Written Testimony of

Ashley Nunes
Director, Federal Policy, Climate and Energy
The Breakthrough Institute

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Committee on Energy and Commerce
Subcommittee on Environment, Manufacturing, & Critical Materials

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Chairman Johnson, Ranking Member Tonko, and Honorable Members of the Committee,

Thank you for the opportunity to submit a written statement to the House Energy Subcommittee on Environment, Manufacturing, & Critical Materials. My name is Ashley Nunes. I am a Senior Research Associate at Harvard Law School and the Director for Federal Policy, Climate and Energy, at the Breakthrough Institute. The institute is a global research center that identifies and promotes technological solutions to environmental and human development challenges. We believe that human prosperity is compatible with an ecologically vibrant planet, and we are committed to a world that is good for both people and nature.

My work at Breakthrough focuses on analyzing the cost effectiveness of emissions reduction initiatives, particularly in the transportation sector. The U.S. transportation sector is responsible for more greenhouse gas (GHG) emissions than any other sector of our economy, accounting for about 27 percent of total U.S. GHG emissions[1,2]. Moreover, total emissions from the transportation sector have steadily increased since the late 1990s despite significant government spending on programs that promote emissions reductions[3]. This mismatch between intent and outcome highlights the need for Congressional scrutiny and action.

I will focus here on electric vehicles (EVs), an emissions-reduction technology toward which President Joe Biden, his predecessors, and Congress have committed sizable public funds. My assessment of this technology's emissions-reduction potential is based on my own work in this area, alongside that of prominent climate analysts, technologists, and social scientists who have been widely cited in the relevant scholarly literatures.

In my testimony, I would like to make four key points:

- First, just because technologies like EVs can lower emissions doesn't mean that they necessarily will. While existing discourse highlights grid decarbonization as crucial to EV success, Breakthrough's analysis shows that how EVs are driven, by whom, and under what conditions also significantly influence the number of miles an EV must be driven to deliver an emissions advantage over its fossil fuel counterparts. Without a change in existing government policy, EV adoption may not meaningfully decrease transportation sector emissions given consumption patterns in American households.

- Second, EV adoption faces challenging cost barriers. EVs today are more expensive to purchase up front than Internal Combustion Engine (ICE) powered vehicles. Moreover, this price disadvantage doesn't fully capture the state of the EV market. In 2011, the inflation adjusted price of a new EV was nearly $44,000. By 2022, that price had risen to over $66,000. EV prices aren't just going up; they are rising faster than inflation and, as Breakthrough's analysis suggests,

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[1] U.S. Department of Transportation. "Climate Action." *U.S. Department of Transportation*, 13 Jan. 2023, https://www.transportation.gov/priorities/climate-and-sustainability/climate-action.

[2] United States Environmental Protection Agency. "Carbon Pollution from Transportation." *United States Environmental Protection Agency*, 19 May 2022, https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation.

[3] United States Environmental Protection Agency. "Sources of Greenhouse Gas Emissions." *United States Environmental Protection Agency*, 18 Apr. 2023, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

faster than ICE vehicle prices. Should the government nevertheless implicitly mandate EV adoption, an approach recently adopted by the Environmental Protection Agency (EPA), it would risk worsening existing inequities in new vehicle ownership while also encouraging some households to continue driving older, more polluting ICE vehicles for longer than they ordinarily would, potentially hindering emissions reductions efforts.

- Third, the path to clean energy requires wide-ranging specialty raw materials for which the United States currently relies on foreign states. Some of these states—Australia, Canada, and Norway to name a few—are long standing U.S. partners that share our values, interests, and preferences. But that is not the case for all the countries that control, as a manner of extraction or processing, a significant share of minerals value chains. Although the Inflation Reduction Act (IRA) aims to consolidate U.S. production and processing capability, these measures may take years to fully bear fruit. In the meantime, production capacity limits coupled with limited alternatives in lithium-ion battery chemistry suggest that EV costs will remain high for American consumers.

- Fourth and finally, there is reason to be optimistic. Although the pathway towards emissions reduction is fraught with challenges, these challenges are not—in Breakthrough's view—insurmountable. America can build better, cleaner, and less mineral-intensive vehicles that consumers want to buy and are, regardless of socioeconomic status, able to afford. Government has a critical role to play in supporting that effort, and given the seriousness of climate change, should do so. That will mean implementing policies that have been carefully deliberated and being amendable to changing these policies when there is incongruence between the policy intent and observed outcome.

1. EV Emissions Reduction Potential

The rationale for EV adoption seems straightforward. By foregoing reliance on fossil fuels during the driving phase, these vehicles emit less carbon compared to gasoline powered alternatives like ICE and hybrid electric vehicles (HEVs). Researchers estimate that over its lifetime, the average EV produces 50 percent less global warming pollution than a comparable gasoline vehicle[4]. Findings like these imply a clear, consistent, and compelling narrative that establishes an EV's emissions advantage over its gasoline powered counterparts.

However, an EV is only a decarbonizer to the extent that it offsets both gas-powered driving emissions *and* the emissions needed to manufacture the EV[5]. The latter is particularly important because manufacturing an EV imposes a far larger upfront carbon cost than does building an ICE vehicle[6]. Consequently, as Bloomberg's Kyle Stock correctly notes, the only way for an EV to cover its own carbon, so to speak, is in miles. Put another way, the question worth asking is not whether an EV runs cleaner than an ICE vehicle, but rather, after how many miles its total carbon footprint becomes smaller than its counterpart's.

My recent work with Lucas Woodley and Philip Rossetti finds that that EVs must travel between 28,069 and 68,160 miles to realize an emissions advantage over similarly sized and equipped ICE vehicles[7]. Meeting those mileage thresholds may seem undaunting given the large distances Americans travel by automobile each year. Families across America regularly drive upwards of 10,000 miles annually in personally owned vehicles. This implies that EVs can deliver an emissions advantage after as little as three years of ownership. However, EV purchasing, and utilization patterns make the math more complicated.

Research shows that the majority of EVs are purchased and used as secondary (or tertiary) vehicles, rather than primary vehicle in a household[8,9]. Because households owing multiple vehicles put fewer miles on secondary (and tertiary) vehicles, EVs in these households must stay on the road for longer than their primary (gasoline powered) counterparts. We estimate that in many American households, EVs must remain in service for upwards of at least 10 years to deliver an emissions benefit (compared to ICE vehicles). There is little evidence that suggests this outcome is being realized today.

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[4] Reichmuth, David, et al. "Driving Cleaner: How Electric Cars and Pick-Ups Beat Gasoline on Lifetime Global Warming Emissions." *Union of Concerned Scientists*, 25 July 2022, https://www.ucsusa.org/resources/driving-cleaner.

[5] Stock, Kyle. "The Wrong Americans Are Buying Electric Cars." *Bloomberg*, 15 Nov. 2022, https://www.bloomberg.com/news/articles/2022-11-15/the-wrong-americans-are-buying-electric-cars?leadSource=uverify+wall.

[6] Hall, Dale, and Nic Lutsey. "Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhouse Gas Emissions." *International Council on Clean Transportation*, Feb. 2018, https://theicct.org/wp-content/uploads/2021/06/EV-life-cycle-GHG_ICCT-Briefing_09022018_vF.pdf.

[7] Nunes, Ashley, et al. "Re-Thinking Procurement Incentives for Electric Vehicles to Achieve Net-Zero Emissions." *Nature Sustainability*, vol. 5, no. 6, 2022, pp. 527–532., https://doi.org/10.1038/s41893-022-00862-3.

[8] Davis, Lucas W. "Electric Vehicles in Multi-Vehicle Households." *Applied Economics Letters*, 1 June 2022, pp. 1–4., https://doi.org/10.1080/13504851.2022.2083563

[9] Xing, Jianwei, et al. "What Does an Electric Vehicle Replace?" *Journal of Environmental Economics and Management*, vol. 107, May 2021, p. 102432., https://doi.org/10.1016/j.jeem.2021.102432.

2. EV Cost Barriers

EVs are expensive. In 2022, the average price of a new EV was at least $20,000 more than a similarly sized ICE vehicle. While consumer costs could fall as production volume scales, the available empirical evidence suggests otherwise[10,11]. Over the last decade, the inflation adjusted price of a new EV has risen by over 50 percent, despite a concurrent increase in sales. The upfront price of going electric isn't just rising; it is even outpacing inflation and increasingly necessitates committing the near entirety of the average American household's annual income[12]. Should government policy require that all new vehicle sales be electric, further price increases risks widening existing inequities in new vehicle ownership[13]. This is particularly true in the EV market, as high-income households already account for a larger share of new EV purchases compared to lower income households[14,15].

Critics may dismiss EV price concerns on three grounds. First, they will argue that affordable new EVs are available for purchase; second, that the higher upfront purchasing price consumers incur is offset by the long-term savings EVs offer; and third, that the used vehicle market offers middle and low-income households an opportunity to purchase EVs at a more affordable price.

Regarding the availability of lower priced new EVs, such models admittedly do exist. In 2022, the lowest price EV cost less than $30,000. Moreover, since 2011, the least expensive EV has averaged an inflation-adjusted price of approximately $32,000, well within the budgetary constraints of many American households. However, these vehicles rarely address the day-to-day range and interior space needs of most households. This may help explain why in 2022 alone, only 12,025 units of the least expensive EV were sold out of a total of more than 700,000 EVs. Plainly put, practically nobody buys these cars[16].

Where long-term savings are concerned, EVs can offer a superior value proposition largely due to their lower fuel and maintenance costs. Electricity is cheaper than gas, and fewer moving parts in an EV means fewer lifetime mechanical issues (compared to gasoline powered vehicles). However, these savings appear insufficient to overcome accelerated vehicle depreciation rates and the rising insurance-

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10 Nordhaus, Ted, and Ashley Nunes. "Don't Expect Mass Adoption of Electric Cars Anytime Soon." *The Wall Street Journal*, Dow Jones & Company, 13 Apr. 2023, https://www.wsj.com/articles/dont-expect-mass-adoption-of-electric-cars-anytime-soon-fc60d894?mod=Searchresults_pos1&page=1

11 Hsieh, I-Yun Lisa, et al. "Learning only buys you so much: Practical limits on battery price reduction." *Applied Energy*, vol. 239, 1 Apr. 2019, pp. 218-224, https://doi.org/10.1016/j.apenergy.2019.01.138.

12 Nunes, Ashley. "The inequities of electric vehicles." *The Financial Times*, 11 Aug. 2021, https://www.ft.com/content/f0659114-94dc-4181-ae50-db0d86b84feb

13 Harper, Sam, et al. "Trends in Socioeconomic Inequalities in Motor Vehicle Accident Deaths in the United States, 1995–2010." *American Journal of Epidemiology*, vol. 182, no. 7, 1 Oct. 2015, pp. 606–614., https://doi.org/10.1093/aje/kwv099.

14 Muehlegger, Erich, and David Rapson. "Understanding the Distributional Impacts of Vehicle Policy: Who Buys New and Used Alternative Vehicles?" *National Center for Sustainable Transportation*, Feb. 2018, https://escholarship.org/content/qt0tn4m2tx/qt0tn4m2tx_noSplash_36244609f162444f3e55c550dfc22cad.pdf.

15 Wappelhorst, Sandra. "The Role of the Used Car Market in Accelerating Equal Access to Electric Vehicles." *International Council on Clean Transportation*, 27 Apr. 2021, https://theicct.org/the-role-of-the-used-car-market-in-accelerating-equal-access-to-electric-vehicles/.

16 Nunes, Ashley. "EVs are selling like hotcakes. Don't rejoice just yet." *The Boston Globe*, 1 Dec. 2022, https://www.bostonglobe.com/2022/12/01/opinion/evs-are-selling-like-hotcakes-dont-rejoice-just-yet/

related expenditures that accompany EV ownership[17]. A 2021 study by Argonne National Laboratory finds that over a 15-year horizon, EVs are more expensive to own than their gasoline powered counterparts[18].

Regarding EV adoption via the used vehicle market, the declining price of new EVs sets a benchmark for valuing used EVs sold during that year. Cost reductions for new EVs are assumed to create downward pressure on the used EV market, such that the benefits of both subsidies and cost reductions on new EVs are passed on to used EV buyers[19,20]. However, assertions of cost reductions for new EVs are inconsistent with historical pricing trends. Higher new EV prices imply higher used EV prices (relative to ICE vehicles). And even if the price of new EVs falls significantly, research suggests that *some* ownership inequity will still be perpetuated, owing to limited supply of more affordable used EV models[21].

In either scenario, households that cannot afford an EV (new or used) may continue to drive their older ICE vehicle for longer than they ordinarily would. Since older vehicles are often more polluting than newer ones owing to technological improvements and existing fuel economy standards, this outcome risks hindering emissions reductions efforts.

Finally, whereas price considerations for American households warrant attention, so does the cost firms incur for manufacturing EVs. EV prices may be rising but even at current price points, manufacturers are struggling with profitability. Ford's EV business lost $2.1 billion in 2022 and is expected to lose another $3 billion in 2023[22]. Colin Langan and Kosta Tasoulis, auto analysts at Wells Fargo, have consistently highlighted the challenging economics facing EV manufacturers, noting that where government-imposed EV sales targets are concerned, "proposed rules seem to ignore the large profit impact to the auto industry."[23],[24] Careful deliberation of automotive policy is warranted given the impact this industry has on jobs and economic mobility.

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[17] Schloter, Lukas. "Empirical Analysis of the Depreciation of Electric Vehicles Compared to Gasoline Vehicles." *Transport Policy*, vol. 126, 2022, pp. 268–279., https://doi.org/10.1016/j.tranpol.2022.07.021.
[18] Burnham, Andrew, et al. "Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains." *Argonne National Laboratory*, U.S. Department of Energy, Apr. 2021, https://publications.anl.gov/anlpubs/2021/05/167399.pdf.
[19] Bauer, Gordon, et al. "When Might Lower-Income Drivers Benefit from Electric Vehicles? Quantifying the Economic Equity Implications of Electric Vehicle Adoption." *International Council on Clean Transportation*, Feb. 2021, https://theicct.org/sites/default/files/publications/EV-equity-feb2021.pdf.
[20] Boudway, Ira. "Used EV Prices Are Falling Just in Time for a New US Tax Credit." *Bloomberg*, 20 Feb. 2023, https://www.bloomberg.com/news/articles/2023-02-20/will-used-ev-prices-keep-going-down-this-year.
[21] Turrentine, Thomas, et al. "The Dynamics of Plug-in Electric Vehicles in the Secondary Market and Their Implications for Vehicle Demand, Durability, and Emissions." *National Center for Sustainable Transportation*, 1 Apr. 2018, https://ncst.ucdavis.edu/research-product/dynamics-plug-electric-vehicles-secondary-market-and-their-implications-vehicle
[22] CBS News. "Ford Says It Will Lose $3 Billion This Year Making Electric Cars." *CBS News*, CBS Interactive, 23 Mar. 2023, https://www.cbsnews.com/news/ford-ev-unit-losing-billions-should-be-seen-as-startup/.
[23] Langan, Colin M., and Kosta Tasoulis. "EPA's Tail-Pipe Dream: Will There Be Enough Lithium for Proposed 2032 Targets?" *Wells Fargo*, 14 Apr. 2023.
[24] Langan, Colin M., and Kosta Tasoulis. "Ford Motor Company (F): Long Road Ahead for BEV Profitability." *Wells Fargo*, 24 Mar. 2023.

3. Critical mineral considerations

Clean energy technologies require more minerals to build compared to their fossil-fuel powered counterparts, owing to functional differences in their underlying energy systems. A typical EV requires six times the critical mineral inputs compared to its ICE powered counterpart[25]. These inputs include lithium, nickel, cobalt, and manganese, all of which are crucial to maintaining battery performance, energy density, and longevity. While reliance on these minerals offers a pathway towards decarbonization, it also imposes a distinct set of challenges.

The United States depends heavily on imports to meet its mineral needs[26]. This dependency has prompted numerous experts to highlight the precarious position the United States finds itself in—at risk of losing our position of global economic leadership and being left vulnerable to supply disruptions and dependent on nations that do not share our values[27,28]. In response, and specific to EV battery minerals, Biden issued the "Presidential Determination Pursuant to Section 303 of the Defense Production Act of 1950, as Amended," which calls for, "the sustainable and responsible domestic mining, beneficiation, and value-added processing of strategic and critical materials for the production of large-capacity batteries for the automotive, e-mobility, and stationary storage sectors are essential to the national defense."[29]

Congress has taken similar action, most notably through the IRA. However, even though laws like the IRA aim to shore up U.S. extraction, processing, and recycling, these efforts offer limited utility because of how minerals are geographically distributed. Breakthrough's analysis of U.S. mine production and recycling capability reveals that the United States will not be able to use local sourcing alone to meet the initial electrification goals set out by the Biden administration (50 percent electrification sales by 2030) (Fig. 1), let alone those announced last week (67 percent electrification sales by 2032). Coordination with our international partners could theoretically help us meet EV mineral needs, but here too challenges persist. Many of our allies have set aggressive electrification goals of their own, and there is, to put it bluntly, only so much mineral supply to go around.

These constraints have prompted renewed interest in alternative battery chemistries, the goal being to alter the mineral requirements of future EV batteries. Among the most promising of these is lithium iron phosphate (LFP), a formulation that forgoes long-standing reliance on manganese and cobalt, minerals that are both expensive and concentrated in nations that do not share our values. However,

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[25] International Energy Agency. "The Role of Critical Minerals in Clean Energy Transitions." *International Energy Agency*, May 2021, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

[26] Tracy, Brandon S. "Critical Minerals in Electric Vehicle Batteries." *Congressional Research Service*, 29 Aug. 2022, https://sgp.fas.org/crs/misc/R47227.pdf.

[27] Wulf, Abigail. "Testimony Submitted on Behalf of Securing America's Future Energy (SAFE)." *Committee on Energy and Natural Resources*, United States Senate, 31 Mar. 2022, https://www.energy.senate.gov/services/files/79FD8935-292A-4DB3-BD9B-2C0195B9C2FB.

[28] Nkulu, Célestin Banza Lubaba, et al. "Sustainability of artisanal mining of cobalt in DR Congo." *Nature Sustainability*, no. 1, 14 Sept. 2018, pp. 495-504, https://doi.org/10.1038/s41893-018-0139-4.

[29] Biden, Joseph R. "Presidential Determination Pursuant to Section 303 of the Defense Production Act of 1950, as Amended, on Airbreathing Engines, Advanced Avionics Position Navigation and Guidance Systems, and Constituent Materials for Hypersonic Systems." *The White House*, 1 Mar. 2023, https://www.whitehouse.gov/briefing-room/presidential-actions/2023/03/01/presidential-determination-pursuant-to-section-303-of-the-defense-production-act-of-1950-as-amended-on-airbreathing-engines-advanced-avionics-position-navigation-and-guidance-systems-and-constitue/.

Breakthrough's analysis of this battery chemistry suggests that—owing to lower energy density—EVs equipped with LFP batteries may be unable to meet the range expectations of American consumers at the price point these consumers expect.

4. Congressional response

The evidence presented thus far does not—and should not—be construed as a dismissal of EVs' potential to reduce carbon emissions in the transportation sector. To be clear, such a reduction is urgent, and EVs can help achieve it. But there is little assurance that such an outcome will be realized. Moreover, emerging evidence suggests that EV adoption could—owing to adoption and usage patterns in American households—have unintended consequences. Indeed, existing EV adoption policies may not facilitate meaningful reductions in transportation sector emissions. Even when reductions are realized, EVs may not be the most cost-effective emissions reduction pathway, at least from the vantage point of public spending. Three steps could address these concerns.

First, EV subsidies should be reserved solely for vehicle replacement purposes[30]. The composition of operational vehicle stock reflects the accumulation of new vehicle sales less vehicle retirements over time[31]. The goal of EV subsidies is to transform the 'propulsion profile' of this stock, not—as is increasingly being observed—raise the overall number of vehicles in stock[32]. More cars on the road, regardless of propulsion type, risks worsening higher traffic volume-related externalities like congestion, noise, and traffic fatalities. Consequently, EV subsidies should be reserved for consumers seeking to replace, not add to, the number of vehicles in their household. Replacement of primary vehicles in a household should be prioritized.

Second, from the vantage point of public spending, policy makers should consider alternative vehicle powertrains that also offer emissions reduction potential[33]. The most notable of these are hybrid-electric vehicles (HEVs), which rely on electric-drive technologies to boost vehicle efficiency through regenerative braking[34]. Breakthrough's work finds HEVs are a more climate friendly alternative to an EV if the EV covers less than approximately 96,000 miles across its lifetime and an HEV covers 180,000 miles (Fig. 2). Furthermore, we note that because HEVs cost significantly less than EVs, the magnitude of EV cost penalties relative to their GHG emission reduction benefits makes HEVs a more promising near-term emissions reduction pathway[35,36].

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[30] Nunes, Ashley, and Lucas Woodley. "Governments Should Optimize Electric Vehicle Subsidies." *Nature Human Behaviour*, 3 Mar. 2023, https://doi.org/10.1038/s41562-023-01557-1.
[31] Keith, David R, et al. "Vehicle fleet turnover and the future of fuel economy." *Environmental Research Letters,* vol. 14, no. 2, 2019, p. 021001., https://doi.org/10.1088/1748-9326/aaf4d2.
[32] Burlig, Fiona, et al. "Household Vehicle Portfolios and EV Demand." *Economics of Transportation in the 21st Century Conference*, National Bureau of Economic Research, 14 Oct. 2022, https://www.nber.org/conferences/economics-transportation-21st-century-fall-2022.
[33] Woodley, Lucas, et al. "Targeted electric vehicle procurement incentives facilitate efficient abatement cost outcomes." *Sustainable Cities and Society* (In press).
[34] Alternative Fuels Data Center. "Electric Vehicle Benefits and Considerations." *Alternative Fuels Data Center*, U.S. Department of Energy, https://afdc.energy.gov/fuels/electricity_benefits.html.
[35] Nunes, Ashley, et al. "Near-Term Policy Pathways for Reducing Car and Light-Truck Emissions." *Environmental Research Letters*, vol. 16, no. 6, 2021, p. 061003., https://doi.org/10.1088/1748-9326/ac04d9.
[36] Nunes, Ashley. "The Biden Administration shouldn't ignore hybrid cars." *The Financial Times*, 27 April. 2021, https://www.ft.com/content/613d0ac5-a848-4f7c-85f5-69bc8b636363

Third and finally, auto makers should be incentivized to produce EVs that are appealing, profitable, and affordable; an automotive grand challenge of sorts that puts American ingenuity and know-how to the test. Such an effort would emulate similar, longstanding initiatives like the Defense Advanced Research Projects Agency Grand Challenge, a government sponsored competition that awards cash prices for making innovative automotive design concepts a reality. Absent the availability of EVs that meet the mobility *and* affordability needs of American households, caution should be exercised lest a de facto mandate for EV adoption widens existing inequities or keeps older, more polluting ICE vehicles in the national vehicle stock for longer.

Thank you again Chairman Johnson, Ranking Member Tonko, and honorable members of the Committee. If I can be of any assistance to you, please feel free to contact me at the Breakthrough Institute.

Ashley Nunes, PhD
Director, Federal Policy, Climate and Energy
The Breakthrough Institute
923 15th St NW
Washington, DC 20005

	Avg yearly requirement for Biden 2030 EV goals	U.S. avg yearly production, from mining (2018–2022)	U.S. avg yearly production, mining + recyling (2018–2022)	Mine production from allies + partners (2022)[c]	Potential to increase production through recycling	U.S. avg yearly economy-wide consumption	Recent trend in U.S. economy-wide consumption
	Thousands of metric tons						
Aluminum[d]	Low: 71 Middle: 160 High: 290	24[a]	1 524	25 000	High	4 600	Steady →
Cobalt	Low: 5 Middle: 12 High: 23	0.6	2.8	19	High	9	Steady →
Copper	Low: 42 Middle: 96 High: 170	1 242	1 399	9 890	High	1 832	Increasing ↑
Graphite	Low: 110 Middle: 240 High: 430	243 (all synthetic, mostly consumed in non-battery industries, especially steel[b])	243 (all synthetic, mostly consumed in non-battery industries, especially steel[b])	48	Low	490	Increasing ↑
Lithium	Low: 11 Middle: 25 High: 46	1	1	101	Low	2	Will increase sharply ↑↑
Manganese	Low: 4 Middle: 10 High: 20	None	None	3 530	Low	754	Steady →
Nickel	Low: 31 Middle: 74 High: 140	17	123	810	High	220	Increasing ↑
Phosphate	Low: 26 Middle: 57 High: 98	23 000	23 000	61 950	Low	25 000	Steady →

a. U.S. mine production from 2021 only
b. Avg synthetic graphite production from 2017–2021
c. Considers countries with a Free Trade Agreement or mutual defense treaty with the United States
d. Aluminum mine production and reserves are converted to aluminum equivalent from bauxite figures. U.S. mine production rates are based on bauxite mining from 2021 only. Aluminum secondary/recycled production values reflect direct production of refined aluminum and are not converted.

- Sufficient for high EV adoption scenario
- Sufficient for medium EV adoption scenario
- Sufficient for low EV adoption scenario
- Insufficient across all EV adoption scenarios
- Processing, refining, or production supply chains highly concentrated in China

— High, medium, and low EV adoption scenarios reflect approximately 54, 30, and 13 million EV sales respectively between 2024 and 2030.

Figure 1: Assessment of mineral production capacity based on the Biden Administration's 2030 electrification goals.

Aggregate EV Utilization (mi.)	EV emissions (g/mi.)	EV emissions + battery replacement (g/mi.)
10,000	1,488.77 🟠 🔵	1,913.77 🟠 🔵
20,000	808.77 🟠 🔵	1,021.27 🟠 🔵
30,000	582.10 🟠 🔵	723.77 🟠 🔵
40,000	468.77 🟠 🔵	575.02 🟠 🔵
50,000	400.77 🟠 🔵	485.77 🟠 🔵
60,000	355.44 🔵	426.27 🟠 🔵
70,000	323.06 🔵	383.77 🟠 🔵
80,000	298.77 🔵	351.89 🔵
90,000	279.88 🔵	327.10 🔵
100,000	264.77	307.27 🔵
110,000	252.41	291.04 🔵
120,000	242.10	277.52 🔵
130,000	233.38	266.08
140,000	225.91	256.27
150,000	219.44	247.77
160,000	213.77	240.33
170,000	208.77	233.77
180,000	204.33	227.94

🟠 ICE: Internal combustion engine vehicle less polluting (~372.7 g/mi)

🔵 HEV: Hybrid electric vehicle less polluting (~272.4 g/mi)

Figure 2: EV emissions impact at varying aggregate utilization levels holding HEV/ICE utilization constant (i.e., 180,000 miles)