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Evaluating strategies to address material supply–demand gaps in the US electric vehicle battery supply chain

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Jieyi Lu [1], Jesse D. Jenkins [2,3], Chris Greig [3] & Denise L. Mauzerall [1,4]

To address supply shortfalls in the electric vehicle battery supply chain, US policy has prioritized expanding domestic production. However, we find that this strategy alone cannot meet future material demand. If announced projects materialize, domestic production can meet 2035 demand for raw lithium, lithium carbonate, lithium hydroxide, electrolytes and separators used in major battery chemistries. However, many other materials still face substantial and persistent gaps even with demand-side strategies, including improved material efficiency, enhanced battery recycling and battery chemistry shifts. Shortfalls of ~30–70% persist for upstream cobalt, graphite, nickel and their midstream refined materials. For some of these materials, gaps may widen because ~30–100% of projected domestic supplies rely on early-stage projects, which may not advance. Downstream, cathode and anode active materials face ~15–75% shortfalls. Therefore, securing US battery materials will require investment across the domestic supply chain, reductions and shifts in material demand and international sourcing.

Electric vehicles (EVs), including battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), have gained an increasing share of global and US automotive markets, reaching 20% of global sales in 2024, including nearly 50% in China and 10% in the USA[1]. These trends are increasing the strategic importance of supply chains to produce the batteries that power them. In this Article, we quantitatively assess strategies for the USA to mitigate material supply–demand gaps for the production of EV batteries, which is necessary for achieving a resilient supply chain[2–4]. Our analysis evaluates the contributions of domestic production expansion, strategies to reduce and shift material demand and the need for imports.

Producing EV batteries requires critical materials whose supply chain comprises four key stages: (1) upstream mining and extraction of minerals such as lithium, nickel, cobalt, graphite and manganese; (2) midstream processing of these minerals into battery chemicals; (3) downstream manufacturing of battery components, cells and packs and (4) end-of-life management via reuse, recycling or disposal. Global production of these critical materials is highly concentrated, with a few countries such as Australia, China, Indonesia, the Democratic Republic of the Congo dominating mining and China dominating the midstream and downstream supply chain[5]. By comparison, the USA has limited capacity across these stages, leaving its ability to meet future battery material demand dependent on imports and therefore vulnerable to global supply disruptions.

In response to these risks, US policy has taken two major approaches in recent years. Under the Biden administration, a security-focused approach sought to expand domestic production, prioritize sourcing from allied countries and reduce reliance on countries of concerns. For example, the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022 (IRA) provided a range of grants, loans and tax incentives to expand mineral mining and processing, battery component and cell manufacturing and end-of-life battery recycling capacity in the USA, while applying sourcing requirements to EV purchase incentives that favour the USA

[1]Princeton School of Public and International Affairs, Princeton University, Princeton, NJ, USA. [2]Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ, USA. [3]Andlinger Center for Energy and the Environment, Princeton University, Princeton, NJ, USA. [4]Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ, USA. e-mail: mauzerall@princeton.edu

and allied countries[6,7]. More recently, the Trump administration has pursued a domestic-first approach that seeks to maximize domestic sourcing and reduce imports. The One Big Beautiful Bill Act of 2025 (OBBBA) directs billions of dollars through federal defence and industrial programs to promote critical mineral development[8]. Despite repealing the EV purchase incentives introduced under the IRA, the OBBBA retains a modified Section 45X Advanced Manufacturing Production Credit that supports domestic sourcing of critical minerals and batteries[8]. The administration has also imposed tariffs to enhance domestic production[9]. Regardless of the approach, whether the USA can secure enough battery materials to meet future demand remains an open question.

While recent US efforts largely emphasize expanding domestic supply, demand-side strategies can play a critical role in reducing material needs and easing pressure on the supply chain. First, enhancing battery recycling can recover materials from end-of-life batteries and can be achieved via increasing end-of-life battery collection, expanding recycling capacity and improving material recovery efficiency[10–12]. Second, a shift to alternative battery chemistries that reduce reliance on scarce materials can be beneficial. For example, transitioning from nickel manganese cobalt (NMC) batteries to lithium iron phosphate (LFP) batteries can reduce the need for nickel, manganese and cobalt, and in some cases, shifting to nickel cobalt aluminium (NCA) batteries can reduce reliance on cobalt and manganese[12,13]. All of these materials face limited domestic production capacity in the USA. Sodium-ion (Na-ion) batteries are also emerging as a potential alternative chemistry due to the abundance of sodium and their compatibility with existing lithium-ion (Li-ion) battery manufacturing infrastructure[14,15]. On the anode side, silicon is increasingly used to replace graphite. Third, improving vehicle efficiency and battery energy density can reduce battery material demand by delivering the same performance and driving range with smaller or lighter batteries[16,17].

A growing number of studies have explored strategies to mitigate vulnerabilities in EV battery supply chains globally and in major countries. However, they have three main limitations. First, the existing literature does not capture the systemic nature of the EV battery supply chain in which multiple materials must be simultaneously supplied for battery production. Most studies examine materials at the mining and processing stages, such as lithium, cobalt, nickel, manganese and graphite[18–22], but overlook materials in the downstream stage. Studies that trace materials through multiple stages of the supply chain typically limit their scope to a single material[23]. Second, it remains unclear how the combination of supply expansion and demand-side strategies affect multiple materials across the supply chain. Most studies assess either supply expansion or demand-side strategies in isolation[12,18,24–26]. When both are studied, the analyses are often limited to one material such as lithium[20,21] or cobalt[23]. Third, the impacts of the OBBBA on the EV battery supply chain remain underexplored. Recent analyses focus on the IRA[25,26], but the OBBBA has substantially modified the IRA and has profound impacts on EV adoption and supply chain investments.

To fill these gaps, we quantitatively evaluate how future US EV battery material demand can be met across the supply chain, covering upstream (raw materials), midstream (refined materials), downstream (components and cells) and recycling for LFP, NCA and NMC batteries. Specifically, we assess (1) how much demand can be met by domestic production under post-OBBBA conditions, (2) how demand-side strategies mitigate gaps and (3) what levels of imports would be required to fully close the gap. We find that domestic expansion and demand-side strategies are not sufficient to meet projected material demand in 2035. Shortages persist across the supply chain. Our findings highlight the continued need for international sourcing alongside investment across the domestic EV battery supply chain and implementation of demand-side strategies.

Analysis of supply- and demand-side strategies

We quantify material supply–demand gaps across the US EV battery supply chain for LFP, NCA and NMC chemistries from 2025 to 2035. (The 2035 results are presented in the main text, and the 2026 and 2030 results are provided in Supplementary Table 13.) On the supply side, we estimate supply from US domestic production (existing and planned projects) and imports independently for each material at each stage, without constraining supply by the availability in preceding stages. On the demand side, we use projected EV sales in the USA following the repeal of EV purchase incentives after the OBBBA, apply estimated battery chemistry shares and trace material requirements through each supply chain stage. On the basis of these estimates, we first evaluate how supply expansion can mitigate supply shortfalls. We then evaluate three demand-side strategies in turn: (1) improving material efficiency via increased vehicle efficiency and battery energy density; (2) advancing recycling and (3) shifting to alternative battery chemistries that use less constrained materials. Finally, we examine the combined impacts of all supply- and demand-side strategies and test the results under alternative EV market developments. The strategies are described in Table 1, with additional details provided in Methods and Supplementary Notes 1 and 2.

Impacts of supply expansion

In the Supply Expansion Scenario, we evaluate potential supply from planned projects in the USA, as well as in Canada and Mexico, where investment decisions have been influenced by US policy. Figure 1 shows supply–demand gaps in 2035 by material, supply source and project status. We find that US domestic supply would be sufficient to meet the demand for multiple materials, including raw materials such as bauxite and lithium; refined materials such as aluminium hydroxide, aluminium sulfate, lithium carbonate and lithium hydroxide; and components such as LFP cathode active materials (CAMs), graphite-silicon anode active materials (AAMs), electrolytes and separators. With imports, the USA can also meet demand for graphite AAM and battery cells. However, supply shortages are projected for cobalt, nickel, graphite, manganese and their refined materials, as well as NMC CAMs, NCA CAMs and binders. Notably, depending on the material, about 30–100% of the upstream and midstream domestic supply relies on early-stage projects that have not yet secured permits, making future availability uncertain, even for materials that appear sufficient.

Upstream, bauxite and lithium stand out as the only materials for which domestic production alone is sufficient to meet projected demand. However, lithium relies heavily on the materialization of early-stage projects: only 6% (67 kt) of demand is met by existing and advanced-stage domestic projects that are already permitted, under construction or operational, with an additional 78% (929 kt) relying on early-stage projects and 17% (197 kt) from recycling the end-of-life EV batteries. Substantial gaps remain for cobalt, nickel, graphite and manganese. Cobalt and nickel face the largest supply shortfalls, with 76% (5 Mt) and 83% (11 Mt) of their respective demand unmet. Domestic supply, including existing supply, advanced-stage and early-stage projects, contributes 14% (825 kt) of cobalt demand and 2% (297 kt) of nickel demand. Imports offer limited relief, covering <1% (823 t) of cobalt demand and 4% (550 kt) of nickel demand. Recycling helps reduce reliance on raw material supply, contributing to about 10% for both cobalt (622 kt) and nickel (1 Mt). In addition, graphite shows a 65% (638 kt) gap, with 8% (78 kt) met by domestic projects and 2% (24 kt) by imports, while recycling offsets 24% (235 kt). Manganese faces a 43% gap (64 kt). There is no contribution from domestic supply because the USA neither mines manganese ore nor hosts any planned investment in new manganese mining. Manganese imports from countries that do not have free trade agreement with the USA (non-FTA), such as South Africa and Gabon, contribute 41% (61 kt) of the demand, whereas other countries add 6% (9 kt). Recycling remains an important supplement, meeting 10% (15 kt) of manganese demand.

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Table 1 | Overview of supply-side and demand-side strategies, scenarios, key parameters and assumptions with all values referring to year 2035 unless otherwise stated

	Supply-side strategy	Demand-side strategies			Supply-side + demand-side strategies
	Supply Expansion Scenario	**Improved Material Efficiency Scenario**	**Enhanced Recycling Scenario**	**Switch to Alternative Battery Chemistries Scenario**	**Combined Strategy Scenario**
Description	Accounts for planned supply-side investments in the USA, Canada and Mexico, existing US production and imports.	Improves vehicle efficiency and battery energy density to reduce battery weight while maintaining range and performance.	Enhances end-of-life battery collection rates, removes recycling capacity constraints and adopts advanced recycling technologies.	Shifts to battery chemistries using less constrained materials.	Integrates all supply- and demand-side strategies.
EV battery demand	EV battery demand reflects discontinuation of the IRA's EV purchase incentives.				
Domestic production and imports	Existing US production, imports and announced investments in the USA, Canada and Mexico.				
Battery weight	~10% reduction (versus 2025).	~20% reduction (versus 2025).	Same as in Supply Expansion Scenario.	Same as in Supply Expansion Scenario.	~20% reduction (versus 2025).
End-of-life battery collection rate	15%.	Same as in Supply Expansion Scenario.	60%.	Same as in Supply Expansion Scenario.	60%.
End-of-life battery recycling capacity	Accounts for existing and announced US projects.	Same as in Supply Expansion Scenario.	No constraint.	Same as in Supply Expansion Scenario.	No constraint.
End-of-life battery material recovery efficiency	100% hydrometallurgical.	Same as in Supply Expansion Scenario.	90% hydrometallurgical and 10% direct recycling.	Same as in Supply Expansion Scenario.	90% hydrometallurgical and 10% direct recycling.
Battery chemistry market share	5% LFP, 68% NMC, 27% NCA and 0% Na-ion. 98% graphite AAMs and 2% graphite-silicon AAMs.	Same as in Supply Expansion Scenario.	Same as in Supply Expansion Scenario.	25% LFP, 33% NMC, 41% NCA and 0.5% Na-ion. 76% graphite AAMs and 24% graphite-silicon AAMs.	45% LFP, 17% NMC, 38% NCA and 0.2% Na-ion. 86% graphite AAMs and 14% graphite-silicon AAMs.

Midstream, aluminium hydroxide and aluminium sulfate, which are processed from bauxite and used in NCA production, fully meet 2035 demand through domestic supply. Demand for lithium carbonate and lithium hydroxide can be supplied by early-stage projects for 73% (90 kt) and 100% (129 kt), respectively. Existing and advanced-stage projects can contribute 10% (13 kt) of lithium carbonate demand and none of the lithium hydroxide demand. Shortfalls exist for cobalt sulfate (64%, 125 kt), nickel sulfate (75%, 663 kt) and manganese sulfate (13%, 18 kt). For cobalt sulfate, domestic production meets only 24% (48 kt) of demand, sourced from a mix of existing, advanced-stage and early-stage projects. Domestic supplies of manganese sulfate and nickel sulfate depend entirely on early-stage projects, meeting 47% (65 kt) and just 4% (36 kt) of their respective demand. Recycling offers a buffer, contributing 10% of demand for cobalt sulfate (20 kt), manganese sulfate (14 kt) and nickel sulfate (91 kt). In addition, imports from Canada and Mexico add <1% (2 kt) of cobalt sulfate, 11% (97 kt) of nickel sulfate and 28% (39 kt) of manganese sulfate, but most remain early stage and uncertain. Imports from other countries contribute <1% for cobalt sulfate (665 t) and nickel sulfate (390 t) and 2% for manganese sulfate (2 kt).

Downstream, we are unable to distinguish project development status due to data constraints[27]. Given the lower investment risks and shorter development timelines of downstream facilities as compared to mining and processing, we assume that all planned manufacturing projects are at the advanced stage. Domestic production expansion shows stronger coverage in the downstream, with 2035 demand fully met for several components, including LFP CAMs, graphite-silicon AAMs, electrolytes and separators. However, NMC and NCA CAMs each face a 60% shortfall (335 kt for NMC; 130 kt for NCA). Domestic production supplies 35% of demand (196 kt NMC; 77 kt for NCA), with another 2% from Canada and Mexico and 3% from other countries. Supply of binders, which are essential for electrode stability and adhesion, remains a concern, with 68% (19 kt) unmet. Imports are expected to meet 32% of demand for binders, with contributions of 4 kt from Canada and Mexico, 2 kt from other FTA countries, 185 t from foreign entity of concern (FEOC) countries (mostly China) and 3 kt from other countries. Demand for LFP, NMC and NCA battery cells can be met by domestic US supply at 76%, Canada and Mexico at 5% and other FTA countries at 19%.

Impacts of demand-side strategies

In the Improved Material Efficiency Scenario, we model potential improvements in material efficiency, which is achievable through increased vehicle efficiency and battery energy density. Specifically, we adjust battery capacity and energy density parameters such that the battery weight would decrease gradually across all battery chemistries from 2025, reaching a reduction of about 20% by 2035[17] (Table 1 and Methods). As shown in Fig. 2a, improving material efficiency alone lowers material demand and mitigates supply–demand gaps across the entire supply chain.

Beginning at the vehicle and battery level, impacts of material efficiency improvements cascade through downstream, midstream and upstream stages. Downstream, improvements are observed for NCA CAMs, NMC CAMs and binders, with supply shortfalls reduced to 50% (86 kt), 50% (223 kt) and 60% (13 kt), respectively. Efficiency gains also lower the demand for components that do not face shortfalls under the Supply Expansion Scenario, including LFP CAMs, AAMs (both

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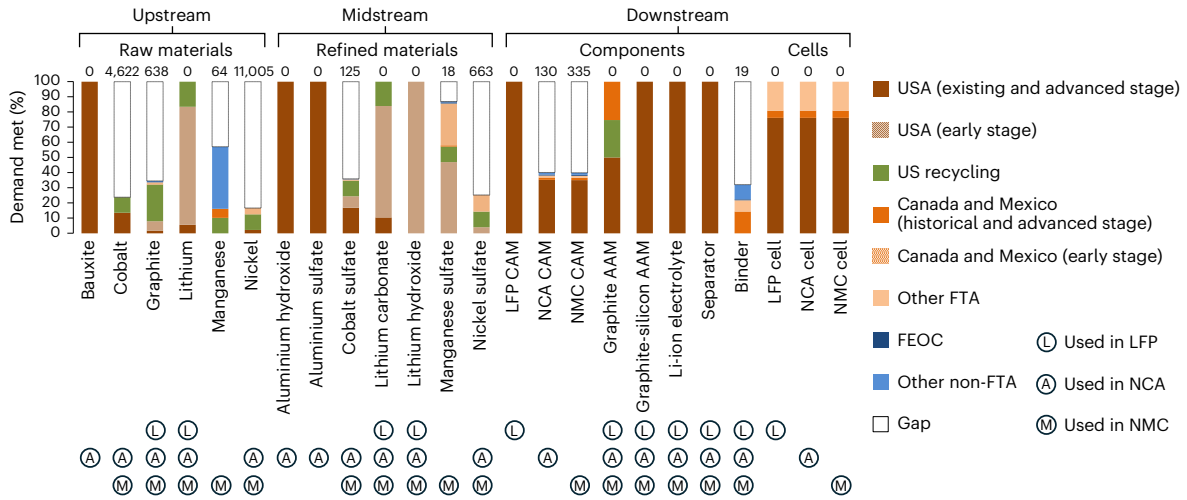

Fig. 1 | Material supply–demand gaps in 2035 under the Supply Expansion Scenario. Bars represent the percentage of demand met, with supply–demand gaps (kt) reported above each bar. Existing supply reflects the recent average annual US production. Historical supply reflects the recent average annual amount of materials imported to the USA. Advanced-stage supply includes planned projects that have been permitted, are under construction or are operational. Early-stage supply includes planned projects that have not yet been permitted. This distinction between advanced and early stage is applied only to upstream raw material and midstream refined material production stages. All component production, cell manufacturing and recycling projects are assumed to be at the advanced stage. US recycling refers to materials recycled from end-of-life batteries in the USA. Other FTA refers to countries with free trade agreements with the USA excluding Canada and Mexico. FEOC refers to foreign entity of concern countries. Other non-FTA refers to countries without free trade agreements with the USA excluding FEOC countries. LFP refers to lithium iron phosphate batteries, NCA refers to nickel cobalt aluminium batteries and NMC refers to nickel manganese cobalt batteries.

graphite and graphite-silicon), electrolytes, separators and battery cells, thereby increasing the margin between expected supply and demand and reducing the reliance on imports.

Midstream, lower downstream demand translates into reduced need for refined materials. The most notable impact is on manganese sulfate, where demand reduction enables domestic supply and imports to fully meet demand. Gaps for cobalt sulfate and nickel sulfate decline to 56% (86 kt) and 69% (488 kt), respectively. Demand also declines for materials that already show sufficient supply under the Supply Expansion Scenario, including aluminium hydroxide, aluminium sulfate, lithium carbonate and lithium hydroxide, providing additional buffer and reducing dependency on early-stage projects.

Upstream, demand reductions enable domestic production to reduce reliance on early-stage projects for lithium. Supply shortfalls also decrease to 71% (3 Mt) for cobalt, 58% (452 kt) for graphite, 29% (35 kt) for manganese and 80% (8 Mt) for nickel.

In the Enhanced Recycling Scenario, we model improvements in recycling through increasing collection rates of end-of-life EV batteries, expanding recycling capacity to accommodate all collected batteries and improving material recovery efficiency by incorporating both hydrometallurgical and direct recycling technologies (Table 1 and Methods). Hydrometallurgical processes recover refined materials, while direct recycling regenerates intact components such as CAMs and binders. Our analysis accounts for the combined impact of these two technologies. Figure 2b shows that enhancing recycling contributes to the availability of recovered materials at both midstream and downstream stages, which in turn lowers the demand for inputs across the supply chain and reduces their gaps.

Downstream, enhanced recycling, particularly through direct recycling, benefits materials that can be recovered in usable form. Notably, 100% of demand for binders in 2035 can be met by expanding recycling. Graphite AAMs also benefit, with 50% (265 kt) of projected demand met by recycled AAMs. NCA and NMC CAMs show modest gains, with recycling meeting about 5% of demand, corresponding to 12 kt and 33 kt, respectively.

Midstream, increasing recycling supplements domestic production of lithium carbonate and lithium hydroxide and reduces the need for production of new materials. Recycling also contributes to mitigating supply–demand gaps for cobalt sulfate, nickel sulfate and manganese sulfate, meeting about 25% of their respective demand, equivalent to 48 kt of cobalt sulfate, 218 kt of nickel sulfate and 34 kt of manganese sulfate.

Upstream, recycled materials reduce reliance on virgin mineral extraction by offsetting a portion of demand for critical minerals. In 2035, enhanced recycling is projected to meet 24% (1 Mt) of cobalt demand, 50% (483 kt) of graphite demand, 29% (342 kt) of lithium demand, 25% (37 kt) of manganese demand and 25% (3 Mt) of nickel demand. However, substantial supply shortfalls remain: 62% (4 Mt) for cobalt, 40% (390 kt) for graphite, 29% (43 kt) for manganese and 69% (9 Mt) for nickel.

In the Switch to Alternative Battery Chemistries Scenario, we develop an optimization model that estimates the maximum EV battery production and the resulting battery chemistry mix based on domestic supply, rather than relying on predetermined assumptions of EV battery chemistry mix as in prior studies[13,18,23,28] (Methods). This represents a best-case, mass-based allocation of battery chemistries that maximizes EV battery production while meeting US sourcing requirements in the upstream, midstream and downstream stages. Our model estimates 122 GWh of EV battery production in 2035, sufficient to support ~2 million EVs, assuming 70 kWh per vehicle (Supplementary Fig. 1). The resulting chemistry mix consists of 25% LFP, 33% NMC, 41% NCA and 0.5% Na-ion batteries, compared to 5%, 68%, 27% and 0%, respectively, under the Supply Expansion Scenario. A similar shift is observed in anode materials, with graphite AAMs and graphite-silicon AAMs comprising 76% and 24%, respectively, versus 99.8% and 0.2% previously. We apply this optimized chemistry mix to the projected 2035 EV battery demand and evaluate the resulting material gaps.

As shown in Fig. 2c, this battery chemistry shift substantially reduces gaps for materials used in NMC batteries, with corresponding improvements midstream and upstream. At the same time, it increases demand for materials used in NCA, LFP and Na-ion batteries, widening gaps for those materials.

Downstream, the shift reduces supply shortfalls for NMC CAMs to 52% (148 kt). However, increased demand for NCA, LFP and Na-ion

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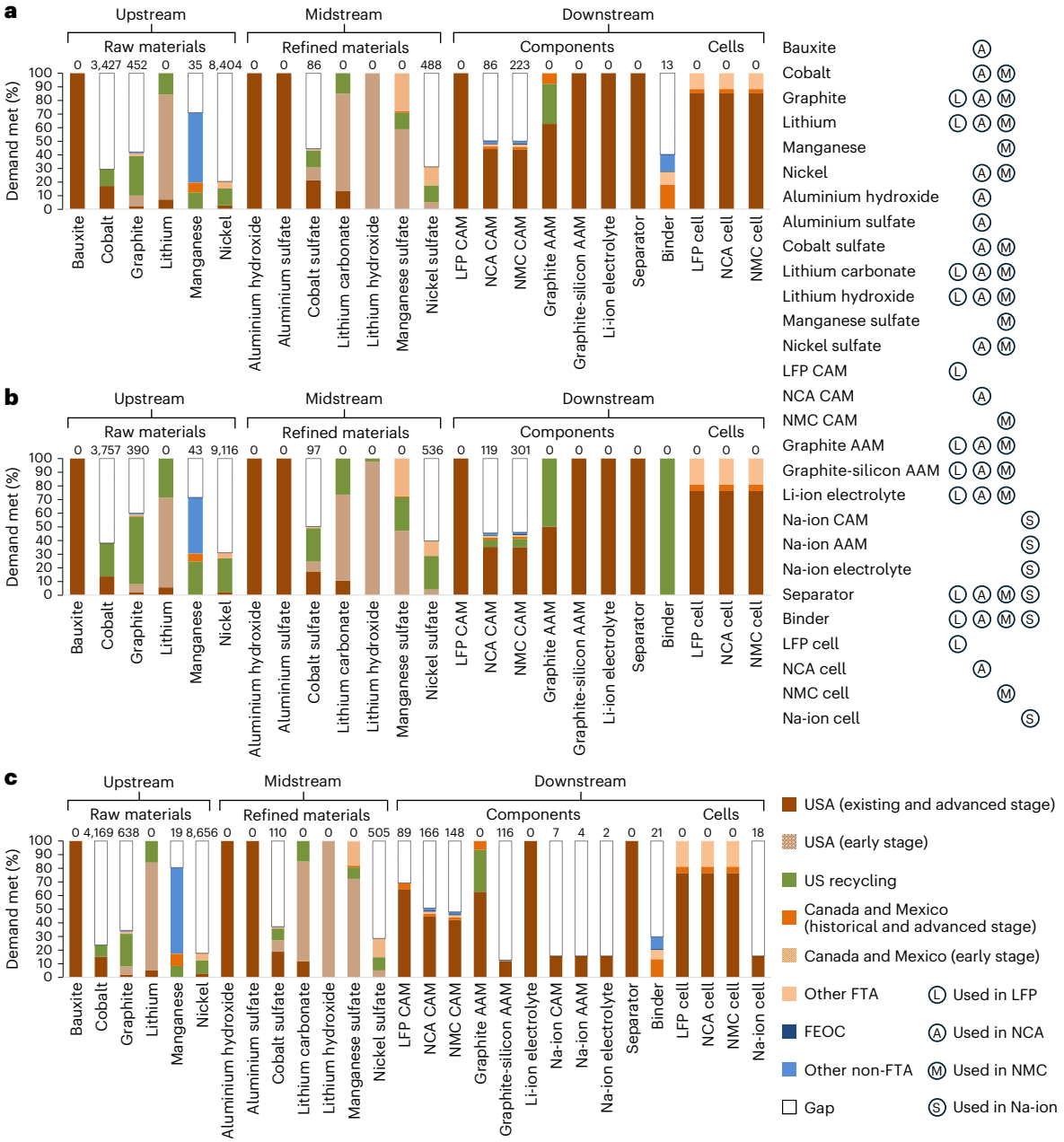

Fig. 2 | Material supply–demand gaps in 2035 under demand-side strategies. **a**, Improved Material Efficiency Scenario. **b**, Enhanced Recycling Scenario. **c**, Switch to Alternative Battery Chemistries Scenario. Bars represent the percentage of demand met, with supply–demand gaps (kt) reported above each bar. Existing supply reflects the recent average annual US production. Historical supply reflects the recent average annual amount of materials imported to the USA. Advanced-stage supply includes planned projects that have been permitted, are under construction or are operational. Early-stage supply includes planned projects that have not yet been permitted. This distinction between advanced and early stage is applied only to upstream raw material and midstream refined material production stages. All component production, cell manufacturing and recycling projects are assumed to be at the advanced stage. US recycling refers to materials recycled from end-of-life batteries in the USA. Other FTA refers to countries with free trade agreements with the USA excluding Canada and Mexico. FEOC refers to foreign entity of concern countries. Other non-FTA refers to countries without free trade agreements with the USA excluding FEOC countries. LFP refers to lithium iron phosphate batteries, NCA refers to nickel cobalt aluminium batteries, NMC refers to nickel manganese cobalt batteries and Na-ion refers to sodium-ion batteries. The corresponding values for material supply–demand gaps in panels **a**–**c** are compared in Supplementary Table 14.

batteries widens shortfalls and introduces new constraints. Shortfalls of NCA CAMs increase to 49% (166 kt). LFP CAMs, which do not face shortages under the Supply Expansion Scenario, are projected to develop a supply shortfall of 31% (89 kt) due to rising demand. The shift towards graphite-silicon AAMs increases their gap to 87% (116 kt). Binder demand also rises, resulting in a shortfall of 21 kt. For Na-ion batteries, increased adoption creates gaps across components and cells, with an overall shortfall of 85%, corresponding to 18 kt for cells, 7 kt for CAMs, 4 kt for AAMs and 2 kt for electrolytes.

Midstream, the chemistry shift reduces gaps in supply-constrained materials. Demand for manganese sulfate is fully met by domestic supply and imports. Shortfalls for cobalt sulfate and nickel sulfate fall to 63% (110 kt) and 71% (505 kt), respectively. Other refined materials, including lithium carbonate, lithium hydroxide, aluminium hydroxide

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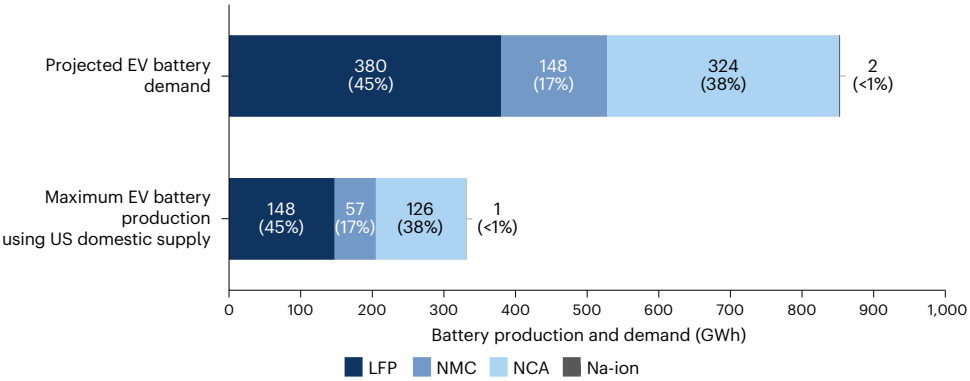

Fig. 3 | Maximum EV battery production using US domestic supply and projected EV battery demand in 2035. Battery production and demand are shown in GWh, with optimized battery chemistry shares in parentheses. Maximum production and optimized chemistry mix are estimated using the optimization model developed in this study ('Optimization model' section in Methods). US domestic supply includes existing supply, planned projects and recycling. Projected EV battery demand in 2035 is calculated based on the REPEAT Project's EV sales projections[29], assuming repeal of federal EV purchase incentives post-OBBBA, and an assumed average battery size of 70 kWh per vehicle. LFP refers to lithium iron phosphate batteries, NCA refers to nickel cobalt aluminium batteries, NMC refers to nickel manganese cobalt batteries and Na-ion refers to sodium-ion batteries.

and aluminium sulfate remain sufficient to meet 2035 demand under the new chemistry mix.

Upstream, substantial shortfalls persist for key critical minerals in this scenario, though gaps for cobalt, manganese and nickel narrow to 76% (4 Mt), 19% (19 kt) and 82% (9 Mt), respectively. The gap for graphite slightly decreases to 638 kt, despite the shift towards LFP chemistries, which have a higher graphite intensity. This is because the large reduction in NMC deployment, together with a shift towards graphite-silicon AAMs, offsets the associated increase in graphite demand. Lithium remains sufficient to meet its 2035 demand.

Impacts of combined supply- and demand-side strategies

In the Combined Strategy Scenario, we evaluate the impact of supply expansion and all three demand-side strategies. Our optimization model estimates the maximum EV battery production at about 331 GWh in 2035, sufficient to support ~5 million EVs, as shown in Fig. 3. However, this estimate falls short of projected 2035 demand of 853 GWh (~12 million EVs). The optimization model also yields a revised battery chemistry mix, 45% LFP, 17% NMC, 38% NCA and 0.2% Na-ion batteries, along with 86% graphite AAMs and 14% graphite-silicon AAMs, which we apply to the projected 2035 EV battery demand to assess material sufficiency under this combined approach.

As shown in Fig. 4, integrating supply expansions with demand-side strategies, including material efficiency, recycling and chemistry shifts, substantially reduces material shortfalls across the EV battery supply chain. However, these strategies remain insufficient to close all gaps.

Upstream, manganese demand can be fully met through recycling (26%, 11 kt) and imports (74%, 31 kt). Other critical minerals, including cobalt, graphite and nickel, show notable improvement compared to the Supply Expansion Scenario, but substantial shortfalls persist, with 58% (2 Mt) of cobalt demand, 32% (260 kt) of graphite demand and 71% (5 Mt) of nickel demand unmet. The improvements also depend heavily on the timely realization of planned projects. For example, of the projected 78 kt of domestic graphite supply, about 60 kt is expected from early-stage domestic projects that have not yet secured permits.

Midstream, cobalt sulfate and nickel sulfate shortfalls shrink to 35% (35 kt) and 54% (232 kt), respectively, and gaps for manganese sulfate are eliminated. However, these outcomes also depend heavily on the completion of planned domestic projects. In particular, 15% (15 kt) of cobalt sulfate, 87% (33 kt) of manganese sulfate and 8% (36 kt) of nickel sulfate demand are expected to be met by early-stage domestic projects. For lithium carbonate and lithium hydroxide, projected sufficiency is only achievable if planned projects are completed and ramp up as scheduled.

Downstream, projected 2035 demand for most battery cells and components is met under the Combined Strategy Scenario. However, key constraints remain. LFP CAMs are projected to experience a 43% gap (176 kt) due to rising demand from chemistry switching, exceeding what recycling and efficiency gains can offset. The supply gaps for NMC and NCA CAMs persist at about 15%, corresponding to 18 kt and 32 kt, respectively. Graphite-silicon AAMs face a gap of 74% (45 kt) due to a shift away from graphite AAMs. Shortfalls continue to remain for Na-ion components and cells, including about 50% for CAMs (1 kt), AAMs (596 t) and electrolyte (338 t) and 52% for cells (3 kt).

To examine the sensitivity of the Combined Strategy Scenario to uncertainty in future EV market development, we assess how projected material gaps may change under two potential development paths in the EV sector (Table 2): (1) higher demand for EVs and (2) higher adoption of larger EVs. The first path reflects stronger EV uptake supported by factors such as declining battery costs, expanding charging infrastructure and state-level EV purchase incentives. The second path accounts for evolving consumer preferences and automaker strategies favouring larger vehicles[17].

Considering a higher EV demand in 2035, which is about 35% higher than in the Combined Strategy Scenario (details of the projections can be found in Methods and the REPEAT Project[29]), projected material shortfalls would widen substantially due to larger battery demand. Upstream, compared to the Combined Strategy Scenario, shortfalls for cobalt increase by 56% (from 1.8 Mt to 2.8 Mt), graphite by 34% (from 260 kt to 349 kt) and nickel by 46% (from 4.6 Mt to 6.7 Mt). Midstream, cobalt sulfate shortfalls increase from 35 kt to 68 kt and nickel sulfate shortfalls increase from 232 kt and 375 kt, while gaps for other materials remain closed. Downstream, gaps for LFP CAMs, NCA CAMs and NMC CAMs grow substantially to 309 kt, 112 kt and 60 kt, respectively. Gaps for Na-ion CAMs, AAMs, electrolytes and cells also widen under this higher-demand path. To capture additional variations in future EV adoption, we also evaluate a lower EV sales trajectory. Under this case, material supply–demand gaps narrow but shortfalls persist for several materials across the supply chain (Supplementary Table 15).

If the market shifts towards larger EVs, projected material shortfalls will also grow (assumptions can be found in Supplementary Table 10). Upstream, shortfalls increase by 12% for cobalt (to 2 Mt), 19% for graphite (to 310 kt) and 10% for nickel (to 5 Mt). Midstream, cobalt sulfate and nickel sulfate shortfalls rise to 42 kt and 261 kt, respectively. Downstream, shortfalls increase to 205 kt for LFP CAMs, 49 kt for NCA CAMs

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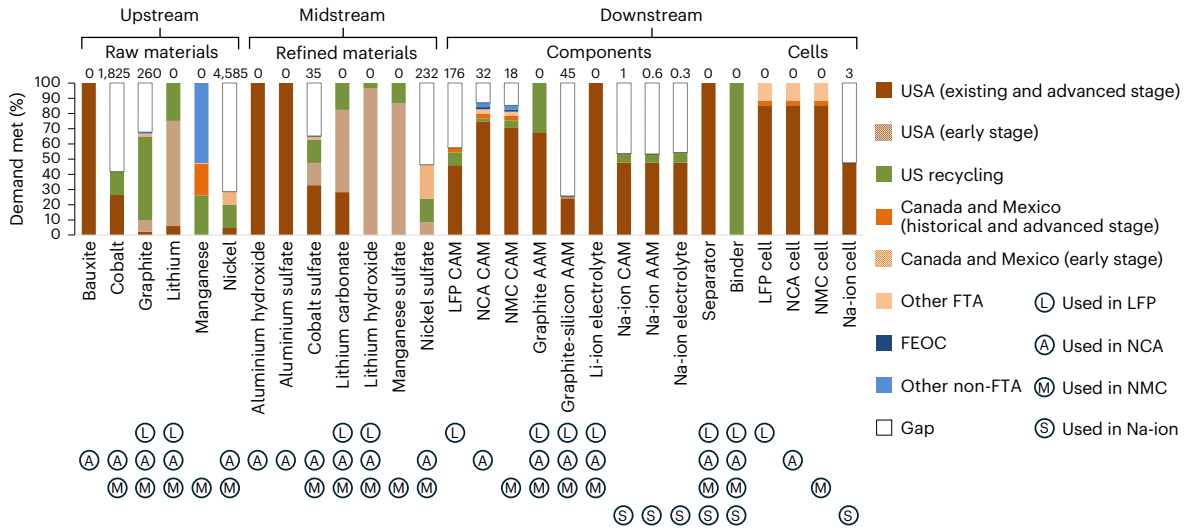

Fig. 4 | Material supply–demand gaps in 2035 under the Combined Strategy Scenario. Bars represent the percentage of demand met, with supply–demand gaps (kt) reported above each bar. Existing supply reflects the recent average annual US production. Historical supply reflects the recent average annual amount of materials imported to the USA. Advanced-stage supply includes planned projects that have been permitted, are under construction or are operational. Early-stage supply includes planned projects that have not yet been permitted. This distinction between advanced and early stage is applied only to upstream raw material and midstream refined material production stages. All component production, cell manufacturing and recycling projects are assumed to be at the advanced stage. US recycling refers to materials recycled from end-of-life batteries in the USA. Other FTA refers to countries with free trade agreements with the USA excluding Canada and Mexico. FEOC refers to foreign entity of concern countries. Other non-FTA refers to countries without free trade agreements with the USA excluding FEOC countries. LFP refers to lithium iron phosphate batteries, NCA refers to nickel cobalt aluminium batteries, NMC refers to nickel manganese cobalt batteries and Na-ion refers to sodium-ion batteries.

and 26 kt for NMC CAMs. Additionally, Na-ion batteries face shortfalls of 1 kt in CAMs, 1 kt in AAMs, 0.4 kt in electrolytes and 4 kt in cell supply.

Discussion

To mitigate material supply–demand gaps for its EV battery supply chain, the USA is building domestic production capacity. Our study shows that expanding domestic capacity alone will not be sufficient to meet material demand across the supply chain under post-OBBBA conditions. Shortfalls persist for several critical materials and may widen if planned mining and processing projects are not completed as scheduled. Demand-side strategies can substantially reduce shortfalls across the supply chain but are insufficient to fill all gaps. These findings suggest that international sourcing, investment across domestic supply chain stages and implementation of demand-side strategies are necessary to meet future US demand for EV battery materials and improve supply chain resilience. Below we discuss key findings and policy implications.

Expanding domestic production can address supply shortfalls for several key materials, including upstream lithium, midstream lithium carbonate and lithium hydroxide and downstream components such as graphite-silicon AAMs, electrolytes and separators, all of which are used across LFP, NMC and NCA batteries. However, substantial shortfalls remain for materials heavily used in NMC and NCA batteries. Upstream and midstream, these include cobalt, nickel, manganese, graphite and their midstream refined materials. Depending on the material, between about 30% and 100% of the projected domestic production relies on yet-to-be-permitted projects, introducing uncertainty about future availability. Downstream, shortfalls exist for NMC CAMs, NCA CAMs and binders. These findings suggest that expanding domestic production alone cannot fully secure battery material supply, particularly when future supply depends heavily on uncertain project delivery.

Through domestic supply expansion and demand-side strategies, US domestic capacity can meet demand for manganese sulfate, graphite AAM and binders. However, persistent gaps remain across the supply chain, particularly for upstream cobalt, graphite and nickel, midstream cobalt sulfate and nickel sulfate and downstream production of Li-ion CAMs, graphite-silicon AAMs and Na-ion components and cells. These results underscore that the USA cannot address material gaps through domestic efforts alone and will require international supply chains. We also find that demand-side strategies have trade-offs. For example, transitioning to LFP batteries reduces reliance on cobalt, manganese and nickel, but it shifts the burden to LFP-specific components, resulting in new constraints. Addressing this requires policies and investment strategies that account for cross-material and cross-stage impacts in the EV battery supply chain.

To meet the material demand across the EV battery supply chain, the USA can pursue three mutually reinforcing strategies: expanding and delivering domestic production as scheduled, reducing and shifting material demand and expanding imports.

Timely completion of planned projects is essential to meeting material demand. However, many of these face major barriers. First, the US mining and processing sectors have historically experienced permitting delays and financing constraints[30], which cast doubt on the feasibility of bringing projects online at the pace required. Second, while downstream manufacturing projects face relatively lower investment risks and shorter development timelines, they are frequently constrained by ramp-up challenges. As such, new facilities generally take longer than planned to achieve target product yields and stabilize operations at scale[31,32]. Third, uncertain long-term EV and material demand due to policy uncertainty weakens investor confidence and discourages capacity expansion, leaving the supply chain ill-prepared for future rebounds in demand, commodity price shocks or geopolitical disruptions. Policy uncertainties since the start of 2025 have already led to cancellations, suspensions and closures across the supply chain. To address these challenges, it is essential to expedite environmentally responsible permitting and channel financial resources to viable and competitive mining and processing projects. In addition, providing technical and workforce support can help manufacturers reduce learning costs and improve yields. It is also crucial to have clear, stable and long-term policy commitments that reinforce investor confidence and sustain capital inflows.

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Table 2 | Material supply–demand gaps in 2035 under the Combined Strategy Scenario reflecting the repeal of the IRA's EV purchase incentives and average vehicle size with battery weight of ~230 kg per vehicle, higher EV demand and a shift to larger EVs with battery weight of ~240 kg per vehicle

	Material	Combined strategy (kt)	Higher EV demand (kt)	Larger EVs (kt)
Raw materials	Bauxite	0	0	0
	Cobalt	1,825	2,847	2,038
	Graphite	260	349	310
	Lithium	0	0	0
	Manganese	0	0	0
	Nickel	4,585	6,716	5,022
Refined materials	Aluminium hydroxide	0	0	0
	Aluminium sulfate	0	0	0
	Cobalt sulfate	35	68	42
	Lithium carbonate	0	0	0
	Lithium hydroxide	0	0	0
	Manganese sulfate	0	0	0
	Nickel sulfate	232	375	261
Components	LFP CAM	176	309	205
	NCA CAM	32	121	49
	NMC CAM	18	60	26
	Graphite AAM	0	0	0
	Graphite-silicon AAM	45	68	50
	Li-ion electrolyte	0	0	0
	Na-ion CAM	1	2	1
	Na-ion AAM	1	1	1
	Na-ion electrolyte	0.3	1	0.4
	Separator	0	0	0
	Binder	0	0	0
Cells	LFP cell	0	0	0
	NCA cell	0	0	0
	NMC cell	0	0	0
	Na-ion cell	3	6	4

Results in all columns consider both supply-side and demand-side strategies.

Demand-side strategies can further narrow material shortfalls by reducing or shifting material needs. First, shifting away from NMC batteries can reduce reliance on constrained materials such as cobalt, nickel and manganese. Local content requirements, such as those restricting sourcing to US production, can incentivize this technology shift. However, because chemistry shifts redistribute material demand, addressing supply challenges requires coordinated action across materials and supply chain stages.

Second, improving vehicle efficiency and battery energy density can reduce the amount of battery materials needed to achieve a given driving range. Vehicle efficiency measures, such as lightweighting, improved aerodynamics and reduced rolling resistance, allow EVs to achieve the same range with a smaller, lighter battery pack. Simultaneously, advances in battery energy density allows more energy to be stored per kilogram, further lowering total battery material requirements while maintaining EV performance and driving range.

We note that a rising share of SUVs and pickups in the US EV market may offset the efficiency and density gains, making it essential to right-size batteries. This can reduce material demand by aligning EV battery pack size with typical daily driving needs[33]. Expanded public charging infrastructure can further support this approach by reducing range anxiety and allowing drivers to rely on smaller packs without compromising mobility. In addition, changing mobility patterns through public transit expansion and shared mobility services can reduce the total number of EVs needed, further lowering material demand[34].

Third, enhancing battery recycling can further reduce material demand. Near-term scaling of recycling faces obstacles due to limited availability of end-of-life batteries. This reflects both the relatively recent growth of the EV market and technological improvements that extend EV lifetime, delaying battery retirement[35]. In the long run, it is important to improve end-of-life battery collection rates, such as by implementing extended producer responsibility programs and restricting exports of end-of-life EVs. These have already been adopted in China and are under consideration in the European Union[36]. Battery passports that include information on battery characteristics and life-cycle history can further help improve end-of-life handling[37]. In addition, most recycling facilities today rely on hydrometallurgical processes, which have limited recovery efficiency. It is important to invest in next-generation recycling technologies, such as direct recycling, which offer improved recovery efficiency by preserving more of the battery's structure and materials.

In addition to domestic supply expansion and material demand reduction, expanding imports is essential for securing EV battery materials. This makes trade a crucial component of EV battery supply

chain resilience. Protectionist approaches, such as increasing tariffs and other trade barriers, may support the domestic supply chain but can also inadvertently raise input costs and reduce material availability for US battery manufacturers, especially in the near term when domestic capacity remains insufficient. Moreover, such approaches may alter global trade flows. Suppliers may redirect exports towards other markets where trade conditions are more favourable, while key producing countries may respond with export restrictions or preferential trade agreements with other countries. These responses could limit US access to diversified, affordable sources of battery materials.

Our results are subject to uncertainties. First, we rely on announced project timelines and expected production to estimate the impacts of planned projects, but these may change due to permitting delays, regulatory uncertainty and changing market conditions. Nonetheless, our analytical framework can be readily updated as the supply landscape evolves, allowing for re-assessment of material gaps. Second, technological advances in both battery chemistries and recycling technologies could potentially alter future material demand. Our study focuses on established and near-commercial battery chemistries, but emerging technologies such as lithium-sulfur and lithium-air batteries may reduce reliance on cobalt and nickel in the future (while increasing demand for lithium)[28]. In terms of recycling, we assume that recovered CAMs from direct recycling retain the same chemistry as the original product (for example, an NMC111 CAM recycled back into NMC111)[33]. By the time batteries reach end of life, these chemistries may no longer match those used in new cells. While not modelled here, emerging upcycling approaches that convert low-nickel chemistries (for example, NMC111) into higher-nickel variants (for example, NMC622 or NMC811)[34,35] may enable cross-chemistry reuse and help address this limitation. Finally, our analysis assumes uniform weight reductions across all battery components when evaluating material efficiency improvement. In practice, many cell design improvements primarily reduce inactive materials such as casings, tabs and current collectors[38]. Our assumption may therefore overstate demand reductions for CAMs, AAMs, separators and electrolytes.

Our analytical framework links chemistry-specific material flows, project development stages and timelines, end-of-life EV battery recycling and trade relationships to understand how domestic supply, demand-side strategies and international trade interact to fulfil EV battery material demand in the USA. This framework is adaptable to other regional and country contexts with appropriate data inputs. Our findings are relevant globally and in the longer term as policymakers in many countries are seeking to expand domestic production of EV batteries to capture economic value and enhance supply chain resilience.

Beyond the policy relevance, our findings are also useful to industry and the research community. For industry stakeholders, our results can help manufacturers and investors gain a more complete view of the supply chain beyond the immediate networks they typically monitor, enabling more informed capacity expansion decisions and helping align battery chemistry choices with material availability and stated US policy goals. For the research community, our study underscores the importance of aligning battery innovation with supply chain realities, helping guide efforts towards chemistries and designs that are both technically advanced and supported by sufficient material supply.

In summary, our study provides a comprehensive and quantitative assessment of strategies to mitigate material supply–demand gaps in the US EV battery supply chain, which is necessary for achieving resilience. Domestic supply expansion and demand-side strategies can substantially reduce material shortfalls but cannot eliminate all constraints. Addressing material shortfalls will require continued access to international supplies and domestic efforts across the full EV battery supply chain.

Methods

Scope of materials and supply chain stages

This study evaluates the supply and demand of materials required to produce three dominant Li-ion battery chemistries in the US EV market: NMC (including NMC111, NMC532, NMC622 and NMC811), NCA and LFP batteries. The analysis spans four key stages of the EV battery supply chain: upstream (mineral extraction), midstream (material processing and refining), downstream (battery component and cell manufacturing) and recycling. In the upstream stage, we focus on the extraction of battery-related critical minerals identified by the US Geological Survey (USGS), including bauxite, cobalt, lithium, manganese, nickel and graphite[18,39]. The midstream stage covers the processing of these raw materials into refined materials, including aluminium hydroxide, aluminium sulfate, cobalt sulfate, lithium carbonate, lithium hydroxide, manganese sulfate and nickel sulfate. The downstream stage includes the production of key battery components, including CAMs, AAMs (both graphite and graphite-silicon), electrolytes, separators and binders, as well as cell manufacturing for NMC, NCA and LFP batteries. Recycling is also included to capture the recovery of materials from end-of-life batteries. While graphite undergoes midstream processing steps such as purification, spheroidization and coating, the resulting coated spherical graphite is typically used directly in AAM production[40]. Therefore, we include graphite in the downstream stage, where it enters the supply chain as part of the AAMs rather than as a standalone intermediate. The supply chain stages do not include battery module or pack assembly because these stages primarily involve mechanical integration and are often vertically integrated with downstream cell production. In the analysis, we include Na-ion batteries as an alternative chemistry in our demand-side strategy to evaluate their potential for enhancing supply chain resilience. Because the sodium used in Na-ion batteries is not currently designated as a critical mineral by the USGS, we focus only on their downstream components.

Modelling framework

We develop a modelling framework to estimate material supply, recycling and demand across the EV battery supply chain and to evaluate the impacts of supply-side and demand-side strategies on addressing material supply–demand gaps. Below, we describe each step of the framework.

Material supply estimations

We compile data on existing domestic production, planned projects and imports of key EV battery materials across the upstream mining, midstream processing and downstream manufacturing stages. Using these data, we estimate material supply in the US from 2025 to 2035. We estimate the supply potential for each stage independently, which allows us to identify specific bottlenecks that would otherwise be obscured by upstream limitations. In addition, we assume that unused material supply in a given year is not carried forward for EV battery production in the subsequent years but is sold into alternative markets or exported. This is consistent with industrial practice in which firms seek to maintain stable material inventories to limit working capital and maximize revenue so as to enhance profitability[41]. Details on the parameters, key assumptions and data sources are provided in Supplementary Note 1.

To estimate existing domestic production, we quantify annual production of each material using a range of government, academic, and industry sources (Supplementary Table 1). To approximate domestic production from 2025 to 2035, we assume it remains constant at the historical average level. We also apply allocation factors to estimate the share of production used in EV batteries.

To estimate supply from projects announced in the USA, we use Argonne National Laboratory's Energy Storage and Electric Vehicle Investment Tracking database[27] (September 2025 version). This version captures project additions and status changes, including pauses, cancellations and closures, after the OBBBA. To validate and complement these data, we cross check project status against Jay Turner's Big Green Machine database[42] (November 2025 version). The Energy Storage and Electric Vehicle Investment Tracking database provides project-level

details, including estimated capacity, production volumes, production start dates and project status. We include only projects that are officially announced and under construction, excluding those classified as rumoured or cancelled. For raw and refined material production, we classify projects as advanced stage if they have received permits and early stage otherwise. For downstream projects, including battery component and cell manufacturing, the database does not report permitting status. We assume that these projects are permitted, given their lower capital intensity and shorter development timelines compared to upstream and midstream projects. To estimate production from 2025 to 2035, we use reported start dates when available. We apply ramp-up timelines from initial production to full production based on supply chain stages[26,43]: four years for upstream and midstream projects, two years for CAM production, AAM production and recycling projects, one year for electrolyte and separator production and three years for battery cell manufacturing.

For both existing production and announced projects, we assume that US supply is first used to meet domestic demand. This is consistent with current US policy priorities to reduce reliance on imports for EV battery materials, although material heterogeneity and processing requirements may necessitate trade for some raw materials in practice[44].

To estimate imports, we use trade data and conduct an extensive review to identify battery-relevant Harmonized System codes at a finer digit level (Supplementary Table 3). We also apply allocation factors to estimate the share of imported materials used in EV battery production. We project 2025–2035 imports by holding them constant at their historical average annual levels, calculated over the most recent years of available trade data for each material. For Canada and Mexico, we also include announced investments in EV battery supply chain projects. To estimate US-bound exports from these projects, we assume that local demand is satisfied first, and the remaining production is exported to the USA because the USA accounts for ~85% of North American EV demand[1] and is geographically proximate and economically integrated with Canada and Mexico. Other key assumptions, including permitting status, start dates and ramp-up timelines, are applied consistently with those used for projects located in the USA. In terms of import origins, we classify countries into four categories: (1) Canada and Mexico; (2) FTA countries that have free trade agreements with the USA, excluding Canada and Mexico and including Australia, Bahrain, Chile, Colombia, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Israel, Jordan, South Korea, Morocco, Nicaragua, Oman, Panama, Peru and Singapore; Japan is also treated as an FTA country for critical minerals; (3) FEOC countries, including China, Russia, Iran and North Korea and (4) non-FTA countries that fall outside the FTA and FEOC categories.

In addition to supply from existing production, announced projects and imports, we estimate recycled materials recovered from end-of-life EV batteries using a material flow analysis approach. We first model battery retirements using a Weibull distribution with chemistry-specific lifetimes. These retirement flows are influenced by historical and projected EV sales and battery chemistry shares. We then estimate annual recoverable materials by applying end-of-life EV battery collection rates, recycling rates and material-specific recovery rates, which vary depending on the recycling technology (that is, hydrometallurgical or direct recycling). End-of-life EV batteries that are not collected in a given year remain in the end-of-life stock and can contribute to recycling feedstock in subsequent years. Finally, because upstream raw materials and, under direct recycling, midstream refined materials are not directly recovered, we estimate the amount of upstream and midstream supply that is avoided due to recycling. These avoided quantities are treated as recycling contributions to mitigating supply–demand gaps.

Material demand estimations

We quantify US domestic demand for each material by tracing material requirements from EV sales to downstream, midstream and upstream stages over 2025–2035. First, we estimate light-duty EV sales (both BEV and PHEV) from 2025 to 2035 based on the Policy Repeal from the REPEAT Project[29], which models the repeal of IRA's 30D and 45 W tax credits and EPA's 'Multi-pollutant Emissions Standards for Model Years 2027 and Later Light-duty Vehicles'. Second, we allocate EV demand across dominant battery chemistries, including NMC (NMC111, NMC532, NMC622 and NMC811), NCA and LFP, using projected market shares for each year. In the Supply Expansion Scenario, the market share is derived from projected battery production informed by planned investments. In the Switch to Alternative Battery Chemistries Scenario and the Combined Strategy Scenario, we use the annual market share determined by our optimization model (details in the 'Optimization model' section). Third, we quantify material demand for each battery chemistry by applying material requirements between supply chain stages. Additional details on the parameters, key assumptions and data sources used in material demand estimations are provided in Supplementary Note 2.

Material supply–demand gaps

Building on the material supply and demand estimations described above, we quantify supply–demand gaps over 2025–2035 for each material as demand minus supply, floored at zero when supply meets or exceeds demand (equation (1)). Additional details can be found in Supplementary Note 3. We note that, when moving from one scenario to another, percentage changes in gaps for a material depends on how close supply is to the demand for that material and therefore vary across materials.

$$\begin{aligned}\mathrm{Gap}_{m,t} = \mathrm{Demand}_{m,t} - \Big(&\mathrm{Supply}_{m,t}^{\mathrm{existing}} + \mathrm{Supply}_{m,t}^{\mathrm{planned}} \\ &+ \mathrm{Supply}_{m,t}^{\mathrm{recycled}} + \mathrm{Supply}_{m,t}^{\mathrm{import}} - \mathrm{Supply}_{m,t}^{\mathrm{export}}\Big),\end{aligned} \tag{1}$$

where $\mathrm{Gap}_{m,t}$ is the unmet demand for material m in year t, $\mathrm{Demand}_{m,t}$ is the demand for material m in year t, $\mathrm{Supply}_{m,t}^{\mathrm{existing}}$ is the existing domestic supply of material m in year t, $\mathrm{Supply}_{m,t}^{\mathrm{planned}}$ is the supply from announced domestic projects for material m in year t, $\mathrm{Supply}_{m,t}^{\mathrm{recycled}}$ is the supply of material m from end-of-life EV battery recycling in year t, $\mathrm{Supply}_{m,t}^{\mathrm{import}}$ is the amount of material m imported to the USA in year t and $\mathrm{Supply}_{m,t}^{\mathrm{export}}$ is the amount of material m exported from the USA in year t. $m \in M$, where M is the set of materials in upstream, midstream and downstream stages, and $t \in T$, where T is the set of years from 2025 to 2035, inclusive.

Optimization model

We develop a linear optimization model to estimate the maximum EV battery production that meets US sourcing requirements from 2025 to 2035, subject to material supply constraints across the supply chain. This represents a best-case allocation of chemistries that maximizes eligible production rather than a market forecast. The model is implemented in Pyomo using Python. The general structure of the optimization model is summarized in equations (2)–(4).

$$\text{Maximize} \sum_{v \in V} \sum_{c \in C} \mathrm{EVBattery}_{v,c,t}, \tag{2}$$

subject to

$$\sum_{v \in V} \sum_{c \in C} \mathrm{MaterialUse}_{m,v,c,t} \le \mathrm{USSupply}_{m,t}, \quad \forall m \in M, \tag{3}$$

$$\mathrm{MaterialUse}_{m,v,c,t} = \mathrm{EVBattery}_{v,c,t} \times \alpha_{m,v,c}, \quad \forall v \in V, \forall c \in C, \forall m \in M, \tag{4}$$

where $\mathrm{EVBattery}_{v,c,t}$ is the mass-based EV battery production for vehicle type v and for battery chemistry c in year t, $\mathrm{MaterialUse}_{m,v,c,t}$ is the amount of material m used to produce EV batteries of vehicle type v

and battery chemistry c in year t, $\mathrm{USSupply}_{m,t}$ is the available domestic supply of material m in year t, $\alpha_{m,v,c}$ is the requirement of material m per unit of battery chemistry c for vehicle type v. $v \in V$, where V is the set of vehicle types, including BEV and PHEV, $c \in C$, where C is the set of battery chemistries, including LFP, NCA, NMC111, NMC532, NMC622, NMC811 and Na-ion batteries, $m \in M$, where M is the set of materials in upstream, midstream and downstream stages, and $t \in T$, where T is the set of years from 2025 to 2035, inclusive.

Definition of supply- and demand-side strategy scenarios

We evaluate supply- and demand-side strategies to mitigate material supply–demand gaps in the US EV battery supply chain. All scenarios are evaluated within the same modelling framework, building on the common method for estimating material demand and supply from 2025 to 2035 ('Material supply estimations' section and 'Material demand estimations' section). Supply-side parameters remain consistent across all scenarios, whereas demand-side assumptions, specifically battery chemistry market shares, battery capacities and energy densities (both of which influence battery weight) and recycling-related parameters, vary depending on the strategy evaluated. Key parameters and assumptions are summarized in Table 1, and details are provided in Supplementary Notes 1 and 2.

In the Supply Expansion Scenario, supply includes existing US domestic production and imports held constant at historical levels, with added contributions from announced projects in the USA, Canada and Mexico. On the demand side, this scenario does not include additional demand-side strategies. Battery chemistry market shares align with projected US production informed by planned investment. In addition, battery capacity (kWh) and energy density (Wh kg^{-1}) are specified by vehicle segment (that is, cars, SUVs and pick-up trucks) and model year and averaged using segment-specific market shares to obtain sales-weighted values (Supplementary Table 10). These values correspond to driving ranges of ~300 miles for BEVs and ~50 miles for PHEVs and are comparable to current EV models[45,46]. End-of-life battery collection rates are assumed to be 15% in 2025 and to remain constant through 2035 (sensitivity results for 5% and 20% collection rates and for diverting collected batteries to second-life applications are provided in Supplementary Note 4). We set the collection rate to zero before 2020 and increase it linearly from 2020 to 2025 to reflect the emergence of EV battery recycling facilities beginning in 2020. Recycling capacity reflects the sum of existing and announced recycling projects. Recovery efficiencies are based on the performance of widely adopted hydrometallurgical recycling technologies.

In the Improved Material Efficiency Scenario, supply-side parameters and assumptions are consistent with the Supply Expansion Scenario. On the demand side, this strategy assumes improvements in vehicle efficiency and battery energy density that maintain driving range while reducing battery weight per vehicle. We implement this by adjusting battery capacity and energy density parameters such that battery weight for each battery chemistry decreases linearly, reaching a reduction of about 20% by 2035 compared to 2025[17].

In the Enhanced Recycling Scenario, supply-side parameters and assumptions are consistent with the Supply Expansion Scenario. On the demand side, we increase end-of-life battery collection rates from 15% in 2025 to 60% in 2035. We assume no constraint on domestic recycling capacity, meaning all collected end-of-life batteries can be processed. Recovery efficiencies are assumed to improve due to the introduction of direct recycling technologies alongside existing hydrometallurgical methods. When modelling direct recycling, we assume that recovered CAMs retain the same chemistry as the original (for example, NMC111 recovered from end-of-life batteries is reused in newly produced NMC111 cells)[47], which reflects the most common application of direct recycling today.

In the Switch to Alternative Battery Chemistries Scenario, supply-side parameters and assumptions are consistent with the Supply Expansion Scenario. On the demand side, we adopt battery chemistry market shares for 2025–2035 based on outputs from the optimization model described in the 'Optimization model' section.

The Combined Strategy Scenario integrates all supply- and demand-side strategies, including expanding production, improving material efficiency via increased vehicle efficiency and battery energy density, enhancing recycling and shifting battery chemistries. We obtain battery chemistry shares for 2025–2035 from the optimization model under this combined strategy.

Data availability

The data that support the findings of this study are available in Supplementary Information. Source data are provided with this paper.

Code availability

The code that is used for this study is available via Zenodo at https://doi.org/10.5281/zenodo.19056258 (ref. 48).

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Author contributions

J.L., J.D.J. and D.L.M. conceived the research idea and designed the study. J.L. constructed the datasets, designed the scenarios, developed the optimization model, performed the analyses and produced the figures and tables. J.D.J., C.G. and D.L.M. contributed to the scenario design and analyses. J.L. wrote the paper. All authors revised and approved the paper.

Competing interests

J.D.J. serves as a technical advisor to Energy Impact Partners and MUUS Climate Partners, which are investors in early-stage companies, including those in the critical materials and battery supply chains. The other authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to Denise L. Mauzerall.

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