2023 roadmap model (ICCT, 2023). This increase in new BEV sales shares corresponds to an increase in BEV sales from about 2.4 million in 2025 to about 8.6 million in 2030 and about 9.7 million in 2032. If automakers sell more advanced technology combustion engine vehicles or plug-in hybrid electric vehicles to comply with the EPA's proposed GHG requirements, the number of BEVs sales, and thus the total battery and raw material demand, would be reduced.

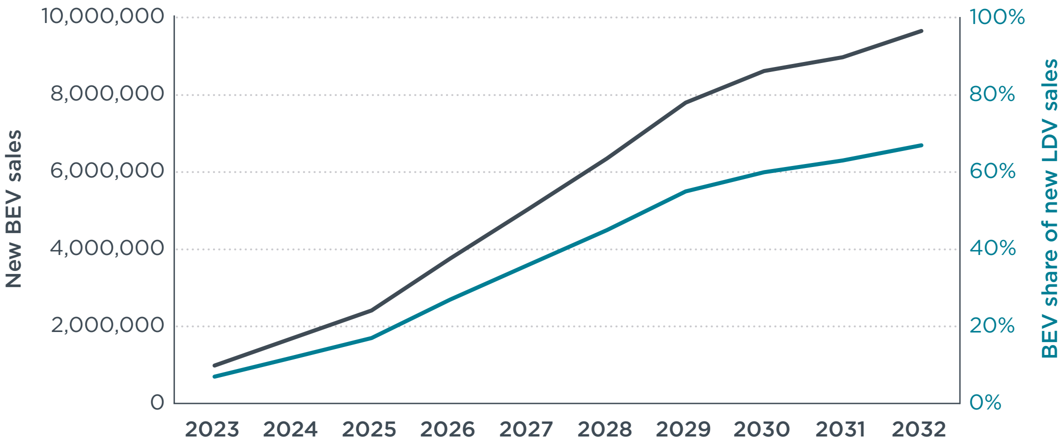

Figure 2. BEV sales and sales shares in the United States, 2023–2032.

Consistent with Slowik et al. (2022) and regulatory modeling by the EPA (EPA, 2023a), an average range of 300 miles is assumed for BEVs of all vehicle classes for all years of the analysis. The annual BEV sales for each class is derived from the share of new 2020 U.S. light-duty vehicle sales in each class based on data from National Highway Traffic Safety Administration (2022). The new BEV sales for each year are allocated such that 27% are cars, 35% are crossovers, 23% are SUVs, and 15% are pickups. This mix of segments is assumed to stay constant over the study period.

The BEV energy efficiencies for each class and each model year are based on Slowik et al. (2022). The initial 2022 BEV energy efficiencies are based on existing model year (MY) 2022 vehicles. Several high-sales volume MY 2022 models inform the initial 2022 average technical specifications for each class (see Slowik et al., 2022). It is assumed that energy efficiency improves by about 3% per year from 2023 to 2030 due to electric component (battery, motor, power electronic) and vehicle-level (mass reduction, aerodynamic, tire rolling resistance) improvements. This rate of BEV energy efficiency improvement assumes that vehicle manufacturers are motivated to provide vehicles with smaller batteries (in kWh) for the same range, resulting in lower costs.

Energy efficiency values for MY 2030 and beyond are based on modeling by California Air Resources Board (2022). The energy efficiencies assumed for 2030 models are somewhat better than those of the high sales volume and best-in-class models from 2023. For example, our 300-mile range car is 0.22 kWh/mile in 2030 compared to the 358-mile long-range Tesla Model 3 at 0.26 kWh/mile. Our 300-mile range crossover is 0.24 kWh/mile in 2030 compared to the 330-mile range Tesla Model Y at 0.28 kWh/mile.

Table 3 summarizes the average battery capacity of 300-mile range BEVs for each class in each year. The sales-weighted average battery capacity for new BEVs declines from about 104 kWh in 2023 to about 75 kWh by 2030 due to the assumed constant 300-mile range and improvements in electric efficiency described above. Based on the above annual growth in U.S. BEV sales (Figure 2) and average battery capacity per vehicle in Table 3, we project that the annual battery demand for U.S. light-duty BEV sales increases from about 230 GWh per year in 2025 to about 650 GWh per year in 2030 and about 720 GWh per year in 2032.

Table 3. Battery capacity (kWh) for new U.S. 300-range BEVs by year and vehicle class through 2032.

Year	Car	Crossover	SUV	Pickup	Sales-weighted average
2023	84	99	113	138	104
2024	81	93	108	133	99
2025	77	88	103	127	94
2026	74	83	98	122	90
2027	71	78	93	117	85
2028	68	74	88	112	81
2029	65	70	84	107	77
2030	64	67	82	104	75
2031	63	67	81	104	75
2032	63	67	81	103	74

Note: Numbers in table are rounded.

We compared these findings of U.S. battery demand with analysis in EPA's Draft Regulatory Impact Analysis (U.S. EPA, 2023b). The impact analysis summarized recent estimates of announced U.S. installed battery production capacity, based on research by Argonne National Laboratory (ANL) and S&P, and developed a "conservative but reasonable" limit on GWh battery supply which was applied into the agency's Optimization Model for reducing Emissions of Greenhouse Gases from Automobiles (OMEGA). Our findings of U.S. battery demand are lower than the announcements of installed capacity reported by ANL and S&P and are lower than the EPA's conservative limit of GWh battery supply that was applied in the OMEGA model (see U.S. EPA, 2023b; ANL, 2022; and S&P Global, 2022). This suggests that announced battery supply may exceed demand from new BEVs in the United States.

Based on research by Tankou, Bieker, and Hall (2023), Figure 3 summarizes the market share of cathode materials in BEV batteries in the United States from 2023–2032 assumed in this analysis. As shown, battery composition is expected to evolve toward higher amounts of nickel and lower amounts of cobalt, such as NMC-811 and NMC-955 replacing the lower-nickel NMC-532 and NMC-622 through 2032. NCA batteries had about 20% market share in 2023, which will decline to about 15% in 2032, and LFP batteries had a market share of about 20% in 2023, which will increase to about 35% in 2032. Although LFP batteries had previously been largely limited to China, Tesla sells Model 3 and Model Y vehicles in the United States which use LFP batteries; other automakers including Ford and Rivian have announced that they will also begin switching to LFP (Kolodny, 2022; Clemens, 2023).

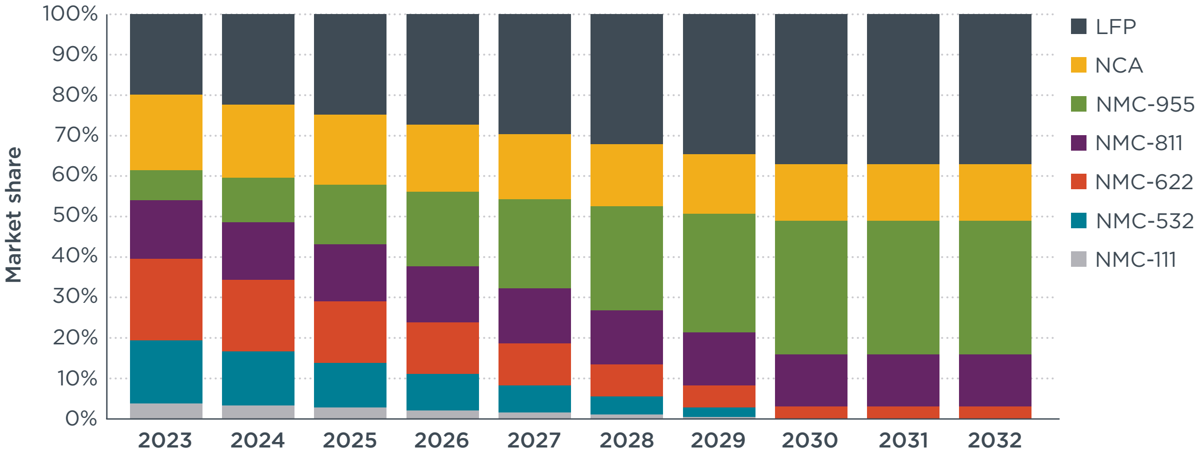

Figure 3. Development of the market share of cathode materials in BEV batteries assumed in this analysis.

Different battery chemistries have their own distinct chemical compositions and material demands on a kilogram per kilowatt-hour (kg/kWh) basis. This is determined by the battery pack specific energy for each chemistry (GREET, 2022) and the relative number of molecules and their molar mass. For example, NMC-811 cathodes contain about 0.10 kg/kWh of lithium, 0.08 kg/kWh of manganese, 0.65 kg/kWh of nickel, and 0.08 kg/kWh of cobalt in 2023. This means that an average MY 2023 300-mile range BEV contains about 10 kg of lithium, about 8 kg of manganese, about 68 kg of nickel, and about 8 kg of cobalt in the cathode. The overall mass of batteries using a given cathode material are assumed to decline by about 20% by 2032 primarily due to a reduction of inactive materials at the cell and pack levels, along with shifts in the anode to a graphite-silicon mix (Slowik et al., 2020). The mass of lithium, manganese, nickel, and cobalt used per kWh of battery capacity, however, is not affected by these improvements. A summary of the metal content of BEV battery cathode materials applied in this analysis in 2023 and 2032 is provided in the appendix.

COMPARISON OF LITHIUM SUPPLY AND DEMAND

Figure 4 presents a comparison between the available lithium supply from the United States and its existing and potential FTA partners, and the domestic demand for lithium required for a new light-duty BEV sales share of 67% by 2032. The solid blue, green, and red lines represent different scopes for reliable lithium supply sources for the United States and the solid orange line indicates the lithium demand from new light-duty BEV sales (see Figure 2). The figure shows that by 2032, even the most conservative scope forecasts an available lithium supply of 1,190 ktpa LCE. We find that 340 ktpa LCE are needed annually by 2032 for the battery packs of about 10.5 million new 300-mile range BEVs.

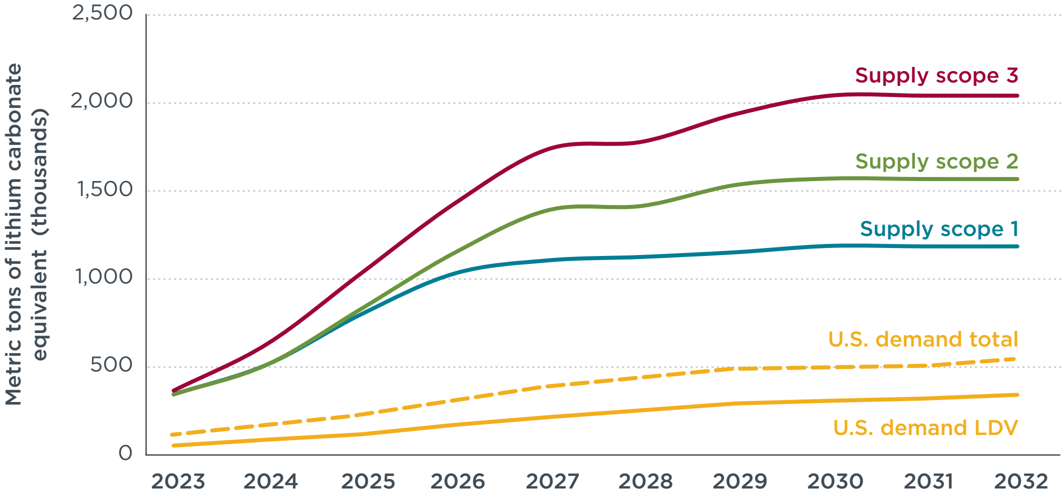

Figure 4. Three scopes of announced lithium supply from United States and its existing and potential FTA and CMA partners compared to lithium demand from new U.S. light-duty BEV sales through 2032.

Although light-duty BEVs represent most lithium demand, other applications require lithium. We assumed the lithium demand from the HDV sector will be 25% of that from the LDV sector (IHS Markit, 2022). We then incorporated the share of lithium demand from non-vehicle sectors from IEA (2023d), which is expected to decrease from 47% of global lithium demand in 2022 to 36% in 2025, 23% in 2030, and 15% in 2035. Utilizing a linear progression from those sources, estimates of total lithium demand are depicted by the dashed orange line in Figure 4. The forecasted total lithium demand in the United States is estimated to be approximately 540 ktpa in 2032. Thus, we found that the lithium supply in from the lowest-volume Scope 1 is greater than the estimates of U.S. lithium demand by a factor of about 1.9.

A key issue to consider is the extent to which the rising global demand for lithium may lead to competition for the supply capacities identified here. We used the distribution of global lithium demand by region forecasted by the ICCT roadmap model (ICCT, 2023) and calculate the lithium demand for the United States and its existing or potential FTA and CMA partners.[3] By applying the same ratio of EV sector and non-EV sector lithium demand as in prior calculations, we find the projected lithium demand for the United States and its existing or potential FTA and CMA partners stands at approximately 1,190 ktpa. These figures show a supply surplus within the United States and its existing FTA and CMA partners for battery minerals in 2032 for Scopes 2 and 3, and project a breakeven supply in in Scope 1, which excludes all announced capacity not yet under construction and supply from potential FTA partners. The result indicates that, despite possible competitive pressures from increased domestic demand in countries with existing U.S. FTAs for battery minerals, the United States is well-positioned to secure sufficient lithium supply to fulfill its domestic needs.

3 We include lithium demand from Africa, Australia, Canada, the European Union, Japan, Latin America, South Korea, and the United Kingdom. These are the regions defined by the ICCT roadmap model that has at least one existing or potential FTA and CMA countries. Thus, it could serve as an upper bound of lithium demand from existing or potential FTA and CMA countries.

LITHIUM, NICKEL, AND COBALT PRICE ASSESSMENT

Stabilized mineral costs is a critical factor for battery costs to continue to fall at the pace and scale needed to achieve upfront BEV price parity with ICE vehicles in the United States in the 2027–2030 timeframe (Slowik et al., 2022). The temporary price increases of lithium, nickel, and cobalt in the 2021–2022 timeframe have raised concerns about the potential of continued high prices to delay expected battery cost reductions by about 2 years (BNEF, 2022). As of mid-2023, prices dropped substantially from their 2022 values, and global average cell costs fell below $100/kWh as a result (Benchmark Mineral Intelligence, 2023). This section investigates historical global lithium, nickel, and cobalt prices and develops four future price scenarios through 2032.

These four distinct price scenarios—low, mid, high, and extreme—were developed using historical price data. Our scenarios start from October 2023, which represents the latest data available at the time of writing this report and serves as starting point for linear projections extending through to 2032. The end points for these low, mid, high, and extreme price scenarios are based on the 25th, 50th, 75th, and 95th percentiles, respectively, of available historical prices.

For lithium, the historical price data are available from May 2017,[4] whereas historical data for nickel and cobalt are available from January 2010. Prices of lithium were derived using spot prices for battery grade lithium carbonate (Li_2CO_3, minimum purity of 99.5%), traded in China in USD per metric ton of LCE (Trading Economics, 2023b). Prices of nickel were collected from International Monetary Fund (2022) using nickel of melting grade (minimum purity of 99.80%) from the London Metal Exchange spot price in USD per metric ton, then were converted to nickel sulphate ($NiSO_4$) equivalent with 22.3% nickel content.[5] Prices of cobalt were collected from International Monetary Fund (2022) using cobalt of minimum 99.80% purity from the London Metal Exchange spot price in USD per metric ton, then were converted to cobalt sulphate ($CoSO_4$) equivalent of 21% cobalt content. Historical prices were converted to 2022 real dollars using CPI inflator of the corresponding month (FRED, 2023).

Figure 5, Figure 6, and Figure 7 show the historical prices of lithium, nickel and cobalt, respectively, along with our low, mid, high, and extreme future price scenarios through 2032. The low, mid, high, and extreme scenarios are represented by thick dashed lines. To provide context to our four future price scenarios, each figure also shows global price forecasts from the best available literature. Future price forecasts from literature were converted to 2022 dollars using 2.5% CPI inflator, which is the average inflation rate between 2010 and 2023.

4 We were only able to apply monthly historical lithium price data going back to May 2017 given the limited availability of historical data.

5 The results may skew slightly higher as the conversion of sulfate to pure metal involves additional steps. This process renders the per-atom cost of nickel more expensive in its purer form.

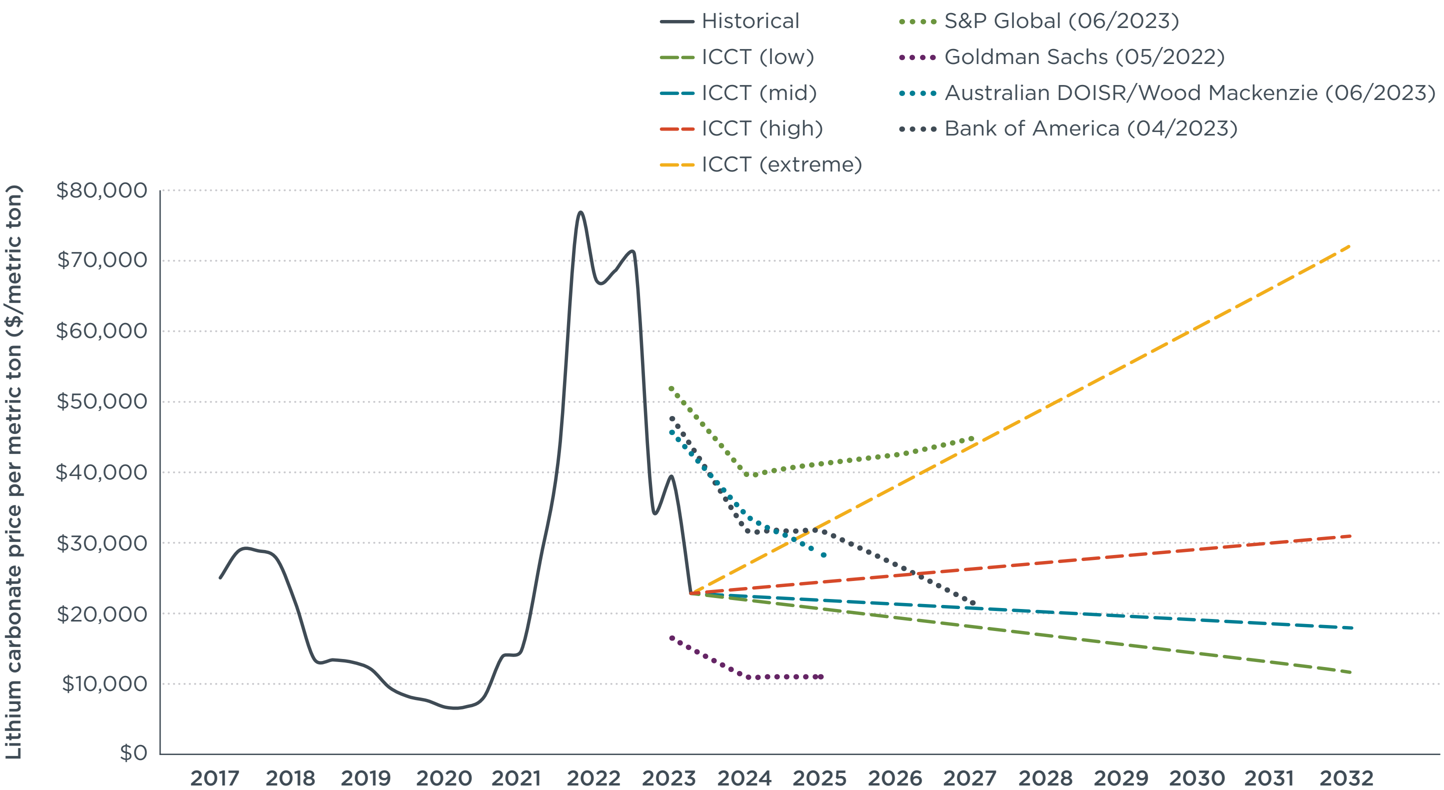

Figure 5. Historical lithium prices and four hypothetical future price scenarios through 2032.

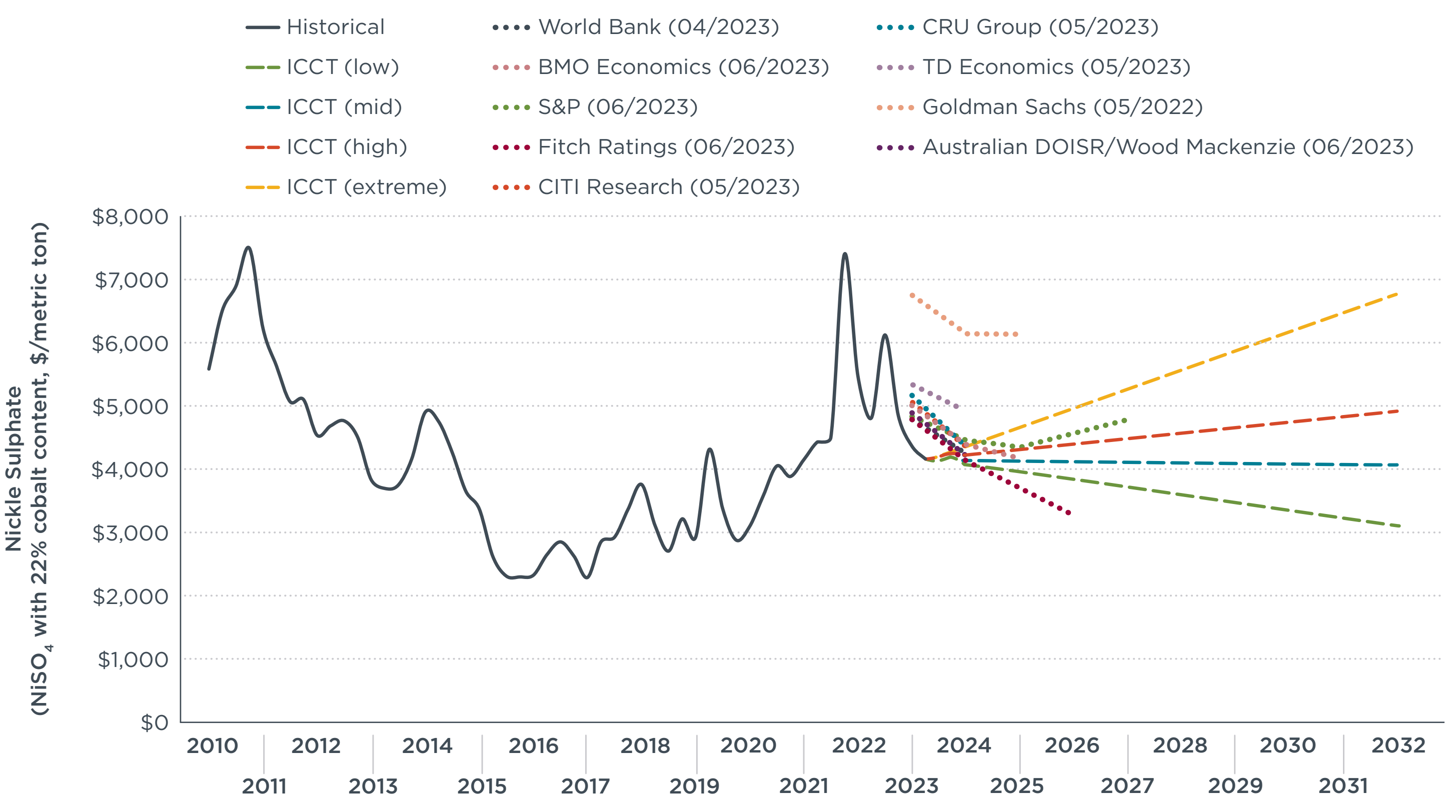

Figure 6. Historical nickel prices and four hypothetical future price scenarios through 2032.

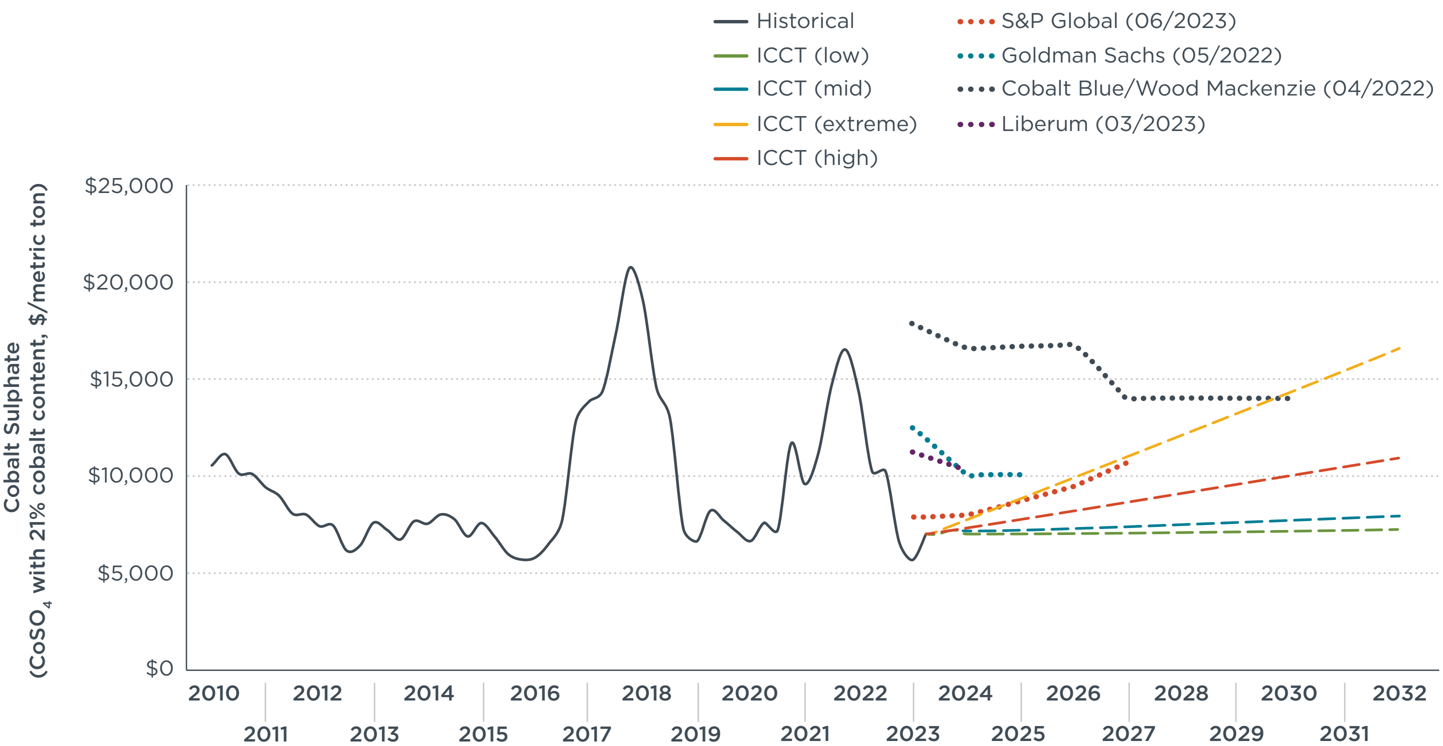

Figure 7. Historical cobalt prices and four hypothetical future price scenarios through 2032.

LITHIUM

The price per metric ton of LCE decreased from a peak of $76,032 in March 2022 to $22,821 in October 2023. Our low, mid, high, and extreme lithium price scenarios correspond to 2032 values of $11,361, $17,851, $31,223, and $71,787 per metric ton of LCE, respectively.

We compared our price scenarios with literature that examines the global lithium supply and demand balance. Although most of the literature does not predict the sudden decline in lithium prices observed during the first half of 2023, there is a broad consensus on a general downward trend. Forecasts from the Australian Department of Industry, Science and Resources, Bank of America, Goldman Sachs, and S&P Global expect lithium prices to continue to decline from their 2022 peaks (Australian DOISR, 2023; Shan, 2023; Godman Sachs, 2023; S&P Global, 2023a).

These forecasts attribute the declining prices primarily to a strong supply-side response worldwide, spurred by recent price spikes and sustained demand; the increased supply is expected to bring the market closer to equilibrium. Our compilation of lithium supply data from the United States and its existing and potential future FTA and CMA partners also confirms a robust supply response, with a substantial increase in North American and Australian refining capacity by 2027.

To further validate our low, mid, high, and extreme lithium price scenarios, we explored the potential future supply and demand dynamics of the global lithium market. Estimates from IEA anticipate that the global lithium supply will amount to 420–460 kt (in lithium metal) per year by 2030, and the global lithium demand based on government electric vehicle targets and commitments will increase to 440 kt (IEA, 2023b; IEA 2023c). This indicates a projected global lithium balance in 2030 that ranges from a slight deficit of 20 kt to a minor surplus of 20 kt. Should additional lithium mining and refining capacities be established, this expansion will stabilize lithium supply to meet demand, thereby mitigating any significant mid-term price spikes.

NICKEL

Historical data indicates that nickel sulfate prices peaked in 2022, with a full-year average of $3,339 per metric ton and a 10-year high of $7,398 per metric ton in March 2022. Prices have since steadily declined, dropping to $4,161 by October 2023. Our low, mid, high, and extreme nickel price scenarios correspond to 2032 values of $3,101, $4,049, $4,902, and $6,809 per metric ton, respectively.

Estimates from IEA anticipate that the global nickel supply will amount to 4190–4210 kt (in nickel metal) per year by 2030 while the global nickel demand based on government electric vehicle targets and commitments will increase to 4500 kt (IEA, 2023b; IEA 2023c). This indicates a projected global nickel balance in 2030 that ranges from a slight deficit of 290 kt to 310 kt.

Several research studies suggest that nickel prices may decline in the next 4 years (BMO Group, 2023; Fitch Ratings, 2023; Goldman Sachs, 2023; Group, 2023; Mining.com, 2023; S&P global, 2023b; Shanghai Metals Market, 2023; TD Economics, 2023; Wood Mackenzie, 2022). Projections beyond 2027 are limited. Most of the literature we investigated expect a price decrease due to the increased supply from Indonesia, which they expect to ultimately lead to a market surplus through 2025. Although Indonesia is not currently an FTA partner with the United States, discussions are underway between these countries to explore potential agreements regarding these minerals (Hunnicutt & Scheyder, 2023). Furthermore, the role of nickel in BEV batteries remains uncertain. In 2022, nickel- and cobalt-free LFP batteries constituted nearly 30% of the global market share. A continued shift towards LFP batteries would further reduce nickel demand.

COBALT

Historical data indicates that cobalt sulfate prices peaked with a full-year average of $17,153 per metric ton in 2018 and of $12,903 per metric ton in 2022, and a 10-year high of $21,393 per metric ton in April 2022. Since its 2022 peak, prices have steadily declined, dropping to $7,018 by October 2023. Our low, mid, high, and extreme cobalt price scenarios correspond to 2032 values of $7,164, $7,942, $10,924, and $16,550 per metric ton, respectively.

To put our low, mid, high, and extreme cobalt price scenarios into context, we explored the future supply and demand dynamics of the global cobalt market. Estimates from IEA anticipated that the global cobalt supply will amount to 310–315 kt (in cobalt metal) per year by 2030, while the global cobalt demand based on government electric vehicle targets and commitments will increase to 265 kt (IEA, 2023b; IEA 2023c). This indicates a projected global cobalt balance in 2030 that ranges from a moderate surplus of 45 kt to 50 kt (12%–14% of projected demand).

There is limited literature on cobalt price forecasts, and particularly recent price forecasts. As shown in the figure, our price forecast is lower than those given by Cobalt Blue (2022) and Goldman Sachs (2023). It is likely these older forecasts did not anticipate additional supply from Congo flooding the market in 2023 and driving down the price (Desai, 2023). However, all forecasts consulted do project declining prices after 2023. The most recent cobalt price forecast from S&P Global (2023a) aligns well with ours through 2025. In the years following, S&P expects the price of cobalt to increase at a faster rate than our high scenario and is similar to our extreme scenario (95th percentile of historical data) in 2030.

Since cobalt is mainly a byproduct of nickel or copper production, Indonesia's ramp-up in nickel production could contribute to an increase in cobalt supply. Continued shifts in battery chemistry towards nickel- and cobalt-free LFP cathode batteries would also reduce cobalt demand. In addition, the continued shift to higher-nickel lower-cobalt NMC-811 and NMC-955 also reduce cobalt demand on a per-kilowatt-hour basis.

OTHER PRICE CONSIDERATIONS

Our wide ranges of raw material price projections are based on the best available data from market spot prices. In practice, raw material prices are typically determined by confidential contract agreements among battery material suppliers and purchasers, many of which are longer-term contracts at lower prices than market spot prices. Therefore, our price projections may overestimate the cost of battery minerals seen by automakers and battery suppliers. Nevertheless, price volatility can impact business decisions from mining companies to automakers. Historcially the industry has responded to market prices by increasing or delaying production to balance supply with demand. At the same time, the development of new mining sites, from exploration to begining commercial production, can take from 4 to more than 20 years, often with an additional 10 years to reach nameplate production capacity (IEA, 2022). While most of the this time is needed for exploration, the actual contruction of a mine is relatively fast. For lithium and nickel mines, for instance, average lead times of 4–5 years from feasibility to the start of production are observed (IEA, 2023c). If market uncertainties result in delays in new exploration, production, and refinement of minerals, additional public policies, funding, or incentives may be needed to ensure new projects come online.

When industry has faced high mineral costs, the global BEV battery market has shifted to technologies with lower cost materials. This reaction is observed in the ongoing trends toward NMC cathodes containing less cobalt, nickel- and cobalt-free LFP cathodes, and most recently the current development of lithium-free sodium-ion batteries. Such technological developments are expected to help the global battery industry navigate around potential supply bottlenecks and price volatility.

BATTERY AND BEV PRICE ANALYSIS

This section analyzes the effect of the above lithium, nickel, and cobalt price scenarios on battery and electric vehicle prices in the United States through 2032. We first developed a bottom-up battery cost analysis to identify the impact of raw material prices on pack-level costs for the four material price scenarios. We then applied these battery pack estimates to the methodology in ICCT's 2022 study on the costs of BEVs in the United States to quantify the overall impact on future BEV prices. Finally, the battery production tax credit and the vehicle purchase incentives of the IRA are applied. We then compared the costs of BEVs and their ICE vehicle counterparts to assess the potential timing of purchase price parity.

BATTERY COSTS

This battery cost analysis built on the most recent ICCT review of estimates for battery pack production costs and future projections, informed by expert sources, research literature projections, and automaker announcements (Slowik et al. 2022). Several battery material and other factors contribute to the expected continued decline in per-kilowatt-hour battery costs.

In terms of battery materials, there has been a global shift from NMC cathodes toward cobalt- and nickel-free LFP cathodes, resulting in lower overall material costs. In parallel, the trend toward nickel-rich NMC cathodes with less manganese and cobalt is expected to continue due to their higher specific energy and lower demand for the relatively expensive cobalt (Figure 3). At the anode-level, the use of graphite-silicon composite increases battery cell specific energy and reduces the demand for graphite. In addition, per-kilowatt-hour cost reductions in the cell electrolyte and separator materials are expected (Wentker, Greenwood, & Leker, 2019; Greenwood, Wentker, & Leker, 2021).

A combination of cell and pack design improvements also contributes to the reduction in the mass of inactive materials, which reduces costs and increases specific energy. This includes improvements in cell format and dimensions (e.g., from cylindrical and pouch to prismatic cells; see Link, Neef, & Wicke, 2023) and at the cell-to-pack level. Other factors include learning, innovation, and reduced production costs per unit due to an increase in production volume to a projected 500,000 or more annually from 2025. Increased plant size, production capacity, and vertical integration reduce per-kilowatt-hour costs for manufacturing; material overhead and scrap; selling and general administrative (SG&A); research and development (R&D); warranty; and profit. The overall effect of this combination of factors is reduced battery pack costs independent of lithium, nickel, cobalt, and other raw battery material prices.

These trends are consistent with other independent battery cost modeling and automaker announcements. UBS (2020) finds a continued reduction in manufacturing, SG&A, profit, R&D, and warranty costs on a per-kWh basis for a range of chemistries. Specifically, per kWh manufacturing costs decline from about $10 to $20 per kWh to about $3 to $6 per kWh from 2020–2021 to 2022–2024. For SG&A, profit, R&D, and warranty, UBS estimates a cost decline from about $27 per kWh to about $10–$16 per kWh depending on the battery chemistry and supplier over that same timeframe. Anderman (2019) estimates a decline in depreciation, overhead, labor, scrap, SG&A, R&D, warranty, and profit from about $45 per kWh to $34 per kWh from 2020–2025. Goldman Sachs (2022b) estimates that by 2025 the combined cost of manufacturing, operation, SG&A, profit, and "other" non-material costs could range from about $26 to $30 per kWh depending on the chemistry.

General Motors forecasts reduced cell costs below $70/kWh and expects about a 40% reduction in cell-level costs that include "enhanced vehicle structures, Ultium cell volume scale, supply chain orchestration, and reuse capabilities" (General Motors, 2022). The company plans for battery production capacity of 160 giga-watt hours and 1.2 million cells per day by the mid-2020s. General Motors executives have cited that the company building its own cells through joint ventures will unlock substantial cost savings (Wayland, 2022).

Tesla plans to reduce battery costs to $55/kWh at the cell level. Many strategies to reduce costs are cathode and anode chemistry changes and reducing raw battery material costs, such as improvements in cell design, cell factory growth, and cell vertical integration. Tesla estimates that bigger cylindrical cells can reduce costs by about 18%, and the company expects new factories with higher volumes to reduce per-kWh costs by an additional 14%. Tesla indicates a reduction of investment per GWh of production by 75% as its capacity increases from 100 GWh in 2022 to 3 TWh by 2030. The company expects its new cathode manufacturing process to reduce cell processing costs by 76%, and cell-vehicle integration will further reduce per kWh costs by an additional 7%. Through these improvements, Tesla expects a 39% decrease in per-kWh costs (Tesla, 2020). Although not explored here, Tesla also expects additional cost reductions due to shifts in cathode and anode materials.

As a precursor to analyzing the impact of changing lithium, nickel, and cobalt prices on battery costs, we first assessed battery costs using consistent raw material prices. Figure 8 shows our assessment of battery costs for 2023 through 2032. The figure shows the costs on several levels, including the costs of the cathode material, the total cell-level material costs, the cell level costs, and the total pack level costs. The figure is based on several inputs including the assumed market share of cathode materials (Figure 3), the specific energy and amount of material of each chemistry on a pack level (GREET, 2022), and the prices of material as of September 2023 $22.8/kg for lithium carbonate, $4.4/kg for nickel sulphate, and $5.7/kg for cobalt sulphate), which are assumed to remain constant. Other battery cost inputs such manganese sulphate, aluminum sulphate, iron sulphate, phosphoric acid, synthetic graphite, and silicon are based data from the Battery Cell Cost Model by Benchmark Mineral Intelligence (2023a) and corroborated with publicly available spot price data as of October 2023 where available (e.g., Trading Economics, 2023a).

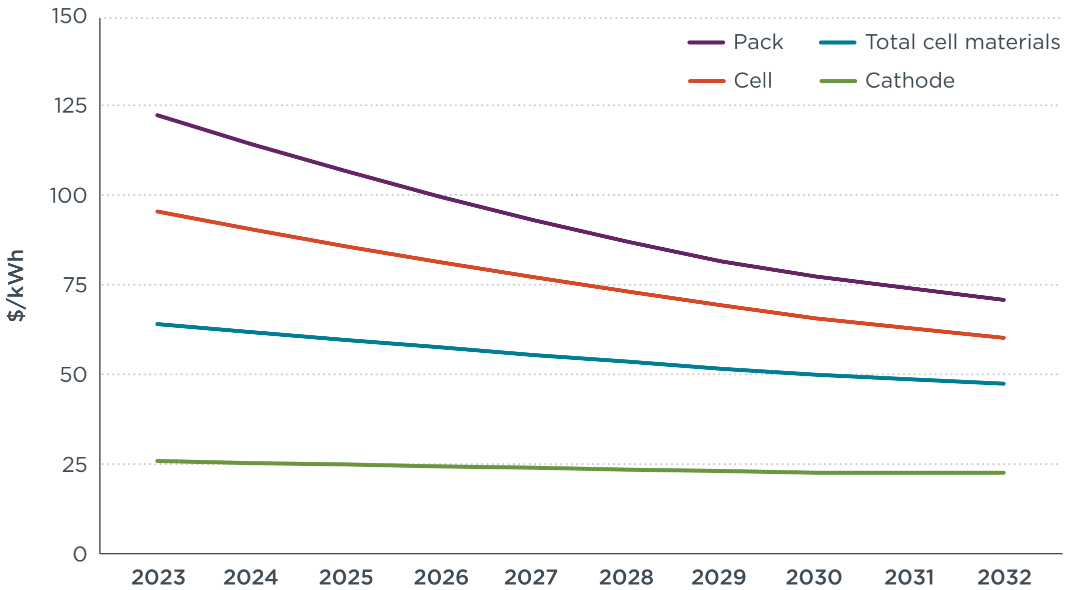

Figure 8. Assessment of battery costs from 2023–2032 with consistent raw lithium, nickel, and cobalt prices from October 2023.

As shown in the figure, the cathode costs, which are the same every year for each chemistry, are about $26/kWh on average. The total cost of all the materials in the cell (cathode material, anode material, electrolyte, separator, current collectors, and housing) declines from about $65/kWh in 2023 to about $50/kWh in 2032 due to reductions in the per-kWh costs of the electrolyte, separator, and reduced mass of the housing. The cell costs add about 50% over the total material costs in 2023 and declines to about 30% in 2032 and include material overhead and production scrap, material processing, cell manufacturing, SG&A, profit, R&D, and warranty. To determine additional costs from combining the cells to modules and packs, we apply a cell-to-pack level cost ratio, which declines from about 0.78 in 2023 to about 0.85 in 2032.

The total cell costs in 2023 are about $98/kWh and decline to about $65/kWh in 2032. This is consistent with reporting by Benchmark Mineral Intelligence (2023b) from September 2023 which showed that global cell-level prices had fallen to below $100/kWh for the first time in two years due largely to reductions in raw material prices. This is also consistent with reporting by BNEF, which found volume-weighted average cell-level battery prices for BEVs of $97/kWh in 2021 and $89/kWh in 2023 (BNEF, 2021; BNEF, 2023).

The total material costs, which include processing, are about 50% of the battery pack costs in 2023. As battery costs fall, raw material prices represent a growing share of total costs; by 2030 material costs are estimated to be about 67% of pack-level costs. Research from 2019–2021 finds that cell-level costs typically make up 70%–80% of pack-level costs (Anderman, 2019; Bloomberg New Energy Finance, 2021), and a 2023 teardown study of the Volkswagen ID4 by FEV found a cell-to-pack cost ratio of 0.82 (U.S. EPA, 2023c).

RAW MATERIAL PRICE IMPACT ON BATTERY COSTS

We applied the four material price scenarios defined above for lithium, nickel, and cobalt for 2024–2032 to assess the effect of changing raw material prices on overall battery pack level costs. The results are shown in Figure 9. The low, mid, high, and extreme price scenario inputs for lithium, nickel, and cobalt are from Figure 5, Figure 6, and Figure 7, respectively. In the mid scenario, where raw material prices shift to about $18.00/kg for lithium carbonate, $4.05/kg for nickel sulphate, and $7.95/kg for cobalt sulphate in 2032, total battery pack-level costs are about $67/kWh. Pack-level costs are reduced to $60/kWh under the low raw material price scenario. Under extreme raw material prices that are 1.5 to 3 times higher than in 2023 ($72/kg for lithium carbonate, $6.80/kg for nickel sulphate, and $16.60/kg for cobalt sulphate), the expected reduction in battery pack costs are limited. As explained above, the assumed raw material prices under this scenario are based on the 95th percentiles of historical prices since 2017 for lithium and 2010 for nickel and cobalt.

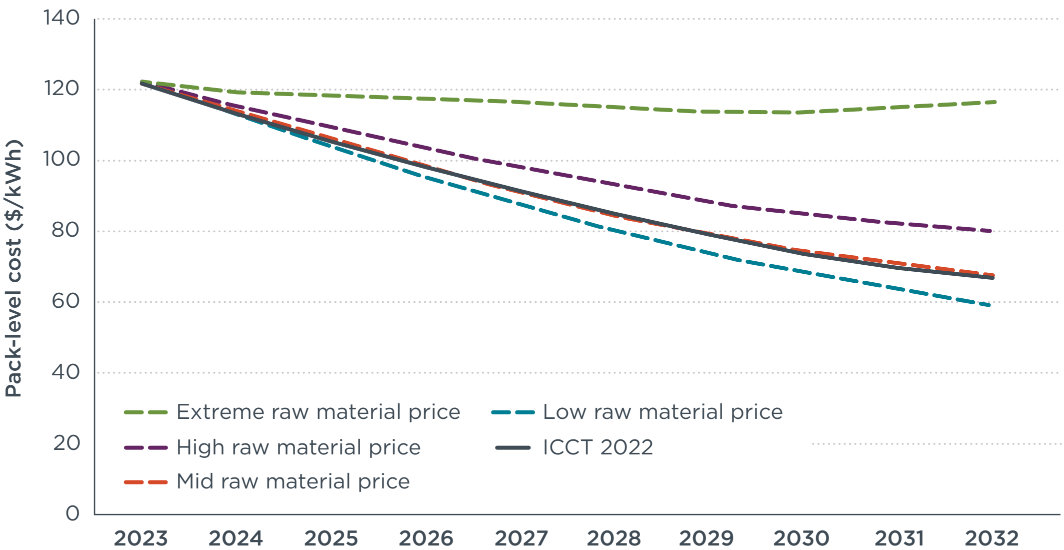

Figure 9. Battery pack costs ($/kWh) under low, mid, high, and extreme raw material price scenarios.

BATTERY ELECTRIC VEHICLE PRICES

We further analyzed BEV prices, based on the above battery pack cost analyses for the raw material price scenarios, with and without tax incentives from the IRA applied. The overall approach of analyzing electric vehicle prices follows that of Slowik et al. (2022), with updates to battery costs based on the above analysis.

Figure 10 shows the findings of upfront purchase prices of conventional combustion engine vehicles and 300-mile range BEVs of the same class. The four BEV lines represent the costs based on the low, mid, high, and extreme raw material price scenarios and are based on the battery pack costs shown in Figure 9. The figure shows 300-mile range electric cars are anticipated to achieve upfront price parity with conventional vehicles around 2027–2028 under the low and mid raw material price scenarios. Under the extreme raw material price scenario, price parity is delayed by about 3 years. The results for crossovers, SUVs, and pickup trucks are shown in the appendix.

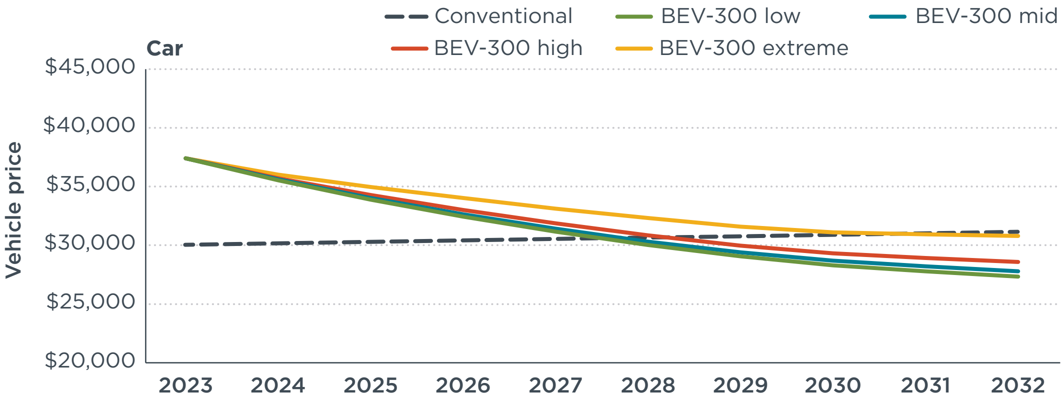

Figure 10. Upfront purchase price of new U.S. conventional and 300-mile range BEVs of the car class with low, mid, high, and extreme raw material price scenarios.

IRA Advanced Manufacturing Production Tax Credit (45X). The Advanced Manufacturing Production Tax Credit (section 45X) provides an incentive to companies of up to $45/kWh, composed of a $35/kWh incentive for cell production and $10/kWh for module assembly in the United States. This credit could be transferred to consumers, effectively reducing the upfront cost of the vehicle. We applied the battery production tax credit (45X) incentive to new BEV prices based on analysis by EPA (2023b), which estimates that 60% of total cells and modules sold in the United States in 2023 were produced domestically and, therefore, are eligible for the credit. This share is assumed to increase linearly to 100% by 2027, and then, as the credit scheme phases out, decline by 25% per year from 75% in 2030 to 0% in 2033. In absolute terms, the estimated value of the battery production tax credit applied to new BEVs sold in the United States is about $27/kWh in 2023, $36/kWh in 2025, $45/kWh in 2027, $34/kWh in 2030, $11/kWh in 2032, and $0 thereafter.

IRA Clean Vehicle Tax Credit (30D). The clean vehicle tax credit (30D) provides an incentive of up to $7,500 for consumers when purchasing qualified electric vehicles. We applied estimates of the average value of the clean vehicle tax credit to new BEVs in our analysis. The estimated average value of the purchase incentive follows the approach of an ICCT and Energy Innovation study of the impact of the IRA on U.S. electric vehicle uptake (Slowik et al., 2023). Specifically, we applied the estimates of the average 30D incentive value from that study's "Moderate IRA scenario" and then further reduce the average new vehicle incentive value by 50% to account for the provision that disqualifies any new electric vehicles from the tax credit if any of the battery components or materials are extracted, processed, or recycled by an FEOC starting in 2025 (Baldwin & Orvis, 2022). Based on all these factors, the average new BEV purchase incentive value applied in this analysis is about $2,500 over the 2023–2032 timeframe.

Figure 11 shows the findings of upfront purchase prices of conventional and 300-mile range BEVs of the SUV class based on the mid raw material price scenario. The BEV curves illustrate the impact of the IRA's 45X and 30D incentives and their impact on upfront price parity. As shown, we find that without any incentives, 300-mile SUVs will reach price parity, on average, around 2028. The incentives reduce BEV prices by several thousands of dollars, and, therefore, accelerate, the timing for upfront purchase price parity by about 3 years. When both the battery production and clean vehicle tax credits are considered, the 300-mile range SUV is expected to reach price parity with its conventional counterpart around 2025. The results for the other light-duty vehicle classes of cars, crossovers, and pickup trucks are shown in the appendix.

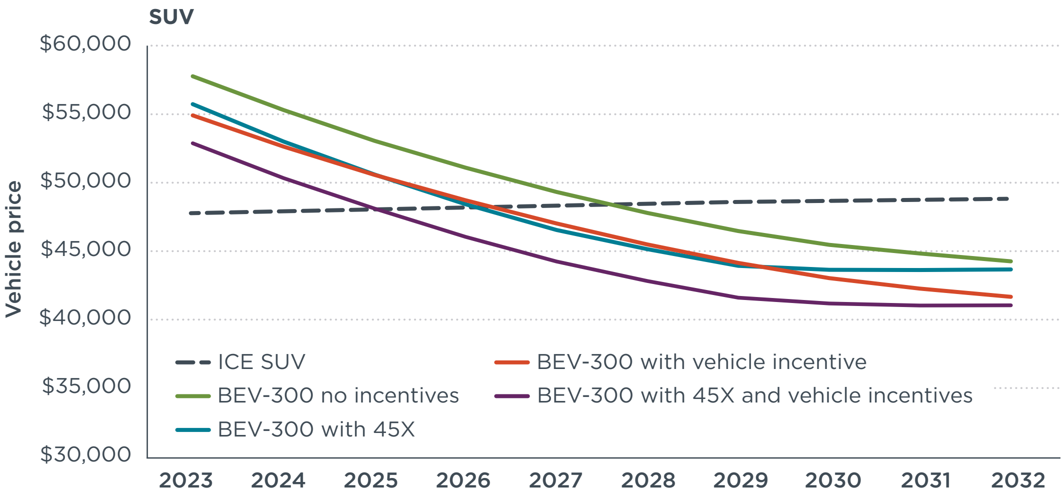

Figure 11. Upfront purchase price of new conventional and 300-mile range BEVs of the SUV class sold in the United States (mid raw material price scenario) with and without IRA incentives.

DISCUSSION

The methodology behind our raw material price scenarios included a broad spectrum of future predictions; these scenarios are consistent with projections from the best available literature. The global supply and demand dynamics are challenging to forecast, and not all future uncertainties can be accounted for in any study. In this section we highlight some uncertainties and opportunities for bolstering the U.S. battery supply chain and its impact on BEV costs in the United States.

RECYCLING

This analysis did not consider the additional mineral supply that could be generated from recycling due to the current scarcity of end-of-life batteries in the United States. Research by Tankou et al. (2023) shows that the global introduction of ambitious recycling policies such as in the European Union's Battery Regulation could reduce the annual demand for key battery materials by 3% by 2030, 11% by 2040, and 28% by 2050. Early planning and investing in recycling can also yield substantial future benefits. A robust recycling industry can mitigate the need for new mineral extraction and simultaneously reduce upstream emissions from battery production (Bieker, 2021).

Confining the recycling process within national boundaries allows for the retention of these materials domestically. This serves to reduce the reliance on external mineral sources, thereby strengthening the resilience and sustainability of the U.S. battery mineral supply chain. Furthermore, recycled battery material content also qualifies for the Clean Vehicle Credit if the recycling takes place in North America, which could further reduce the costs of batteries from recycled materials. If the costs of recycling used battery materials are more affordable than the costs of mining and refining of new materials, recycling could contribute to further reduce battery and electric vehicle costs.

GRAPHITE

Graphite is used as anode material in BEV batteries, either alone in a composite with small amounts of silicon (Institute for Energy Research, 2023). Both synthetic graphite and natural graphite can be used in BEV batteries. As of 2023, China dominates graphite production and processing capacity (IEA, 2023e).

Section 30D of the IRA stipulates that starting in 2025, electric vehicles containing critical minerals (or material in the case of synthetic graphite) that are produced by FEOCs will not be eligible for the $3,750 tax credit. China is classified as a FEOC in the CHIPS and Science Act. If Section 30D is interpreted to define FEOCs in the same way, that will substantially reduce the number of BEVs that can qualify for the clean vehicle tax credit.

Our analysis acknowledged the uncertainty regarding how FEOCs will be defined in the application of the IRA tax credit. We drew upon the findings of Baldwin and Orvis (2022). In their mid-scenario, they project that by 2030 about 78% of the newly manufactured BEVs will satisfy the critical mineral requirements. Moreover, their mid-scenario excludes 50% of new vehicles due to non-compliance with the FEOC criteria. We incorporated this assumption into our study. In 2023, China announced graphite export controls effective starting December 1, 2023, which require export permits for some graphite products to protect national security (Liu & Patton, 2023). This situation underscores a potential risk and necessitates action to establish more natural graphite mining and synthetic graphite production and refining capacities within the United States or with its existing and potential future FTA and CMA partners.

SECURING A RESPONSIBLE BATTERY MATERIAL SUPPLY CHAIN

Battery raw material extraction can provide economic opportunities to source countries, but governance and accountability are needed to ensure that doing so is in the public interest. Improving environmental and social conditions is key to bolstering the reliability and integrity of the supply chain. More responsible raw material sourcing; the use of renewable energy in mining, refining, and manufacturing; and material recovery and recycling will contribute to a more sustainable and ethical supply chain (Transport & Environment, 2019).

U.S. policies and regulations to ensure sustainable and ethical battery material mining and refining practices appear limited as of mid-2023. The European Union has set a precedent in this area with its Battery Regulation, which require companies to identify and mitigate social and environmental risks in the supply chain of cobalt, lithium, nickel, and natural graphite. The Center for American Progress (2023) suggests that the United States collaborate with FTA countries to establish sustainability and human rights standards. The proposal also emphasizes the importance of supporting local communities—often indigenous—that are impacted by mining activities to ensure an equitable and just transition. At the same time, greater recycling capacity could substantially reduce the need for additional extraction.

COMPETITION FOR LITHIUM RESOURCES

The scope of the lithium supply assessment presented in this report illustrates the potential U.S. supply that is relatively more reliable and eligible for IRA tax credits compared to lithium that is sourced elsewhere. There is great potential for much more battery and raw material production from non-U.S. and non-U.S. FTA and CMA markets that, from the U.S. perspective, are likely to be less reliable and are ineligible for IRA tax credits. Global demand for these batteries and raw materials is similarly great.

Our analysis identified a lithium supply surplus when comparing supply from projects in the United States and its existing and potential FTA and CMA partners as of 2023 with lithium demand from BEVs in all these same markets. Outside of these markets, there is additional demand, as well as additional supply. We investigated with less granularity how global lithium BEV demand compares with announced supply, based on data from IEA (IEA, 2023b; IEA 2023c). The IEA data indicate that global lithium demand will reach about 440 kt in 2030, compared to announced global lithium supply of about 420–460 kt. This indicates a projected global lithium balance in 2030 that ranges from a slight deficit of 20 kt to a minor surplus of 20 kt, or about 5% more or less than the projected demand. Any additional new or expanded lithium mining and refining capacities would further ensure that global demand will be met.

The global battery and raw material supply chain is complex, and there is no guarantee that battery and raw material supply within United States and FTA and CMA markets will be obtainable for these markets. Still, the supply and demand findings presented here indicate that there is enough lithium capacity to meet demand for new BEVs, and policies like the IRA that link incentive eligibility to material sourcing can bolster supply chains.

TECHNOLOGICAL PROGRESS

This study applied the best available estimates of incremental battery and vehicle technological advancements and does not consider nascent or next-generation technologies or important technological breakthroughs. Still, the pace and scale of efficiency improvements at the vehicle-level, in battery anodes, and with the cell-to-pack ratio modeled here contribute to reduced battery and raw material demand on a per-vehicle basis. If the rate of technological progress for BEV efficiency or battery specific energy advances at a lower rate than modeled here, the battery and raw material demands would be comparatively greater. In contrast, faster rates of BEV energy efficiency improvement or breakthroughs in solid-state, sodium-ion, or other batteries could potentially lead to reduced battery and raw material demand and lower costs.

The assumed market share of new battery cathodes is another key factor in quantifying the demand of raw materials and the total battery costs. If the market share of lower-cost cobalt-free LFP cathodes are relatively greater than assessed here, the per-kilowatt-hour demand of lithium, nickel, and cobalt would be reduced, and the total battery costs would be lower than identified above. For example, if 100% of new battery cathodes were LFP in 2030, battery pack level costs in 2030 would be about 5% to 16% lower than shown in Figure 9 for the low and extreme raw material price scenario, respectively.

Consistent with our findings above, recent research by S&P global found that U.S. and FTA country lithium supply is likely to be sufficient to meet U.S. demand (S&P Global, 2023d). However, S&P found that cobalt and nickel are both unlikely to be sourced by the United States and its FTA and CMA partners in volumes high enough to meet U.S. demand. Our analysis considered these global supply dynamics by assuming that the United States is an importer of these materials and applies global prices. Our analysis also assumed that half of new BEV sales are ineligible for the 30D tax credit because of the entities of concern and critical mineral percent value provisions. Although exact comparisons are difficult due to lack of transparency, S&P's assessment of U.S. light-duty battery and raw material demand is far higher than quantified here. S&P's average pack size (kWh) per vehicle is about 50% greater than the ICCT values applied here for 2032, and the S&P global study does not specify the average new BEV electric range or the distribution of new sales by light-duty vehicle class. Compared to this analysis, the S&P estimates of nickel and cobalt demand appear to be higher due to the assumed higher share of NCA and lower share of LFP battery cathodes modeled in their demand assessment.

CONCLUSIONS

This paper analyzed key questions regarding the development of the U.S. battery supply chain and its impact on battery and BEV costs from 2023–2032. The study quantified the potential lithium supply to the United States that is eligible for IRA tax credits, generated four price scenarios for lithium, cobalt, and nickel from 2023 to 2032, and applied those price scenarios into bottom-up battery pack and BEV cost modeling to assess the impact of changing raw material prices on the timing of purchase price parity in the United States.

This study reached four key conclusions:

More than 100 lithium mining and refining projects are in operation or planned in the United States and its existing and potential future FTA and CMA partners as of 2023. Together, these facilities amount to a lithium extraction capacity of 1,310 ktpa and a refining capacity of 1,030 ktpa in 2025. By 2032, the extraction capacity is projected to increase to 2,170 ktpa, and the refining capacity to 2,040 ktpa. By 2032, the United States would account for approximately 17% of this mining capacity and 27% of this refining capacity. Countries with existing FTA and CMA like Australia, Canada, Chile, and Peru would account for 56% in mining and 47% in refining capacity. Potential countries for future CMA such as Argentina would account for 28% of mining and 21% of refining capacities considered in this analysis.

The United States has potential to secure a lithium supply that far exceeds the lithium demand from new light-duty BEV sales. This analysis projected U.S. lithium demand from new light-duty BEVs to be approximately 340 ktpa in 2032, which is based on a 67% new sales share in 2032 and an average BEV range of 300-miles. This 340 ktpa demand value represents about 17%–33% of the announced supply in the United States and its existing FTA and CMA partners by 2032. When accounting for additional U.S. lithium demand beyond light-duty vehicles, we estimate that demand could increase to 540 ktpa in 2032, which is less than 50% of the announced supply from our most-conservative estimates that exclude projects not yet under construction. When considering increased lithium demand outside of the United States from its FTA and CMA partners, announced lithium supply still exceeds or is equal to the demand. From a global perspective, the limited literature suggest that global lithium supply may approximately align with global demand by 2030, indicating that any additional new and expanded mining and refining capacity could further ensure that demand could be met.

Battery pack and BEV costs are linked to raw material prices, but substantial and continued battery and BEV cost reductions are expected under most raw material price scenarios. Based on our mid raw material price scenario for lithium, nickel, and cobalt, which correspond to a 50th percentile of historic prices, we projected that battery pack costs decline from about $122/kwh in 2023, to about $91/kWh in 2027, and to $67/kWh in 2032. Under our 25th percentile low raw material price scenario, pack-level costs are reduced to $60/kWh in 2032, whereas under our 75th and 95th percentile high and extreme raw material price scenarios, pack-level costs are about $80/kWh and $115/kWh in 2032, respectively. Based on our mid raw material price scenario, we projected that the upfront purchase prices of average new 300-mile range BEVs will be comparable to those of their gasoline counterparts in the 2028–2029 timeframe for cars, crossovers, SUVs, and pickup trucks without any government incentives, in large part due to technological advancements in BEV energy efficiency and battery specific energy. Under a worst-case extreme raw material price scenario in which lithium, nickel, and cobalt increase to the 95th percentile of their historic prices by 2032, we found that the timing for when BEV purchase prices will be comparable to that of their gasoline counterparts could be delayed by about 2–3 years.

The IRA incentives in the United States for battery production and BEV purchases accelerates the timing for purchase price parity by about 3 years. This study applies estimates of the average value of the IRA Advanced Manufacturing Production Tax Credit (45X) for batteries and the Clean Vehicle Tax Credit (30D) for BEVs, which are estimated to be about $2,000 per vehicle for batteries and about $2,500 for new BEV purchases on average over the 2023-2032 timeframe. When both incentives are combined, upfront BEV prices are reduced by up to $4,500 on average, which accelerates the timing for purchase price parity with conventional alternatives by about 3 years. Critically, the estimates of the Clean Vehicle Tax Credit incentive values assume that half of all new BEV sales comply with the new FEOC provision which disqualifies any new BEVs from the tax credit if any of the battery components or materials are extracted, processed, or recycled by an FEOC starting in 2025. If relatively more or fewer new batteries and their components are sourced from FEOCs, then the average incentive for new BEV purchases would be relatively greater or lesser than estimated here.

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APPENDIX

CRITICAL MINERALS PORTION OF THE IRA'S CLEAN VEHICLE TAX CREDIT

The Clean Vehicle Tax Credit purchase subsidy consists of a battery component portion and a critical mineral portion that each amount to a tax credit of $3,750. To qualify for the battery component portion, a percentage of the value of the vehicle battery components needs to be manufactured or assembled in North America. For the critical mineral portion, a percentage of the value of the critical mineral in the battery needs to be either recycled in North America or extracted or processed in the United States or a country with which the United States has an FTA.

As of 2023 the United States has FTAs with the following countries: Australia, Bahrain, Canada, Chile, Colombia, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Israel, Jordan, Mexico, Morocco, Nicaragua, Oman, Panama, Peru, Singapore, and South Korea Countries the United States has a CMA with are also expected to be eligible. Although not a formal FTA with the United States, the U.S. Treasury Department entered a critical mineral agreement with Japan, which is equivalent to having an FTA for the purpose of these tax credit rules. The same is expected for Argentina, Indonesia, and the European Union, where CMA discussions with the United States are underway (Barragan, 2023).

The applicable percentages for the critical mineral content are set to increase annually from 40% in 2023 to 80% in 2027. The Notice of Proposed Rulemaking from IRS and Treasury proposes a three-step process to determine the percentage of the value of the critical minerals in a battery that contribute towards meeting this requirement (Internal Revenue Service, 2023). This process includes determining procurement chains, identifying qualifying critical minerals, and calculating qualifying critical mineral content.

Figure A1 summarizes part of the process used to determine a vehicle's eligibility for the tax credit. The requirement is satisfied if the "qualifying critical minerals" contained in a battery meets the applicable percentage. The applicable percentage is 40% for 2023 and will tighten by 10 percentage points annually until plateauing at 80% in 2027. To be considered a "qualifying critical mineral," the Treasury Department and the Internal Revenue Service propose that each critical mineral procurement chain satisfy a 50% value added test, which would be met if 50% or more of the value added to the critical mineral by extraction or processing is derived in either the United States or a country with which the United States has an FTA. Additionally, the Treasury Department and the Internal Revenue Service are considering an annual increasing scale for the value-added percentage in the future (similar to the aforementioned applicable percentage scale). Table A1 and Table A2 further describe the critical mineral requirements using a battery pack with hypothetical critical mineral mix.

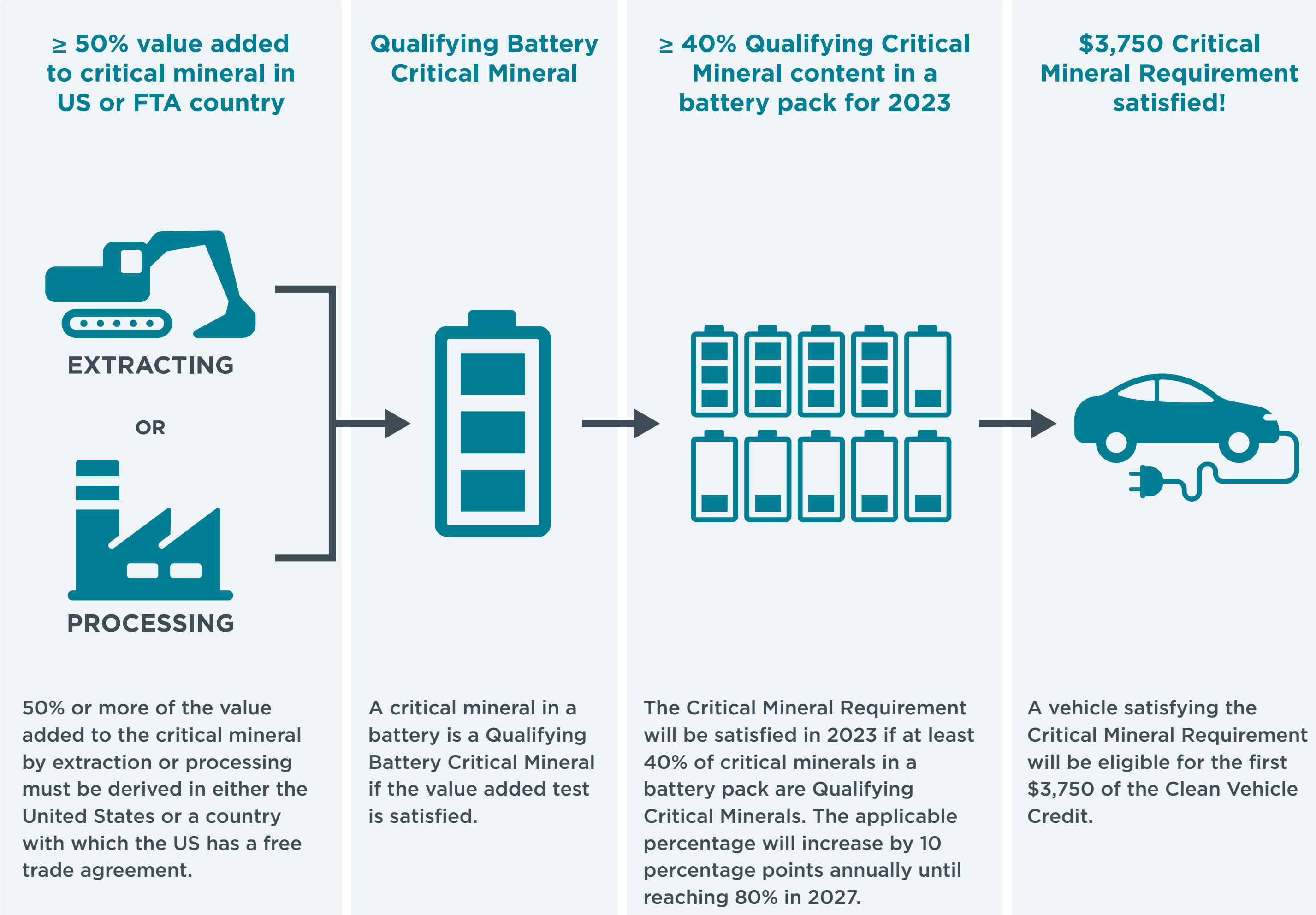

Figure A1. Critical mineral requirement from the updated Clean Vehicle Credit, April 2023.

Table A1. Qualifying critical mineral test (50% value-added test) example.

Critical Mineral	% of value-added from extraction in the United States, FTA or CMA country	% of value-added from processing in the United States, FTA or CMA country	Qualifying critical mineral? (50% value-added test)
Li	80%	0%	Yes, from extraction
Co	0%	0%	No
Ni	25%	75%	Yes, from processing
Graphite	40%	30%	No

Table A2. Cumulative value passing test example.

Critical Mineral	Qualifying critical mineral? (50% value-added test)	% of value from the battery pack	Cumulative qualifying critical mineral share
Li	Yes, from extraction	25%	25%
Co	No	10%	0%
Ni	Yes, from processing	35%	35%
Graphite	No	20%	0%
Total			60%

Foreign Entities of Concern. The final rule published in September 2023 by the Department of Commerce clarified the definition of "foreign entity of concern" for the CHIPS and Science Act of 2022 (U.S. Department of Commerce, 2023). According to the definition, an entity is designated as a FEOC if it is owned by, controlled by, or under the jurisdiction or direction of a country included in the list provided by 10 U.S.C. 4872(d). Under the proposal for the CHIPS Act any entity formed in a covered nation or any entity where at least 25 percent of owned/controlled voting interest is subject to the jurisdiction or direction of a covered nation (CHIPS and Science Act, 2022). Currently, covered nations include the Democratic People's Republic of North Korea, the People's Republic of China, the Russian Federation, and the Islamic Republic of Iran. If the Department of Treasury mirrors the same definition for FEOC as proposed for the CHIPS and Science Act (CHIPS and Science Act, 2022) in its final rule on 30D clean vehicle tax eligibility, the lithium sourced from these joint ventures may not qualify, and therefore might disqualify an EV from receiving clean vehicle tax credit beginning in 2025. The IRS proposed guidance released in April 2023 states that any electric vehicle containing any battery components that are manufactured by FEOC starting in 2024 will not qualify, and any electric vehicle containing any critical minerals that were extracted, processed, or recycled by a FEOC starting in 2025 will not qualify (Internal Revenue Service, 2023). However, how FEOC will be defined is still unclear (Jack et al., 2023).

In our supply and demand analysis for lithium in the United States, Scope 1 (least supply) encompasses lithium sources located in the United States and its existing or potential FTA and CMA partners. We intentionally exclude lithium supplies from FEOCs to ensure that the sources we investigate are reliable. Moreover, such scope aligns with the qualification criteria in Section 30D of the Clean Vehicle Credit. Achieving qualification for this tax incentive could position the United States as a more favored buyer, increasing the dependability of these mineral sources. FTAs usually provide reduced or eliminated tariffs, making exports to the United States financially more attractive. This economic benefit is amplified when coupled with the Clean Vehicle Tax Credits. The combined effect of tariff reductions and tax benefits makes FTA country exports of critical minerals to the U.S. market more cost effective.

BEV COST MODELLING

Table A3 shows the pack-level specific energy (in watt-hours per kilogram) for the different lithium-ion battery chemistries applied in this analysis for 2023 and 2032. The data are taken from GREET (2022) for 300-mile range BEVs (see Iyer & Kelly, 2022). As shown, batteries using NMC cathodes with higher nickel content have higher specific energy compared to those with lower nickel content. Batteries with LFP cathodes have the lowest specific energy of the chemistries applied. For batteries produced in future, the analysis assumes an increased share of silicon-graphite anodes, as well as a reduction of the amount of inactive materials used at the cell and pack level. Until 2032, these trends increase the overall pack-level specific energy of a battery with a given cathode material by about 5% and 20%, respectively. To provide context to the 2023 values from GREET (2022), several high-volume BEV models sold in the United States in 2023 have battery pack specific energy values that are greater than applied here. For example, several Tesla models have a specific energy value of about 187 Wh/kg, and the Ford F150 Lightning has a specific energy rating of 198 Wh/kg (U.S. Department of Energy, 2023; Ford, 2022).

Table A3. Summary of specific energy (Wh/kg) for lithium-ion battery packs for different chemistries in 2023 and 2032 in this analysis.

Year	NMC-111	NMC-532	NMC-622	NMC-811	NMC-955	NCA	LFP
2023	158	164	165	174	180	170	133
2032	192	199	200	211	218	206	161

For each battery chemistry, the amount of material in kilogram per kilowatt-hour (kg/kWh) is based on the battery pack specific energy (Table A3) and the relative amount of each element and the corresponding molar mass. Table A4 summarizes the content of a selection of key materials (in kg material per kWh of battery capacity) assumed for batteries in 2023 and 2032. The material content in the cathode remains the same for all years. At the anode, a shift from graphite anodes to anodes with a graphite-silicon composite reduces the amount of graphite while increasing the amount of silicon. Relative to batteries using graphite anodes, using a graphite-silicon composite anode increases pack-level specific energy (in watt-hours per kilogram) by about 5%. This improvement is weighted by the market share of batteries using graphite-silicon composite anode. We assume that the share of batteries with a graphite-silicon composite anode increase from 5% in 2022 to 55% by 2032. The values in the table reflect a market share weighted average as the percentage of batteries with a graphite-silicon anode mix increases from 5% in 2022 to 55% by 2032. The amount of graphite in batteries using graphite anodes is 9 kg/kWh (IEA, 2023d) and the amount of graphite and silicon in batteries using graphite-silicon anodes is assumed to be about 0.34 kg/kWh of graphite and 0.09 kg/kWh of silicon, based on IEA (2023d) and Dai, Kelly, Dunn, and Benavides (2018).

Table A4. Summary of material content for key materials in battery cathodes and anodes assumed in this analysis in 2023 and 2032 (kg/kWh).

Year	Material	NMC-111	NMC-532	NMC-622	NMC-811	NMC-955	NCA	LFP
2023	Lithium	0.12	0.11	0.10	0.10	0.09	0.10	0.08
	Nickel	0.34	0.46	0.52	0.65	0.70	0.67	0.00
	Manganese	0.32	0.26	0.16	0.08	0.04	0.00	0.00
	Cobalt	0.34	0.18	0.17	0.08	0.04	0.13	0.00
	Aluminum	0.00	0.00	0.00	0.00	0.00	0.02	0.00
	Phosphorous	0.00	0.00	0.00	0.00	0.00	0.00	0.36
	Graphite	0.84	0.84	0.84	0.84	0.84	0.84	0.84
	Silicon	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2032	Lithium	0.12	0.11	0.10	0.10	0.09	0.10	0.08
	Nickel	0.34	0.46	0.52	0.65	0.70	0.67	0.00
	Manganese	0.32	0.26	0.16	0.08	0.04	0.00	0.00
	Cobalt	0.34	0.18	0.17	0.08	0.04	0.13	0.00
	Aluminum	0.00	0.00	0.00	0.00	0.00	0.02	0.00
	Phosphorous	0.00	0.00	0.00	0.00	0.00	0.00	0.36
	Graphite	0.59	0.59	0.59	0.59	0.59	0.59	0.59
	Silicon	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Figure A2 shows the upfront purchase price of new U.S. conventional vehicles and 300-mile range BEVs for cars, crossovers, SUVs, and pickup trucks under the low, mid, high, and extreme raw material price scenarios. As shown, under the low and mid raw material price scenario price, parity is anticipated around 2028 (cars, crossovers, SUVs) to 2029 (pickups). In comparison, the expected timing for price parity under the worst-case extreme raw material price scenario is delayed by about two to three years.

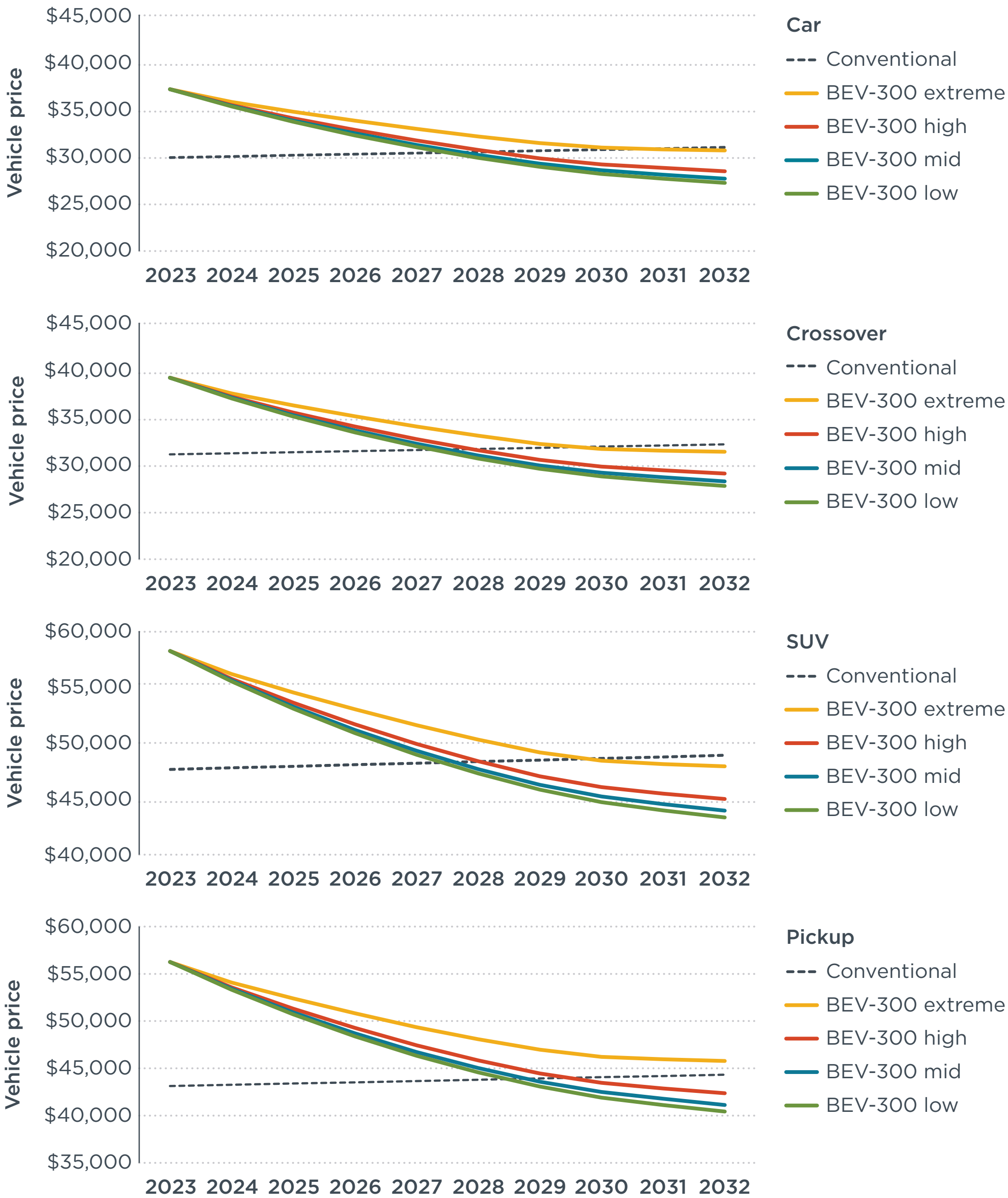

Figure A2. Upfront purchase price of new U.S. conventional and 300-mile range BEVs for cars, crossovers, SUVs, and pickup trucks with low, mid, high, and extreme raw material price scenarios.

Figure A3 shows the upfront purchase price of new U.S. conventional vehicles and 300-mile range BEVs for cars, crossovers, SUVs, and pickup trucks based on the mid raw material price scenario, with and without IRA battery production and clean vehicle tax incentives. As shown, the battery production and clean vehicle tax credits combined reduce BEV prices by about $4,000 (cars) to $5,000 (pickups) and accelerate the timing for upfront purchase price parity by about three years.

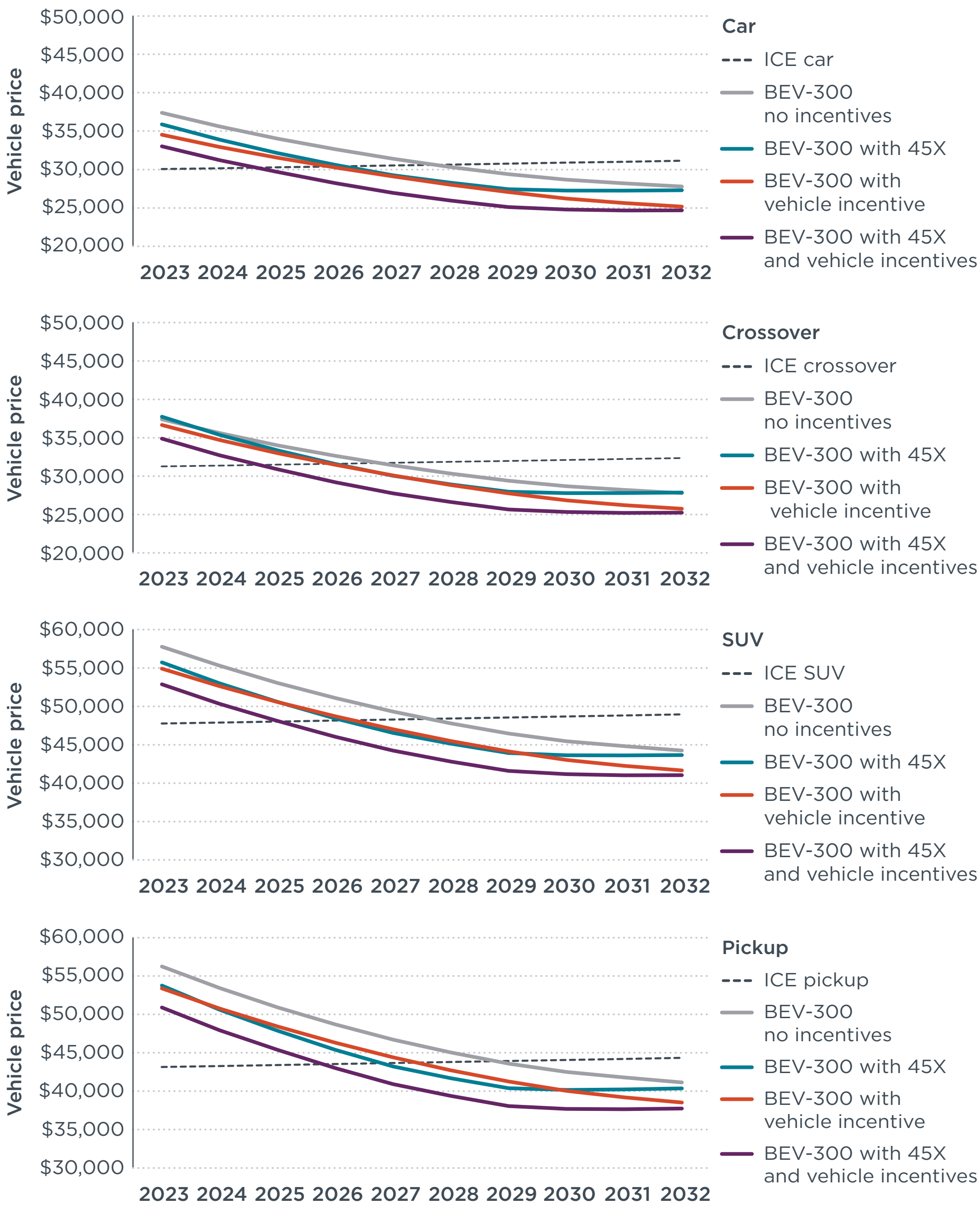

Figure A3. Upfront purchase price of new U.S. conventional vehicles and 300-mile range BEVs for cars, crossovers, SUVs, and pickup trucks (mid raw material price scenario) with and without IRA incentives.

LITHIUM SUPPLY CAPACITIES

Table A5 and Table A6 show the raw data for 55 lithium mining and 54 lithium refining facilities and their capacity, respectively, for existing, new, or expanding mining and refining projects in the United States and existing and potential FTA and CMA countries as of June 2023.

Table A5. Lithium mining facilities and their capacity in the United States and its existing and potential future FTA and CMA countries (Tier 1, 2 ,3 countries).

Country	Plant Name	Tier	FEOC	Status	Material Type	Projected lithium capacity ('000 tonnes)										
						'22	'23	'24	'25	'26	'27	'28	'29	'30	'31	'32
United States	Silver Peak Mine	1	No	Active	Lithium Carbonate (LCE)	5	5	5	10	10	10	10	10	10	10	10
United States	Thacker Pass Mine	1	No	Under development	Lithium Carbonate (LCE)					33	33	33	33	66	66	66
United States	Rhyolite Ridge Project	1	No	Prospective	Lithium Carbonate (LCE)					24	24	24	24	24	24	24
United States	Carolina Lithium Project	1	No	Prospective	lithium hydroxide					46	46	46	46	46	46	46
United States	Tennessee Lithium	1	No	Prospective	lithium hydroxide											
United States	Hell's Kitchen Lithium	1	No	Under development	lithium hydroxide				43	43	43	43	43	43	43	43
United States	Clayton Valley Lithium	1	No	Prospective	Lithium Carbonate (LCE)					27	27	27	27	27	27	27
United States	Kings Mountain	1	No	Prospective	Spodumene concentrate (6%)						52	52	52	52	52	52
United States		1	No	Under development	Lithium Carbonate (LCE)				11	11	11	35	35	35	35	35
United States	USMag Lithium	1	No	Active	Lithium Carbonate (LCE)	10	10	10	10	10	10	10	10	10	10	10
United States	South West Arkansas Project	1	No	Prospective	lithium hydroxide						46	46	46	46	46	46
Australia	Finniss Lithium Project	2	No	Active	Spodumene concentrate (6%)	2	27	29	28	29	29	24	21	24	21	21
Australia	Kathleen Valley	2	No	Under development	Spodumene concentrate (6%)			74	74	74	74	74	104	104	104	104
Australia	Bald Hill	2	No	Active	Spodumene concentrate (6%)	23	23	23	23	23	23	23	23	23	23	23
Australia	Mount Cattlin	2	No	Active	Spodumene concentrate (6%)	29	29	29	29	29	29	29	29	29	29	29
Australia	Mount Holland	2	No	Under development	Spodumene concentrate (6%)			28	56	56	56	56	56	56	56	56
Australia	Pilgangoora	2	No	Active	Spodumene concentrate (6%)	56	101	101	101	148	148	148	148	148	148	148
Australia	Wodgina	2	No	Active	Spodumene concentrate (6%)	37	37	37	37	37	111	111	111	111	111	111
Australia	Greenbushes	2	Yes	Active	Spodumene concentrate (6%)	199	199	199	199	199	199	199	199	199	199	199
Australia	Mount Marion	2	Yes	Active	Spodumene concentrate (6%)	67	134	134	134	134	134	134	134	134	134	134
Canada	North American Lithium project	2	No	Active	Spodumene concentrate (6%)			33	33	33	33	33	33	33	33	33
Canada	James Bay	2	No	Under development	Spodumene concentrate (6%)			48	48	48	48	48	48	48	48	48
Canada	Rose Lithium-Tantalum Project	2	No	Active	Spodumene concentrate (6%)				33	33	33	33	33	33	33	33
Canada	Whabouchi lithium mine	2	No	Under development	Spodumene concentrate (6%)					32	32	32	32	32	32	32
Canada	Moblan Lithium Project	2	No	Prospective	Lithium Carbonate (LCE)						25	25	25	25	25	25
Canada	Authier Lithium Project	2	No	Active	Spodumene concentrate (6%)		17	17	17	17	17	17	17	17	17	17
Canada	Georgia Lake Project	2	No	Prospective	Spodumene concentrate (6%)						15	15	15	15	15	15
Canada	Separation Rapids Lithium	2	No	Prospective	Lithium hydroxide						23	23	23	23	23	23
Canada	Clearwater Lithium Project	2	No	Prospective	Lithium hydroxide				31	31	31	31	31	31	31	31
Canada	Thompson Brothers Lithium Project	2	No	Prospective	Spodumene concentrate (6%)						24	24	24	24	24	24
Canada	Frontier Lithium Project	2	No	Prospective	lithium hydroxide								19	19	19	19
Canada	Frontier Lithium Project	2	No	Prospective	Lithium Carbonate (LCE)								7	7	7	7
Chile	La Negra conversion plant/Atacama salt flat	2	No	Active	Lithium Carbonate (LCE)	44	85	85	85	85	85	85	85	85	85	85
Chile	Salar Del Carmen/Salar de Atacama salt flats	2	No	Active	Lithium Carbonate (LCE)	95	130	220	220	220	220	220	220	220	220	220
Chile	Salar Del Carmen/Salar de Atacama salt flats	2	No	Active	lithium hydroxide	32	39	46	46	46	46	46	46	46	46	46
Chile	Maricunga	2	No	Under development	Lithium Carbonate (LCE)				15	15	15	15	15	15	15	15
Chile	Laguna Verde	2	No	Prospective	Lithium Carbonate (LCE)					20	20	20	20	20	20	20
Peru	Falchani Lithium Project	2	No	Prospective	Lithium Carbonate (LCE)						23	23	23	23	23	23
Argentina	Fenix Project	3	No	Active	Lithium Carbonate (LCE)	20	24	34	38	56	68	68	77	98	98	98
Argentina	Kachi	3	No	Under development	Lithium Carbonate (LCE)			25	25	25	50	50	50	50	50	50
Argentina	Centenario-Ratones	3	No	Under development	Lithium Carbonate (LCE)				24	24	24	24	24	74	74	74
Argentina	Sal de Oro	3	No	Under development	lithium hydroxide				39	39	39	39	39	39	39	39
Argentina	Sal de Vida	3	No	Under development	Lithium Carbonate (LCE)			15	15	15	45	45	45	45	45	45
Argentina	Olaroz	3	No	Active	lithium carbonate (LCE)	13	13	13	16	16	16	33	33	33	33	33
Argentina	Rincon	3	No	Prospective	Lithium Carbonate (LCE)			30	30	30	30	30	30	30	30	30
Argentina	Cauchari/Olaroz	3	Yes	Under development	Lithium Carbonate (LCE)			40	40	40	40	40	40	40	40	40
Argentina	Mariana	3	Yes	Under development	Lithium Carbonate (LCE)			10	10	10	10	10	10	10	10	10
Argentina	Tres Quebradas	3	Yes	Under development	Lithium Carbonate (LCE)			20	20	20	20	20	20	20	20	20
Argentina	Angeles	3	Yes	Prospective	Lithium Carbonate (LCE)			25	25	25	25	25	25	25	25	25
Austria	Wolfsberg Lithium Project	3	No	Under development	lithium hydroxide				16	16	16	16	16	16	16	16
Brazil	Grota do Cirilo	3	No	Under development	Lithium Carbonate (LCE)			37	104	104	104	104	104	104	104	104
Finland	Keliber	3	No	Under development	lithium hydroxide					23	23	23	23	23	23	23
Germany	Vulcan Lithium Project	3	No	Under development	lithium hydroxide					37	37	37	37	37	37	37
Ghana	Ewoyaa Lithium	3	No	Under development	Spodumene concentrate (6%)				54	54	54	54	54	54	54	54

Note: tier 1 = United States, tier 2 = Countries with *FTA or CMA* with the United States, tier 3 = C*ountries currently discussing CMA* with the United States

Table A6. Lithium refining capacity from the United States and its existing and potential future FTA and CMA countries (Tier 1, 2 ,3 countries).

Country	Plant Name	Tier	FEOC	Status	Material Type	Projected lithium capacity ('000 tonnes)										
						'22	'23	'24	'25	'26	'27	'28	'29	'30	'31	'32
Argentina	Bessmer City	1	No	Active	lithium hydroxide	8	8	15	15	15	15	15	15	15	15	15
Australia	Tesla Lithium Refinery	1	No	Under development	lithium hydroxide				31	31	31	31	31	31	31	31
Canada	Tesla Lithium Refinery	1	No	Under development	lithium hydroxide				31	31	31	31	31	31	31	31
Ghana	Tennessee Lithium	1	No	Under development	lithium hydroxide				46	46	46	46	46	46	46	46
United States	Silver Peak Mine	1	No	Active	lithium carbonate (LCE)	5	5	5	10	10	10	10	10	10	10	10
United States	Thacker Pass Mine	1	No	Under development	lithium carbonate (LCE)					33	33	33	33	66	66	66
United States	Rhyolite Ridge Project	1	No	Under development	lithium carbonate (LCE)					24	24	24	24	24	24	24
United States	Carolina Lithium Project	1	No	Under development	lithium hydroxide					46	46	46	46	46	46	46
United States	Hell's Kitchen Lithium	1	No	Under development	lithium hydroxide				43	43	43	43	43	43	43	43
United States	Clayton Valley Lithium	1	No	Under development	lithium carbonate (LCE)					27	27	27	27	27	27	27
United States	Round Top	1	No	Prospective	lithium carbonate (LCE)											
United States	South West Arkansas Project	1	No	Prospective	lithium hydroxide						46	46	46	46	46	46
United States	Bonnie Claire Project	1	No	Prospective	lithium carbonate (LCE)											
United States	Mega-Flex	1	No	Under development	lithium hydroxide						77	77	154	154	154	154
United States	Compass Minerals Lithium	1	No	Under development	lithium carbonate (LCE)				11	11	11	35	35	35	35	35
United States	USMag Lithium	1	No	Active	lithium carbonate (LCE)	10	10	10	10	10	10	10	10	10	10	10
Argentina	Naraha	2	No	Active	lithium hydroxide			15	15	15	15	15	15	15	15	15
Australia	Kemerton Plant (Greenbushes and Wodinga)	2	No	Active	lithium hydroxide		77	77	77	154	154	154	154	154	154	154
Australia	Mount Holland	2	No	Under development	lithium hydroxide			39	77	77	77	77	77	77	77	77
Australia	Kathleen Valley	2	No	Prospective	lithium hydroxide								44	44	44	44
Australia	Finniss Lithium	2	No	Prospective	lithium hydroxide											
Australia	Gwangyang	2	No	Active	lithium hydroxide			33	66	66	66	66	66	66	66	66
Canada	North American Lithium project	2	No	Prospective	lithium carbonate (LCE)					23	23	23	23	23	23	23
Canada	Rose Lithium-Tantalum Project	2	No	Prospective	lithium hydroxide						47	47	47	47	47	47
Canada	Becancour conversion facility (via Whabouchi mine)	2	No	Under development	lithium hydroxide					32	32	32	32	32	32	32
Canada	Moblan Lithium Project	2	No	Prospective	lithium carbonate (LCE)						25	25	25	25	25	25
Canada	Thunder Bay (via Separation Rapids Lithium mine)	2	No	Under development	lithium hydroxide						23	23	23	23	23	23
Canada	Clearwater Lithium Project	2	No	Under development	lithium hydroxide				31	31	31	31	31	31	31	31
Canada	Thompson Brothers Lithium Project	2	No	Prospective	lithium hydroxide				31	31	31	31	31	31	31	31
Canada	Frontier Lithium Project	2	No	Prospective	lithium hydroxide								19	19	19	19
Canada	Frontier Lithium Project	2	No	Prospective	lithium carbonate (LCE)								7	7	7	7
Chile	La Negra conversion plant/Atacama salt flat	2	No	Active	lithium carbonate (LCE)	44	85	85	85	85	85	85	85	85	85	85
Chile	Salar Del Carmen/Salar de Atacama salt flats	2	No	Active	lithium carbonate (LCE)	95	130	220	220	220	220	220	220	220	220	220
Chile	Salar Del Carmen/Salar de Atacama salt flats	2	No	Active	lithium hydroxide	32	39	46	46	46	46	46	46	46	46	46
Chile	Maricunga	2	No	Under development	lithium carbonate (LCE)				15	15	15	15	15	15	15	15
Chile	Laguna Verde	2	No	Under development	Lithium Carbonate (LCE)					20	20	20	20	20	20	20
Peru	Falchani Lithium Project	2	No	Prospective	lithium carbonate (LCE)						23	23	23	23	23	23
Australia	Kwinana Plant (Greenbushes)	2	Yes	Active	lithium hydroxide	9	37	74	74	74	74	74	74	74	74	74
Argentina	Fenix Project	3	No	Active	lithium carbonate (LCE)			4	8	26	38	38	47	68	68	68
Argentina	Kachi	3	No	Under development	lithium carbonate (LCE)			25	25	25	50	50	50	50	50	50
Argentina	Centenario-Ratones	3	No	Under development	lithium carbonate (LCE)				24	24	24	24	24	74	74	74
Argentina	Sal de Oro	3	No	Under development	lithium hydroxide				39	39	39	39	39	39	39	39
Argentina	Sal de Vida	3	No	Under development	lithium carbonate (LCE)			15	15	15	45	45	45	45	45	45
Argentina	Olaroz	3	No	Active	lithium carbonate (LCE)	13	13	13	16	16	16	33	33	33	33	33
Argentina	Rincon	3	No	Under development	lithium carbonate (LCE)			30	30	30	30	30	30	30	30	30
Austria	Wolfsberg Lithium Project	3	No	Under development	lithium hydroxide				16	16	16	16	16	16	16	16
Brazil	Grota do Cirilo	3	No	Under development	Lithium Carbonate (LCE)			37	104	104	104	104	104	104	104	104
Canada	Guben lithium converter (via Georgia Lake Project mine)	3	No	Under development	lithium hydroxide					25	25	25	25	25	25	25
Finland	Keliber	3	No	Under development	lithium hydroxide					23	23	23	23	23	23	23
Germany	Guben lithium converter (via Finniss lithium Australia)	3	No	Under development	lithium hydroxide					12	12	12	12	12	12	12
Germany	Vulcan Lithium Project	3	No	Under development	lithium hydroxide					37	37	37	37	37	37	37
Argentina	Cauchari/Olaroz	3	Yes	Under development	lithium carbonate (LCE)			40	40	40	40	40	40	40	40	40
Argentina	Mariana	3	Yes	Under development	lithium carbonate (LCE)			10	10	10	10	10	10	10	10	10
Argentina	Tres Quebradas	3	Yes	Under development	lithium carbonate (LCE)			20	20	20	20	20	20	20	20	20
Argentina	Angeles	3	Yes	Under development	Lithium Carbonate (LCE)			25	25	25	25	25	25	25	25	25

Note: Tier 1 = United States, Tier 2 = Countries with *FTA or CMA* with the United States, Tier 3 = C*ountries currently discussing CMA* with the United States www.theicct.org

communications@theicct.org

@theicct.org

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