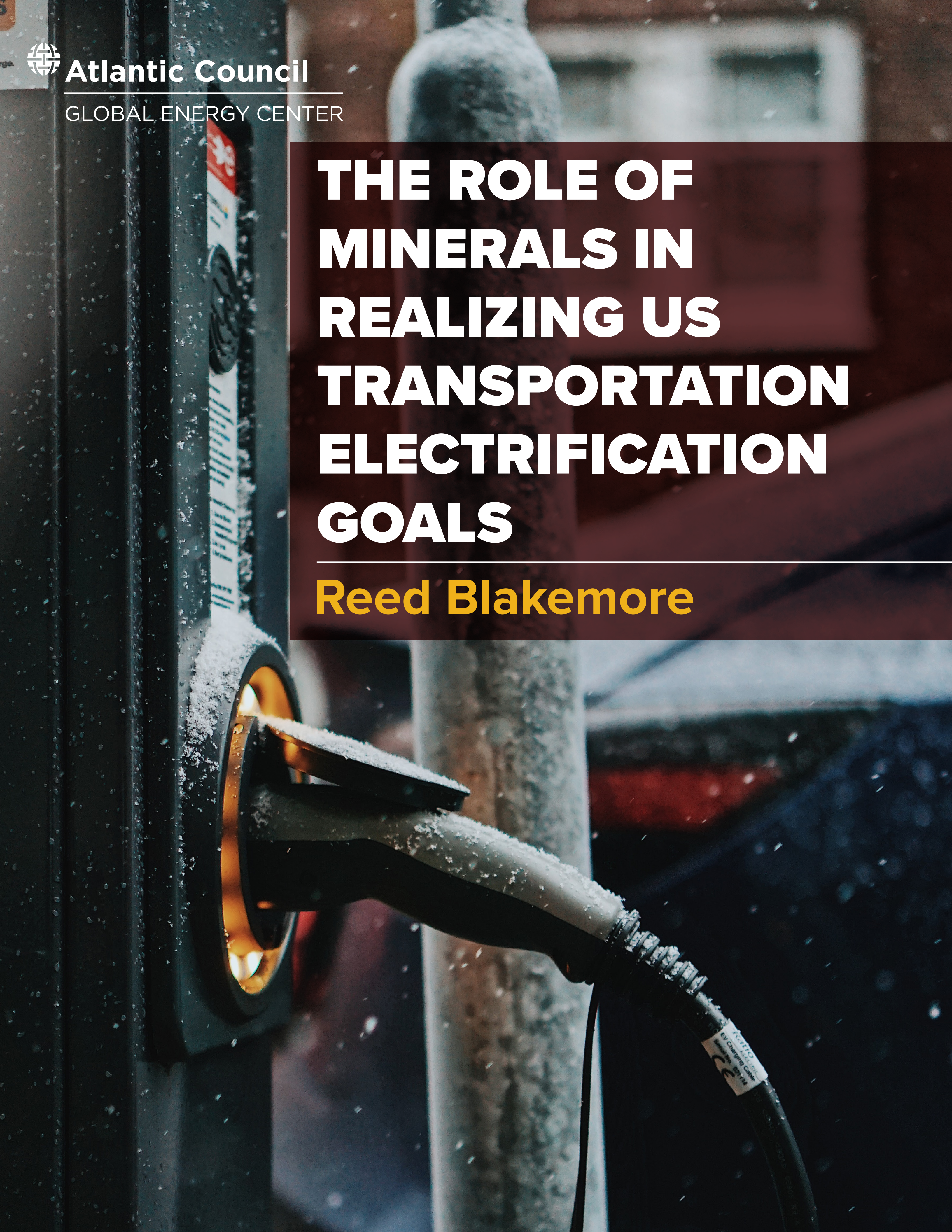

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THE ROLE OF MINERALS IN REALIZING US TRANSPORTATION ELECTRIFICATION GOALS

Reed Blakemore

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Cover: An electric car charges in a snowfall.
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EXECUTIVE SUMMARY

In its first year, the Biden administration has made transportation electrification and associated infrastructure development a central pillar of the domestic energy transition and post-pandemic economic recovery. This includes an announcement to electrify the entire federal fleet and electrify 50 percent of all new car sales by 2030. If successful—and assuming continued deployment and advancement of electric vehicle models by the US auto industry—the US electric vehicle (EV) market will likely surpass the projection of the International Energy Agency (IEA) of 8.1 million electric car sales in the US in 2030 by orders of magnitude.[1]

The components necessary to empower scaled EV adoption—batteries, drivetrain, and vehicle components, as well as charging infrastructure—all have individual mineral requirements that will need to be met as the automotive industry continues to electrify. EV batteries require lithium, nickel, cobalt, and iron. Vehicle drivetrains require significant amounts of Rare Earth Element (REE)-based permanent magnets to transfer stored battery power into movement. Charging infrastructure, both public and private, will require extensive amounts of copper wiring to provide confidence to consumers in their ability to access charging points and travel safely.

As a result, domestic demand for EV-associated minerals and materials will accelerate. For example, a recent supply chain review by the Biden administration projected that electrifying just 20 percent of domestic light-duty vehicles would require approximately 25, 49, and 22 percent of the total global nickel, lithium, and cobalt (respectively) that was mined in 2019. The administration's goal of deploying 500,000 new charging stations by 2030 could immediately add 4,000,000 kg of infrastructure-related copper demand to the market.

Such a rapid electrification of the US vehicle fleet and corresponding growth in EV minerals demand will only add to a global mineral supply chain already feeling the strain of the energy transition and transportation electrification. A recent IEA report on the mineral demands of the energy transition projected that global EV deployment rates will create demand for forty-three and forty-one times as much lithium and nickel, respectively, in 2040 compared to 2020. In the same report, overall global demand for EV-related minerals (to include additional EV-minerals such as rare earths, copper, and silicon) increases 30 times by 2040 as well.

Put simply, the realization of the Biden administration's transportation electrification goals will put the United States at the center of rapidly-growing minerals demand. This is driving concerns about the risks of mineral import dependency, securing sufficient mineral supplies such that the cost of an EV does not become prohibitive, and ensuring that the mineral intensity of an EV future does not come at the expense of a sustainable, transparent, and well-governed energy system.

US automakers, policy leaders, and the mining industry are already beginning to take action to address these possible risks. Industry leaders are beginning to explore ways to reduce the relative mineral intensity of EV batteries and vehicle components, with an eye to cost and performance. Automakers and miners are collaborating to establish supply partnerships, granting the auto industry direct access to the mineral supply chain. The Biden administration, meanwhile, is examining options to increase mineral supplies at home and abroad, while exploring initiatives for increased recycling and continuing support for the US Department of State's Energy Resource Governance Initiative (ERGI) to reinforce sustainability across the supply chain.

Policymakers and industry actors are working to secure a healthy EV mineral supply chain; however, those efforts might pale in comparison to the scale and pace of mineral demand growth. This poses a number of risks and opportunities that policymakers should consider, in particular, the risks of an unhealthy supply chain imposing prohibitive costs on automakers and consumers, as well as the opportunity for Washington—through prompt and decisive action— to ensure that the investment, governance, and environmental stewardship of minerals development is done in a sustainable way that empowers US leadership in the electrification of transportation.

To this end, this report recommends a series of principles which policymakers should consider in parallel to their transportation electrification targets:

- Aim for an overabundance of mineral supplies by investing in best-in-class domestic mineral resources and expertise, while collaborating with partner countries to grow capacity throughout the mineral supply chain;
- Encourage cross-industry partnerships to reinforce the EV value chain from mine to road;
- Place sustainability at the forefront of the EV mineral conversation to establish the centrality of mineral resiliency, taking action to ensure verifiable environmental stewardship, sustainable investment practices, and good governance at home and abroad.

The Biden administration's goals for electric vehicle deployment will have a transformative impact on the broader decarbonization and economic goals of the United States. Minerals will be critical to make that transformation successful, and policymakers should not forget their importance as the policy pathways for EV deployment fall into place.

1 "Global EV Outlook 2021: Prospects for Electric Vehicle Deployment," IEA, April 2021, https://www.iea.org/reports/global-ev-outlook-2021/prospects-for-electric-vehicle-deployment#abstract.

INTRODUCTION

The electrification of transportation is a key priority to meet nationally determined contributions under the United Nations Framework Convention on Climate Change (UNFCCC), in addition to meeting broader energy security, industrial leadership, and local environmental goals.[2] For example, China recently imposed a mandate that 40 percent of all vehicle sales by 2030 must be electric, the EU's recent "Fit for 55" plan aims for 100 percent of vehicle sales to be emission-free by 2035, and a growing number of countries are exploring the possibility of a complete ban on vehicles with an internal combustion engine (ICE) at some point in the future.[3]

The United States is an important part of the global transition to electrified transport. Though electric vehicles (EV) are a growing share of total vehicle sales in the United States—one of the largest automotive markets in the world—the Biden administration is poised to accelerate that transition. Already, President Joe Biden has made transportation electrification and associated infrastructure development a central pillar of both domestic energy transition and post-pandemic economic recovery, announcing ambitions to electrify the entire federal fleet and electrify 50 percent of all new car sales by 2030. Even without these ambitions translated into policy, thanks to continued pledges from US automakers to electrify their own fleets, the 2021 EV outlook of the IEA projects that the US EV market will grow to 8.1 million vehicles by 2030.[4] The transportation electrification story in the United States, therefore, is only just beginning.

The pursuit of transportation electrification will accelerate domestic demand for associated minerals and materials, including cobalt, lithium, nickel, copper, and rare earth elements (REEs), among others. Such mineral demand growth will occur across the automotive sector—batteries, vehicle components, associated charging components, and grid infrastructure—and continue to evolve as the automotive industry responds to innovation expectations for rapid-charging batteries, expanded miles traveled, and more sustainable business models.

Growing domestic demand for minerals as a result of transportation electrification also will occur in tandem with a rapid acceleration of demand for energy transition-related minerals around the world. Already, studies from both the World Bank and the IEA project a fourfold increase in demand for key minerals in renewable and advanced energy technologies between now and 2040 in order to meet the goals of the Paris Agreement. Of this, the role of global EV sales in driving mineral and metal demands in the energy transition will be significant; for example, a recent IEA report on the mineral demands of the energy transition projects that global EV deployment rates will demand forty-three and forty-one times as much lithium and nickel, respectively, in 2040 compared to 2020.[5] As it stands, whether or not sufficient, sustainable, and resilient supplies of these minerals can be brought to market remains a significant area of concern for industry leaders and policymakers alike.

The story of US automotive electrification, therefore, is closely tied to a rapidly evolving global mineral supply chain. This issue brief will explore the minerals involved in the EV ecosystem, the expected growth in demand for those minerals as US auto manufacturers respond to domestic ambitions for transportation electrification, what commitments to EV manufacturing and infrastructure will be essential as deployment continues to gain pace, and the strategies policymakers should consider in order to secure resilient and sustainable sources of these minerals.

This paper will first address projected EV growth in the United States, accounting for both the policy signals coming out of the Biden administration as well as additional goals set by US original equipment manufacturers (OEMs). It will then examine the key mineral requirements for electrifying the transportation sector and evaluate how these mineral requirements will likely increase as the United States continues to pursue its electrification ambitions. Finally, it will explore current efforts from policymakers and the private sector to ensure those minerals demands are met, and where gaps exist as the United States pursues its electrification goals.

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2 Robert J. Johnston and Lily Ghebrai, *Asian Energy Transition: Moving the Oil Market One Step Closer to Peak Demand?*, Atlantic Council, January 8, 2018, https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/asian-energy-transition-moving-the-oil-market-one-step-closer-to-peak-demand.

3 Nancy W. Stauffer, "China's transition to electric vehicles," *MIT Energy Initiative,* November 25, 2020, https://energy.mit.edu/news/chinas-transition-to-electric-vehicles/; "EU climate plan will make emissions-free cars accessible for all," *Transport & Environment,* July 14, 2021, https://www.transportenvironment.org/discover/eu-climate-plan-will-make-emissions-free-cars-accessible-for-all/; Alex Keynes, "CO2 performance standards and alternative fuels infrastructure proposals: the right direction, but lacking short-term ambition," Heinrich Böll Stiftung, September 23, 2021, https://eu.boell.org/en/2021/09/23/co2-performance-standards-and-alternative-fuels-infrastructure-proposals-right-direction.

4 "Global EV Outlook 2021: Prospects for Electric Vehicle Deployment," IEA, April 2021, https://www.iea.org/reports/global-ev-outlook-2021/prospects-for-electric-vehicle-deployment#abstract.

5 "The Role of Critical Minerals in Clean Energy Transitions," IEA, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions.

TRANSPORTATION ELECTRIFICATION AND POLICY FORCES IN ACCELERATING EV DEPLOYMENT

Policy and the Modern EV Market

The modern EV market in the United States is roughly two decades old. The 2000 US release of the Toyota Prius—the world's first mass-produced hybrid electric vehicle (HEV)—and the 2006 launch of Tesla Motors, now known as Tesla Inc., represent two starting points in the upward trajectory of EV sales that has followed.[6] In the years since, the electrification of transport in the United States has steadily progressed in response to policy support that has encouraged EV/HEV deployment and led to a growing number of EV/HEV model releases by auto manufacturers. A few major developments of note include: the allocation of $115 million toward nationwide charging infrastructure under the 2009 American Recovery and Reinvestment Act; the rollout of new, stricter Corporate Average Fuel Economy (CAFE) standards and limits to tailpipe emissions at the federal and state level beginning in 2012, which included a credit system for automakers to produce fully electric and hybrid vehicles; and additional federal EV purchasing incentives throughout the Obama administration.[7] In addition to financing EV infrastructure and, in some cases, directly enabling EV purchases, these policies took advantage of growing consumer concern regarding greenhouse gas emissions and climate change by improving the consumer rationale for EV purchases.

As a result, US EV sales grew from twenty thousand in 2011 to 100,060 in 2016, according to the IEA, with approximately thirty different models being offered across the industry.[8] Despite this increase, by 2016 this accounted for less than 3 percent of the approximately 17 million vehicles sold in the United States.

After taking office in 2017, President Donald Trump reversed many of the EV-friendly federal policies implemented throughout the eight years of his predecessor. Yet despite a less favorable policy environment, a rapidly improving suite of EV options for US consumers supported continued steady growth in US EV sales during the Trump administration.[9] EV annual sales grew by 130,000 vehicles between 2017–2019, reaching a peak of roughly 360,000 vehicles sold in 2018, before declining slightly in 2019 and 2020.[10]

Automakers Take the Lead

The continued growth of EV sales, even in a less EV-friendly policy environment, points to an important dynamic that has characterized the EV market in the years since: continued investment in electrification and decarbonization from the automotive industry. Ford and General Motors (GM) have announced EV investments of $29 billion and $27 billion, respectively, through 2025.[11] BMW expects hybrid and electric vehicle options to account for between 15 percent and 25 percent of its sales by 2025.[12] Jaguar expects its entire line of models to be electric by the same year. Tesla Founder Elon Musk has expressed a goal for 2030 sales to reach 20 million vehicles per year.[13] Further, Audi has announced that it will stop producing ICE vehicles by 2033, and GM has set an entirely carbon-neutral operational target by 2040.[14]

Meanwhile, growing attention from major automotive manufacturers to electrification has developed in tandem with a rapidly evolving set of new electrified automakers operating in the United States.[15] Continued traction for the electrification of public transport

6 Electric vehicles have been available for some time, with varying levels of success and market share. However, limited top speeds and driving distance have prevented early EV models from truly gaining much consumer attention outside of periods of high oil prices and environmentally focused auto enthusiasts. As a result, the phrase "modern EV market" is used to describe the period of EV and hybrid sales growth over the past twenty years that has been more consistent and had more longevity; "The History of the Electric Car," US Department of Energy, September 15, 2014, https://www.energy.gov/articles/history-electric-car.

7 "EV Charging Stations Take Off Across America," US Department of Energy, November 19, 2012, https://www.energy.gov/articles/ev-charging-stations-take-across-america; Rachel Becker, "California's Fight over Tailpipe Emissions, Explained," *Cal Matters,* last updated June 23, 2020, https://calmatters.org/explainers/california-auto-emissions-standards-fight-with-donald-trump-explained/; Daniel Sperling and Anthony Eggert, "California's climate and energy policy for transportation," *Energy Strategy Reviews* 5 (2014), 88-94, https://escholarship.org/content/qt5r75m45b/qt5r75m45b.pdf; David Shepardson and Bernie Woodall, "Electric Vehicle Sales Fall Short of Obama Goal," *Reuters*, January 20, 2016, https://www.reuters.com/article/us-autos-electric-obama-insight/electric-vehicle-sales-fall-far-short-of-obama-goal-idUSKCN0UY0F0.

8 "Global electric car sales by key markets, 2015-2020," IEA, last updated December 2, 2020, https://www.iea.org/data-and-statistics/charts/global-electric-car-sales-by-key-markets-2015-2020; "Electric Vehicle Sales Fall Short of Obama Goal."

9 While the significant rise in US EV sales in 2018 was led by Tesla's delivery of 139,372 units of its Model 3 that year, 2018 also offers several other noteworthy successes, including improvements to range and affordability of longstanding EV offerings, such as the Chevrolet Volt and Toyota Prius Prime. A number of new EV models debuted in 2018, including two models from Kia that had over 200 miles of battery range, at the same time that luxury brands such as Mercedes, BMW, and Jaguar all began to roll out electrified models.

10 "Global Electric Car Sales by Key Markets, 2015-2020."

11 Annie White, "Here Are All the Promises Automakers Have Made About Electric Cars," *Car and Driver,* June 26, 2021, https://www.caranddriver.com/news/g35562831/ev-plans-automakers-timeline/.

12 White, "Here Are All the Promises Automakers Have Made About Electric Cars."

13 Zachary Shahan, "Why Is Elon Musk Targeting 20 Million Tesla Sales A Year by 2030?" *Clean Technica,* April 19, 2021, https://cleantechnica.com/2021/04/19/why-is-elon-musk-targeting-20-million-tesla-sales-a-year-by-2030/.

14 Shahan, "Why Is Elon Musk Targeting 20 Million Tesla Sales A Year by 2030?"

15 Who Makes All the EVs? Breaking Down Which Companies Sell Electric Cars," *Motortrend*, May 14, 2021, https://www.motortrend.com/features/electric-car-companies-make-electric-cars/?.

US President Joe Biden signs an executive order on transforming the country's auto fleet at the White House in Washington, DC, in August 2021. REUTERS/Jonathan Ernst

(where challenges related to range and charging infrastructure are less severe) has also encouraged new EV bus-manufacturing companies like Proterra and BYD, both of which have headquarters in California (though BYD is a Chinese-owned company).[16]

All told, the groundwork for the electrification of US consumer auto sales is in place even in the absence of significant policy support, especially as automakers have begun to expand beyond traditional consumer vehicles into luxury and light-duty trucks and explore the next steps needed for widespread EV deployment, such as sufficient charging infrastructure.

The Role of the Biden Administration

The arrival of the Biden administration is a possible turning point in the US EV market. Following numerous calls throughout President Biden's 2020 presidential campaign for rapid electrification of the domestic automotive sector, in August President Biden signed an executive order to electrify 50 percent of new car sales by 2030 as part of a broader package of decarbonization initiatives under its goal to reach net-zero domestic emissions by 2050.[17]

As of November 2021, the administration appears to be pushing toward this automotive electrification goal primarily through two separate efforts aimed at continuing the momentum that the domestic auto industry has gained over the past decade:

1. Reestablishing (or possibly surpassing) Obama-era tailpipe emissions standards. As early as January 2021, President-elect Biden was reportedly already considering a rapid return to the federal emissions tailpipe standards that had been rolled back by his immediate predecessor.[18] Following an announcement in August 2021, the administration set a goal to return annual emissions improvements to 3.7 percent per year by 2026 and return fuel efficiency standards to 52 miles per gallon by that same year.[19] Doing so will continue to provide tailwinds to existing initiatives from the automotive industry to transition its offerings toward predominantly or entirely electric models.

2. Federal spending to encourage EV adoption. The administration has announced ambitious spending plans to incentivize continued consumer faith and interest in EVs as a viable transportation option. This includes the goal of building a national network of 500,000 charging stations and the development of "alternative fuel corridors."[20] Though the administration's initial levels of ambition also included $100 billion in EV purchasing incentives, the Infrastructure Investment and Jobs Act was pared back to $7.5 billion for EV charging-station development and an additional $5 billion in federal support for

16 Shaandin Cedar, "5 Electric Bus Makers Shifting into Next Gear," *GreenBiz*, June 1, 2021, https://www.greenbiz.com/article/5-electric-bus-makers-shifting-next-gear.

17 Tom Krisher and Hope Yen, "Biden Mileage Rule to Exceed Obama Climate Goal," *AP*, July 27, 2021, https://apnews.com/article/technology-joe-biden-government-and-politics-climate-change-climate-dd404e566e5f849f2aa05662f4752e8a; "FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies," White House Press Release, April 22, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/; Coral Davenport, "Biden, in a Push to Phase Out Gas Cars, Tightens Pollution Rules," *New York Times*, last updated August 9, 2021, https://www.nytimes.com/2021/08/05/climate/biden-tailpipe-emissions-electric-vehicles.html.

18 David Shepardson, "Biden to Order Agencies to Revisit Vehicle Tailpipe Emissions Standards," *Reuters*, January 20, 2021, https://www.reuters.com/business/environment/biden-order-agencies-revisit-vehicle-tailpipe-emissions-standards-2021-01-20/.

19 David Shepardson and Jeff Mason, "Biden Seeks to Make Half of New U.S. Auto Fleet Electric by 2030," *Reuters,* August 5, 2021, https://www.reuters.com/business/autos-transportation/biden-set-target-50-evs-by-2030-industry-backs-goal-2021-08-05/; "Biden Mileage Rule to Exceed Obama Climate Goal."

20 "FACT SHEET: Biden Administration Advances Electric Vehicle Charging Infrastructure," White House Press Release, April 22, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-biden-administration-advances-electric-vehicle-charging-infrastructure/.

Selected Outlooks for EV Deployment in the US

Institution (Date of Projection)	US EV Forecast
IHS Markit, "EV Outlook" (February 2021)*	10 percent of all cars sold by 2025
IEA, "Stated Policies Scenario" (April 2021)**	34 percent of new vehicles sold by 2030
Bloomberg BNEF "Economic Transition Scenario" (June 2021)***	75 percent of new passenger vehicles sold by 2040

* Sean Szymkowski, "Electric Cars Will Double Their Market Share in 2021, Forecast Says," CNET, February 23, 2021, https://www.cnet.com/roadshow/news/electric-cars-sales-market-forecast/.
** "Global EV Sales by Scenario," IEA, last updated April 28, 2021, https://www.iea.org/data-and-statistics/charts/global-ev-sales-by-scenario-2020-2030.
*** "EVO Report 2021," BloombergNEF, 2021, https://about.bnef.com/electric-vehicle-outlook/.

electric buses.[21] Targeted federal support for buses in particular is a major area of focus for the administration, which set a goal to electrify 50,000 diesel transit buses (approximately 70 percent of the current fleet) by 2030.[22] This would reportedly increase the value of the electric bus market fivefold (to $2.7 billion per year) by 2025.[23] Additional spending plans for grid modernization and power transmission will also help to facilitate the spread of charging stations beyond highly trafficked metropolitan corridors.[24]

Each of these efforts indicate a level of ambition across the administration that will likely grow in the coming years. EV purchasing incentives, for example, were dropped from the Infrastructure Investment and Jobs Act but but are currently included in the planned 'Build Back Better' reconciliation package (formerly known as the American Families Plan), although the incentive plan is still being negotiated at the time of writing.[25] Earlier this year, the administration expressed a goal to electrify the entire federal fleet, accounting for roughly 650,000 vehicles.[26] Though President Biden has yet to set an ICE phase-out target (which twelve states have called upon him to do), each of these initiatives will, by virtue of the market signaling power of the federal government, continue to reinforce the confidence of auto manufacturers to continue to invest in their electrified offerings.[27]

Furthermore, the administration's ambitions for an electrified transportation sector are tied to ensuring the continued industrial strength of the automotive industry and the opportunities for job creation. Early declarations from the Biden administration in January of this year to create a million auto industry jobs have placed job creation at the center of the president's decarbonization and electrification narrative.[28] The administration's messaging has followed suit: the initial announcement of the American Jobs Plan in April of this year was grounded, in part, on the goal of leading the EV market, while the message of job creation has been a successful tool to garner bipartisan support for the infrastructure package as it moves through Congress.[29]

Additional momentum from the policy community has added a tailwind to a positive EV adoption forecast in the United States. Though a 2018 analysis from the Edison Electric Institute projected that EVs would make up approximately 7 percent of total vehicles on the road and 20 percent of new vehicles sold by 2030, momentum from both industry and policymakers has improved these forecasts considerably, as described in the figure above.[30]

Importantly, the sales data between 2017–2020 and the improved forecasts for EV sales over the next several years point to the resiliency of EV market growth, particularly in a less favorable (if not combative) policy environment. This would suggest that infrastructure and affordability will remain challenges to scaled EV adoption in the short term, yet such challenges have more of an impact on the speed of the transition to an electrified transportation sector, rather than the transition occurring at all. Indeed, the proverbial electric train (or bus, passenger vehicle, or light-duty vehicle) has most likely left the station.

21 Sean Szymkowski, "Biden Plan Calls for $100B in EV Rebates and That's Huge," *CNET*, April 8, 2021, https://www.cnet.com/roadshow/news/biden-ev-rebates-infrastructure-plan/; US House approves $1 trillion infrastructure bill," Argus Media, November 6, 2021, https://www.argusmedia.com/en/news/2271448-us-house-approves-1-trillion-infrastructure-bill.

22 Sean Szymkowski, "Biden Agrees to $973B Bipartisan Infrastructure Plan, EV Subsidies Axed," *CNET*, June 24, 2021, https://www.cnet.com/roadshow/news/biden-infrastructure-ev-subsidies-charging-network/; Tina Bellon, "Factbox: Five Facts on Why Electric Buses are Key to Biden's Green Agenda," *Reuters*, July 14, 2021; https://www.reuters.com/business/sustainable-business/five-facts-why-electric-buses-are-key-bidens-green-agenda-2021-07-14/.

23 Bellon, "Factbox: Five Facts on Why Electric Buses are Key to Biden's Green Agenda."

24 "FACT SHEET: Biden Administration Advances Expansion & Modernization of the Electric Grid," White House Press Release, April 27, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/27/fact-sheet-biden-administration-advances-expansion-modernization-of-the-electric-grid/; Drew Desilver, "Today's Electric Vehicle Market: Slow Growth in U.S., Faster in China, Europe," Pew Research Center, June 7, 2021, https://www.pewresearch.org/fact-tank/2021/06/07/todays-electric-vehicle-market-slow-growth-in-u-s-faster-in-china-europe/.

25 Szymkowski, "Biden Agrees to $973B Bipartisan Infrastructure Plan, EV Subsidies Axed."

26 David Shepardson, "Biden Vows to Replace U.S. Government Fleet with Electric Vehicles," *Reuters*, January 25, 2021, https://www.reuters.com/article/us-usa-biden-autos/biden-vows-to-replace-u-s-government-fleet-with-electric-vehicles-idUSKBN29U2LW.

27 "Twelve U.S. States Urge Biden to Back Phasing Out Gas-Powered Vehicle Sales by 2035," *Reuters*, April 21, 2021, https://www.reuters.com/business/twelve-us-states-urge-biden-back-phasing-out-gas-powered-vehicle-sales-by-2035-2021-04-21/; Jim DiPeso, "Biden Lists Climate as High Priority," *NewsData*, last updated November 13, 2020, https://www.newsdata.com/clearing_up/clearing_it_up/potomac-biden-lists-climate-as-high-priority/article_067d2e92-2608-11eb-984f-f34f582abba9.html.

28 Joann Mueller, "What Biden's EV Push Could Mean for Jobs," *Axios*, January 22, 2021, https://www.axios.com/what-bidens-ev-push-could-mean-for-jobs-ff4e0bb8-1121-4cba-84e0-5b069c7ef8a5.html.

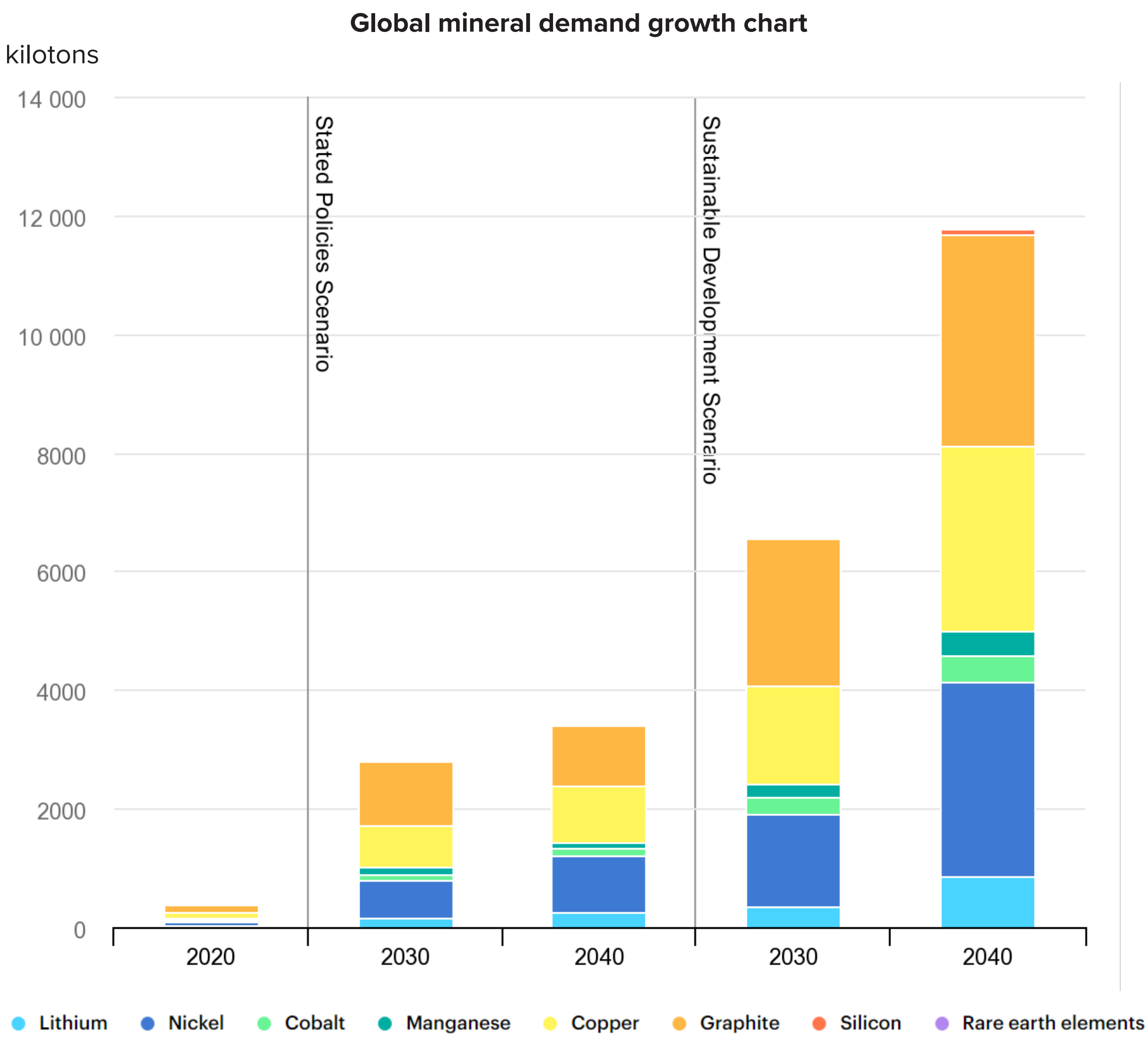
29 "FACT SHEET: The American Jobs Plan," White House Press Release, March 31, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/.

30 "EEI Celebrates 1 Million Electric Vehicles on U.S. Roads," Edison Electric Institute, November 18, 2018, https://www.eei.org/resourcesandmedia/newsroom/Pages/Press%20Releases/EEI%20Celebrates%201%20Million%20Electric%20Vehicles%20on%20U-S-%20Roads.aspx.

EVS, MINERALS, AND THE ENERGY TRANSITION IN THE UNITED STATES

Electric vehicle manufacturing and deployment will likely play a dominant role in the US energy transition, regardless of whether the Biden administration's successors share similar ambitions for decarbonization and net-zero emissions.

The components necessary to empower scaled EV adoption—batteries, drivetrain and vehicle components, as well as charging infrastructure—all have individual mineral requirements that will need to be met as the automotive industry continues to electrify. This will create a particularly strong signal for US mineral demands, particularly should the US automotive sector pursue electrification with an eye to retaining US auto manufacturing. The following section explores the mineral needs of the components of the EV ecosystem.



Total mineral demand from new EV sales by scenario, 2020-2040, IEA, Paris
https://www.iea.org/data-and-statistics/charts/total-mineral-demand-from-new-ev-sales-by-scenario-2020-2040.

Batteries

There are three broad categories of battery types used in electric vehicles: lithium-ion (Li-ion), nickel-metal hydride, and lead-acid batteries.[31] Of these, Li-ion is increasingly the prevailing battery chemistry used in most electric vehicles on the market today, with analysis by the Union of Concerned Scientists finding that more than 60 gigawatt-hours (GWh) of Li-ion battery capacity has been deployed since 2010 across approximately one million EVs in the United States.[32] In 2020, global production of Li-ion cells surpassed 150 GWh per year.

A Li-ion battery consists of lithium ions traveling from an anode (predominantly graphite) to a cathode, the composition of which most often consists of a combination of lithium, nickel, manganese, cobalt, aluminum, and/or iron.[33] The composition of the cathode bears most strongly on the overall mineral demands of the battery, as well as its cost. Concerns about the price of cobalt and the sustainability, stability, and labor rights in the cobalt supply chain have led to consistent efforts to reduce the cobalt intensity of the Li-ion battery, particularly through the adoption of nickel-cobalt-aluminum cathodes (NCA) and nickel-manganese-cobalt (NMC) alternatives. Lithium-iron-phosphate (LFP) batteries, which are cobalt-free, are also gaining traction. Each of these different subchemistries offer their own advantages regarding energy density (and consequently, charge and range) and production cost. As a result, the average cobalt intensity of batteries is expected to decline by 60 percent between 2018 and 2035, with GM's new Ultium Battery, in particular, reaching a 70 percent net reduction in cobalt intensity.[34]

Though the preoccupation with cobalt intensity in newer Li-ion batteries is merited, it obscures the complexity of projected mineral requirements for future Li-ion battery demand. Reductions in overall cobalt intensity through alternative Li-ion chemistries will result in increased demand for nickel and manganese, while graphite will continue to be a necessary mineral component for battery anodes. Recent analysis by the IEA projects that—in order to meet the battery demands of its Sustainable Development Scenario—demand for manganese, nickel, cobalt, graphite, and lithium will be eight, nineteen, twenty-one, twenty-five, and forty-two times greater, respectively, in 2040 relative to 2020.[35]

Perhaps more importantly, differences in performance and cost between each of the cathode compositions in various battery types has yet to yield a truly dominant battery chemistry, which will likely further shape the demand profiles of each of these minerals relative to each other. LFP chemistries, due to their reduced cost but lower range, are popular in China, where there is a higher density of charging infrastructure. Tesla, for example, is reportedly making a longer-term shift toward LFP batteries to continue to bring down vehicle costs with an eye toward a battery line that is roughly two-thirds iron based (LFP) and one-third nickel based (NMC).[36] NMC batteries offer greater range and are currently preferred throughout the United States, with GM's Ultium battery currently claiming the highest nickel and lowest cobalt content in a large battery.[37]

The battery composition of the electrified automotive sector will shape future battery mineral demands from the US auto industry. On the one hand, the cost-effectiveness of LFP batteries has proven more attractive as a solution for entry-level EV models, thereby growing overall market share of that particular chemistry and mineral demand. On the other hand, US domestic preferences for small to midsize trucks and luxury vehicles, which typically demand higher performance and ever-greater range capacity, demand more mineral-intensive battery types.

Meanwhile, the availability of sufficient lithium and nickel supplies will remain a prevailing concern within the battery space. Although lithium carbonate supplies are currently in surplus, global demand could reach 2.8 million metric tons by 2028, with only 2 million metric tons of production capacity that same year.[38] Another analysis from Benchmark Mineral Intelligence points to a 26,000 metric ton lithium supply gap in 2021 that will grow to 1.1 million metric tons by 2030.[39] Nickel demand for EV batteries is expected to grow by 29.2 percent per year between 2021 and 2030, and as a result uncertainty as to whether existing and new supplies can keep pace have also emerged as a major risk to the battery and EV supply chains, increasing the costs of new EVs to the consumer and delaying (if not halting) EV deployment goals.

31 "Batteries for Hybrid and Plug-In Electric Vehicles," US Department of Energy Alternative Fuels Data Center, accessed October 18, 2021, https://afdc.energy.gov/vehicles/electric_batteries.html.

32 "Electric Vehicle Batteries: Addressing Questions about Critical Materials and Recycling," Union of Concerned Scientists, February 11, 2021, https://ucsusa.org/sites/default/files/2021-02/ev-battery-recycling-fact-sheet.pdf.

33 "Electric Vehicle Batteries: Addressing Questions about Critical Materials and Recycling."

34 "Electric Vehicle Batteries: Addressing Questions about Critical Materials and Recycling;" Dave Vanderwerp, "How GM'S Ultium Battery Will Help It Commit to an Electric Future," *Car and Driver*, July 7, 2021, https://www.caranddriver.com/features/a36877532/general-motors-ev-ultium-battery-electric-future/.

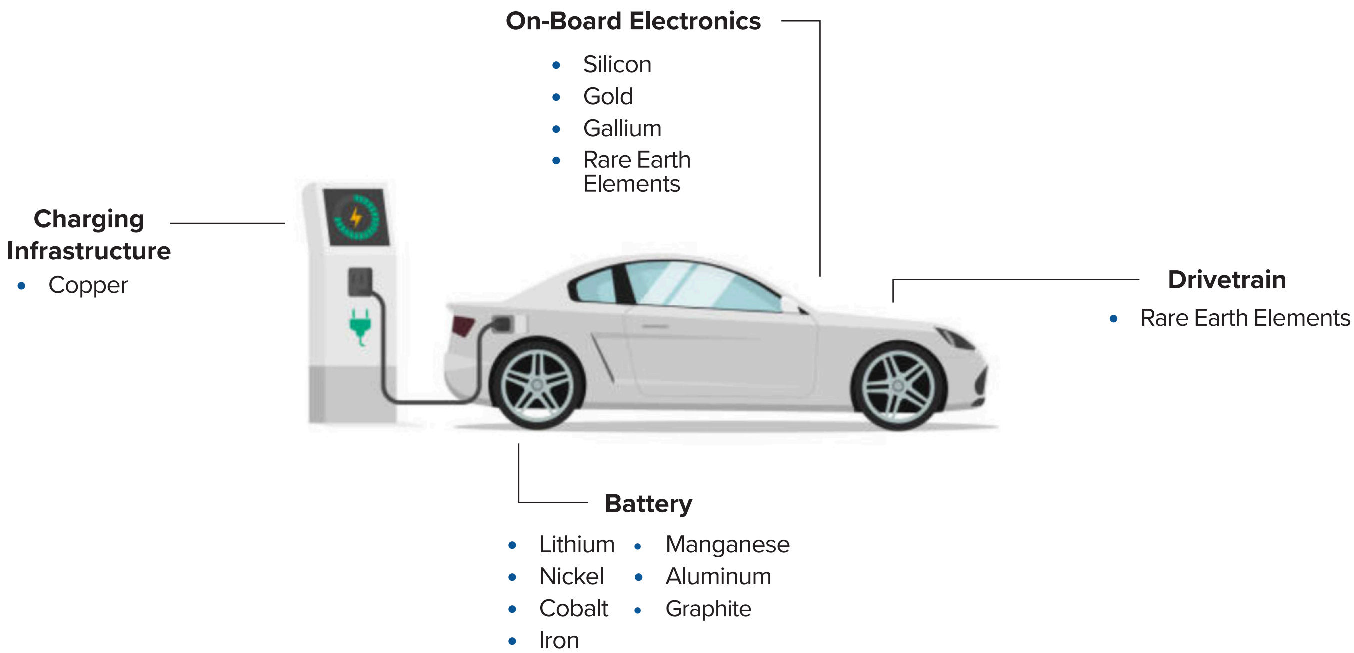
35 "Mineral Requirements for Clean Energy Transitions," IEA, May 2021, https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/mineral-requirements-for-clean-energy-transitions.

36 Aria Alamalhodaei, "What Tesla's Bet on Iron-Based Batteries Means for Manufacturers," *TechCrunch*, July 28, 2021, https://techcrunch.com/2021/07/28/what-teslas-bet-on-iron-based-batteries-means-for-manufacturers/.

37 "GM's All-Electric Future, Powered by Ultium Batteries: How Our All-New Modular EV Architecture and Ultium Battery System Will Deliver a Full Lineup of EVs for All Customers," General Motors Press Release, accessed October 18, 2021, https://media.gm.com/content/dam/Media/images/US/Release_Images/2020/sep/0916-UltumDrive/GM-EV-Fact%20Sheet-1-Architecture-and-Ultium-Battery-System.pdf.

38 Maria Gallucci, "EVs Will Drive a Lithium Supply Crunch," *IEEE*, May 5, 2021, https://spectrum.ieee.org/evs-to-drive-a-lithium-supply-crunch.

39 "Fears of a Lithium Supply Crunch May Be Overblown," *Physics Today*, May 1, 2021, https://physicstoday.scitation.org/doi/10.1063/PT.3.4745.



Drivetrains and Vehicle Components

Though batteries for electric vehicles demand a significant amount of attention due to their mineral intensity, the vehicle itself requires a significant range of minerals and metals across the other components and subcomponents needed to produce a finished EV. Similar to the EV battery, the mineral intensity of these components is closely related to vehicle size, range, and performance, meaning mineral demand from vehicle subcomponents will closely respond as the variety of EV models continues to grow.

For example, the drivetrain (the parts of the car that translate stored energy from the battery into forward movement) of most electric vehicles uses a permanent magnet-based motor to improve performance and reduce cost yet, as a result, requires significant amounts of REEs, specifically neodymium (though praseodymium and dysprosium are also necessary).[40] Similar permanent magnets are also important throughout the rest of the electronics of an EV and, as a result, a standard EV model would require approximately 0.5 kilograms (kg) of REEs per vehicle, with larger or more high-performance models such as trucks or buses being considerably more REE-intensive, primarily due to the size of the drivetrain.[41]

Electric vehicles are also considerably more copper-intensive than ICE vehicles due to the amount of high-voltage cabling required throughout the vehicle, with battery-powered EVs requiring 183 pounds of copper per vehicle compared to approximately 49 pounds in a conventional vehicle.[42] Copper requirements are also incredibly sensitive to size and performance: an electric bus, for example, contains nearly 814 pounds of copper.[43] Copper's conductivity is second only to silver, making it essential for EVs and largely irreplaceable.

Finally, EVs demand a range of subcomponents that have mineral requirements of their own. These range from the electronics, circuit boards, and associated semiconductors (silicon, gallium, gold, and silver) necessary for onboard computers and other systems found in an ICE, to thermal shielding around the battery casing (silicon), to additional metals (e.g., aluminum) necessary to make the vehicle lighter and more efficient.

The supply chain issues around vehicle componentry are similar to those for the battery, in which scaling supply to meet expected demand is emerging as a significant problem. Here, REEs are a primary area of focus for automakers, given the close association between those minerals and vehicle cost and performance. Though relatively abundant, REEs are most frequently found as byproducts of other minerals and metals, and thus need to be retrieved through environmentally hazardous processing. As a result, REE development is significantly exposed to costs associated with environmental regulation and waste management. Market share is typically dominated by those willing or able to subsidize or circumvent those costs, such as China, which produced approximately 132,000 of the 210,000 tons of REEs in

40 Ryan Long, "Electric vehicles and rare earths," The Edison Group, January 29, 2019, https://www.edisongroup.com/edison-explains/electric-vehicles-and-rare-earths/.

41 "Minerals Used in Electric Cars Compared to Conventional Cars," IEA, last updated May 4, 2021, https://www.iea.org/data-and-statistics/charts/minerals-used-in-electric-cars-compared-to-conventional-cars.

42 "Copper Drives Electric Vehicles," Copper Development Association, Inc., accessed October 18, 2021, https://www.copper.org/publications/pub_list/pdf/A6191-ElectricVehicles-Factsheet.pdf.

43 "Copper Drives Electric Vehicles."

2019.[44] Nonetheless, global REE production is also insufficient relative to EV deployment goals, with an expected shortage of 48,000 tons by 2030, which is equivalent to roughly 25 million to 30 million EVs.[45]

EV Infrastructure and Charging

The mineral requirements for an electrified transportation sector also go beyond the vehicle: charging infrastructure and associated expansions of the electrical grid are critical to enabling EV deployment and encouraging demand. To this end, the Biden administration's initial focus on EV infrastructure is well-placed and plays an equally important role in the broader conversation about mineral demand growth as a result of transportation electrification.

Transportation electrification requires a large amount of copper to support increased grid connectivity and charging locations. For example, a Level 2 port (drawing on 220-volt electric supply and needing approximately one to two hours for a full charge) uses roughly 8 kg of copper per station. Assuming the administration's goal of deploying 500,000 new charging stations by 2030 is limited to Level 2 chargers, this would immediately add approximately 4 million kg of infrastructure-related copper demand to the market over that period.[46] However, even this projection possibly underestimates the true scale of copper demand, given anticipated consumer preference for fast-charging public stations (i.e., Level 3 Direct Current Fast Charging) that are more copper-intensive. Furthermore, it omits additional deployment of at-home charging stations, which will likely grow in tandem with EV sales growth given the significant consumer appeal for an EV to charge overnight or when simply sitting at home and not being used.

Similarly, grid development will further add to overall copper demand. In addition to the expansion of the grid in order to meet additional charge points in rural areas, this infrastructure falls into two categories: grid adaptation for fleet electrification, and grid modernization for smart-metering and at-home charging. In both cases, copper componentry related to providing significant adjustments to grid management and electricity demand will be a necessary part of the future US EV ecosystem, but this will only add to an immediate uptick in broader US copper demand as those systems are deployed.

Consequences of an Electrified Transportation Sector on Mineral Demands in the Energy Transition

The mineral demands of a fully electrified transportation sector will be significant. The Biden administration's ambition to support rapid electrification through a number of policy packages—combined with continued investment support in new EV models and deployment from across the automotive industry—will require an unprecedented transformation of mineral supply chains to meet EV manufacturing goals, but it will also empower innovations in rapid-charging batteries, vehicle miles traveled, and sustainable business models. Supply chains will also need to adjust quickly to increasing demands for additional charging infrastructure, as well as an expanded and modernized grid to support the expansive deployment of electric vehicles.

Overall, the increased deployment of mineral-intense, clean energy technologies will bring about a transformational acceleration of critical mineral demand, and electric vehicles are poised to play a dominant role in that demand growth. Indeed, a recent IEA report on the mineral demands of the energy transition projects that global EV deployment rates will demand forty-three and forty-one times as much lithium and nickel, respectively, in 2040 compared to 2020.[47] In the same report, overall global demand for EV-related minerals (including additional EV minerals such as rare earths, copper, and silicon) will increase thirty times by 2040.[48]

While the IEA's report takes a global view of the future demand forecast, it raises important issues that the United States would be wise to consider: how aggressive electrification of domestic transportation might further shape global demand for minerals that are critical to the energy transition and, in particular, what the US share might be of that burgeoning demand. An often-cited data point from the Biden administration's hundred-day review of mineral supply chains was that the electrification of 20 percent of the US light-duty vehicle fleet with Li-ion batteries will constitute approximately 25 percent, 49 percent, and 22 percent of the total global nickel, lithium, and cobalt, respectively, that was mined in 2019. Electrification of 100 percent of the fleet would require 127 percent, 245 percent, and 114 percent of 2019 of global production for those same minerals.[49]

44 "U.S. Geological Survey, Mineral Commodity Summaries – Rare Earths, January 2020," U.S. Geological Survey, accessed October 18, 2021, https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-rare-earths.pdf.

45 "Rare Earth Magnet Market Outlook to 2030," *Adamas Intelligence,* August 2020, https://www.adamasintel.com/report/rare-earth-magnet-market-outlook-to-2030/.

46 "Copper Drives Electric Vehicles;" "Copper Intensity in the Electrification of Transport and the Integration of Energy Storage," International Copper Association, April 2017, https://copperalliance.org/wp-content/uploads/2017/05/2017.04-E-Mobility-Factsheet-4.pdf.

47 "The Role of Critical Minerals in Clean Energy Transitions."

48 "The Role of Critical Minerals in Clean Energy Transitions."

49 Reed Blakemore, "Biden-Harris Administration Hundred-Day Supply Chain Review: Key Takeaways for Minerals Security in the Energy Transition," Atlantic Council, June 10, 2021, https://www.atlanticcouncil.org/blogs/energysource/biden-harris-administration-hundred-day-supply-chain-review-key-takeaways-for-minerals-security-in-the-energy-transition/.

The consequence of the United States rapidly increasing its share of global minerals demand will be a significant—and sudden—pressure on mineral supply chains to fulfill that demand. To that end, there are several concerns for policymakers to consider. The first surrounds general anxiety about existing US dependence on importing certain critical minerals. Rapid transportation electrification might also accelerate concerns around global supply chain resiliency and mineral access, especially should transportation electrification proceed in the United States in tandem with a desire to ensure that automotive production, for the most part, remains a domestic industry.

A second concern is simply a matter of math. Many minerals that will be critical to the energy transition—including several which are specifically relevant to transportation electrification—are currently not produced in quantities sufficient to meet projected demand increases. Supply increases will be necessary, though a lack of adequate investment and the amount of time needed to bring a new mine online are significant headwinds to establishing that supply at pace with the desired deployment timeline for many new energy technologies, EVs included.

A third concern is to ensure that the mineral intensity of an EV future does not come at the expense of a sustainable, transparent, and well-governed energy system. The fulfillment of a rapid increase in minerals demand through low-standard, poorly sourced minerals should be avoided and would undermine the climate and sustainability goals underpinning US transportation electrification in the first place. Furthermore, sustainability-minded mineral supply chains will unlock additional and much-needed pools of capital from so-called ESG-based investment (which entails analysis of environmental, social, and governance factors), which has, thus far, not contributed extensively to investments in the minerals upstream.

These concerns will surround the path forward for domestic transportation electrification in the United States and become more pressing as the timeline for larger-scale EV deployment grows closer. The administration, therefore, should carefully consider the role that minerals will play throughout its EV ambitions.

LAYING THE GROUNDWORK FOR AN ELECTRIFIED FUTURE: THE RESPONSE OF US INDUSTRY

As the transport sector in the United States rapidly electrifies, the uncertainty surrounding the capacity of the current supply chain to meet the mineral intensity of an electrified future has led stakeholders across the United States to explore possible hedges or mitigation strategies to limit their exposure to a strained supply chain. Many OEMs, for example, are now beginning to closely examine the material intensity of their components mineral by mineral, aiming to further understand the relative mineral intensity of their various models and how exposed they might be within a broader mineral supply chain. Concerns over adequate, secure, and sustainable supplies have already resulted in several strategies to mitigate possible risks.

Reducing Mineral Intensity

An immediate focus of industry has been to limit the overall mineral intensity of transportation electrification. Examples include the continued efforts by OEMs to limit the REE-intensity of drivetrains and automotive componentry. The Tesla Model S, for example, relies on a permanent magnet motor as well as an induction motor, which comprises a series of copper conductors.[50] Though not US-based OEMs, Nissan, Renault, Toyota, Volkswagen, and Daimler are also exploring further REE reductions in their drivetrains.[51]

There are emerging opportunities, particularly with new battery technologies, to help reduce overall mineral intensity. Previously-mentioned efforts by both GM and Tesla will likely arrive in time for many new EVs to depend less on cobalt than their predecessors. Ford's announced partnership with SK Innovation Co. to produce in Georgia a battery composed of 90 percent nickel, 5 percent cobalt, and 5 percent manganese is another such example, and is notably planned for use in its F-150 truck, a segment of the industry that is critical to encouraging scaled EV adoption in the United States.[52] In June 2021, the Department of Energy announced six new battery-manufacturing projects through Argonne National Laboratory, bringing the number of battery research projects through the national labs to thirteen, at a total value of nearly $15 million over the next three years.[53] Meanwhile, several new battery chemistries on the horizon, such as solid-state and lithium-metal batteries, also hold the potential to reduce overall mineral dependency.

Continued automaker concerns around performance, range, cost, and speed of deployment to the consumer fleet, however, limit the window of time for extensive reductions in mineral intensity for key components of the car, with the drivetrain being one particularly challenging obstacle. Furthermore, reductions in mineral intensity are becoming ever more marginal relative to broader demand growth; attempts to reduce mineral intensity in EV batteries currently are more effective at displacing demand for cobalt or manganese in favor of nickel, while doing little to alleviate demand for other minerals such as lithium. As a result, these innovations are likely to do little to reduce the overall additional strain on the mineral supply chain that is likely to arrive in the coming years.

Breakthrough technologies are on the horizon and should not be counted out; the innovations in EV battery and drivetrain technologies that are enabling rapid cost reductions and performance improvement today represent a significant accomplishment in a relatively short period of time. The question now is whether any new breakthrough technologies aimed at significant reductions to mineral intensity can overcome a steep technological cost curve and reach scale at a pace that matches the rate of the administration's goals for EV deployment. Though such technologies may enable luxury-model low-mineral vehicles in the future, it is not unreasonable to assume that the widely deployed consumer EV of 2025 and 2030 will likely have a comparable mineral intensity to those being developed today, and material changes in the overall mineral demand forecast as a result of transportation electrification are thus unlikely.

Supply Chain Security and Sustainability

Much of the current conversation around managing a rapidly growing mineral demand forecast is devoted to the health of the minerals supply chain. These concerns largely boil down to two issues: securing the supply of sufficient mineral resources to meet the demands of a mineral-intensive transition to electric vehicles, and establishing the sustainability of that supply chain in terms of environmental protection, transparent governance, and human rights.

Security of Supply

The automotive sector, as the frontline industry in the race to electrify, is closely watching the evolution of the minerals market, mindful of the semiconductor shortage in early 2021 and its sharp impact on automobile production. Vertical integration into multiple components of the mineral supply chain to secure sourcing has already emerged as an early approach, and several notable partnerships have already been announced. Tesla

50 "Factbox: Automakers Cutting Back on Rare Earth Magnets," *Reuters*, July 19, 2021, https://www.reuters.com/business/autos-transportation/automakers-cutting-back-rare-earth-magnets-2021-07-19/; Fred Lambert, "Tesla Motor Designer Explains Model 3's Transition to Permanent Magnet Motor," *electrek,* February 27, 2018, https://electrek.co/2018/02/27/tesla-model-3-motor-designer-permanent-magnet-motor/.

51 "Factbox: Automakers Cutting Back on Rare Earth Magnets."

52 Bengt Halvorsen, "Ford-SKI Battery Venture Will Supply American EVs, Might Ease Transition to Solid State," *Green Car Reports*, May 20, 2021, https://www.greencarreports.com/news/1132323_ford-ski-battery-joint-venture-american-evs-solid-state.

53 Christina Nunez, "DOE Awards Funding to Six Argonne Battery Manufacturing Projects," Argonne National Laboratory, October 2, 2020, https://www.anl.gov/article/doe-awards-funding-to-six-argonne-battery-manufacturing-projects.

has secured three separate deals with BHP, Vale, and Trafigura Group for nickel supplies as of July 2021, and it also briefly considered direct ownership in a Nevada-based lithium mine in autumn 2020.[54] GM also recently announced an investment partnership with Controlled Thermal Resources to develop lithium resources in California.[55] Nonetheless, the question facing many OEMs is how far up the value chain they want to directly invest in order to secure supply, and at what point extensive vertical integration into unfamiliar industries or supply chains might become its own risk.

The US government also has sought to alleviate supply concerns by reshaping the US approach to the mineral supply chain. Thus far, efforts by the Trump and Biden administrations to review the supply chain have steadily matured from a focus on stockpiling key minerals to a more holistic approach that emphasizes the long-term economic risks of passive US engagement. For example, the Biden administration's recent hundred-day review of the battery mineral supply chain identified a clear need for the localization of critical supply chain segments, as well as active cooperation with like-minded partners to increase raw mineral supplies at home and abroad.[56] A follow-on strategy released by the Department of Energy also set out the goal to "catalyze and support private sector adoption and capacity for sustainable domestic critical mineral and material supply chains."[57] The US International Development Finance Corporation (DFC) has also begun to explore direct investments into the supply chain, notably a recent equity investment in a technology metals firm, TechMet.[58] Finally, the Biden administration's 100 Day Supply Chain Review released in Spring 2021 recommended improving the efficiency of permitting for new mines, which has long been a major obstacle for mining companies and investors to confidently pursue new domestic mineral projects and manage risk during the development of a new mining site that can take well over ten years due to a cost-intensive, laborious, and at times duplicative permitting process. Continued investment at home and abroad, as well as consideration of how to streamline the launch of new minerals projects, will be critical to promptly growing sufficient supplies of minerals to meet EV goals.[59]

Sustainability Concerns

Meanwhile, the administration continues its effort to ensure the sustainability of the global minerals supply chain given the considerable emissions, environmental, and land-use hazards as well as labor concerns that have bedeviled the mining industry in the past. At the core of this effort has been the recognition by both the automotive industry and policymakers that much of the global supply chain currently occurs outside of norms and best practices for governance and sustainable stewardship and, left unaddressed, new supplies in response to demand signals would pose similar sustainability and resiliency risks to both the United States and its partners. This recognition led to the Trump administration's establishment of the Energy Resource Governance Initiative, and to the growing interest throughout the Biden administration to collaborate through informal bodies such as the Quadrilateral Security Dialogue (aka the Quad), which comprises the United States, Japan, India, and Australia. In both bodies, shared interest in growing mineral demand associated with the energy transition is being leveraged to improve supply chain norms across the board, and also develop new opportunities to build new, sustainable sources of supply at home and abroad.

In both supply security and sustainability, the mining industry has an important role to play. Indeed, there is tremendous opportunity for the industry to fulfill a rapid acceleration of US mineral demands with corresponding supplies, which is notable given the untapped domestic potential for additional copper, lithium, and REE mining and processing. Here, the type of partnerships currently underway between the mining industry and OEMs are likely to become a hallmark of transportation electrification, with mining companies establishing offtake agreements with OEMs where relevant, effectively allowing the automotive industry to secure supply without taking on the business risk of moving its center of gravity too far up the supply chain.

Yet the expertise of the mining industry can help to address the automotive industry's concerns around electrification and mineral demands, particularly as it relates to the relationship between

54 Henry Sanderson, "Tesla Signs Nickel Deal with BHP to Secure Non-Chinese Supply," *Financial Times*, July 21, 2021, https://www.ft.com/content/250d6dc7-d6e2-47d0-b76e-a9abaab5eeae; Barbara Smith, "Tesla has Reportedly Abandoned a Plan to Buy a Mining Company in Nevada," *Business Insider*, September 29, 2020, https://www.businessinsider.com/tesla-abandons-acquisition-deal-talks-nevada-mining-company-cypress-report-2020-9.

55 "GM to Source U.S.-Based Lithium for Next-Generation EV Batteries Through Closed-Loop Process with Low Carbon Emissions," General Motors Press Release, July 2, 2021, https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2021/jul/0702-ultium.html.

56 *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*, The White House, June 2021, https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

57 "Critical Minerals and Materials: US Department of Energy's Strategy to Support Domestic Critical Mineral and Material Supply Chains," U.S. Department of Energy, January 2021, https://www.energy.gov/sites/prod/files/2021/01/f82/DOE%20Critical%20Minerals%20and%20Materials%20Strategy_0.pdf.

58 "Public Information Summary: TechMet Limited," *US Development Finance Corporation,* accessed October 18, 2021, https://www.dfc.gov/sites/default/files/media/documents/9000104280.pdf.

59 "Murkowski Announces Big Wins for Alaska in Infrastructure Bill," Lisa Murkowski Press Release, August 2, 2021, https://www.murkowski.senate.gov/press/release/murkowski-announces-big-wins-for-alaska-in-infrastructure-bill-.

sustainability and growing mineral supplies. Though the mining industry, as a whole, has a complicated history with environmental best practices, an emphasis on sustainability is already emerging as a major area of focus from OEMs and is garnering significant attention from mining companies that want to seize the opportunities of the energy transition, especially as verifiably sustainable practices become critical to attracting much-needed investment from untapped pools of ESG-focused capital. In addition to attracting investment, mining companies can encourage and expand upon these sustainability-minded opportunities, such as by introducing new sources of supplies through advanced recovery of certain minerals from waste and as by-products, with Rio Tinto's model of "full-value mining" being one such opportunity.

Recycling

Finally, policymakers and the auto industry are both looking to recycling as a possible solution to help alleviate supply concerns associated with rapid growth in mineral demand. Indeed, a robust recycling effort will be absolutely critical to a secure and sustainable minerals ecosystem, particularly as the number of EV batteries in circulation begins to grow apace with EV deployment around the United States. In addition to the potential for climate and environmental benefits, ensuring the appropriate recovery and, where possible, recirculation of EV-related minerals will not only reduce waste but also add another source of raw mineral supplies over the long term. The Biden administration is scaling domestic recycling quickly, citing the potential to cut the need for new copper, lithium, cobalt, and nickel supplies by 55 percent, 25 percent, 35 percent, and 35 percent, respectively, by 2040 through recycling.[60] The Department of Energy's ReCell Center is also exploring improvements to mineral yields from battery recycling, while a host of start-ups, such as the Nevada-based Redwood Materials, are providing an early look into the possible business models for a nascent battery-recycling industry.[61]

Recycling plays a significant role in the Biden administration's ambitions for transportation electrification. However, it is still unclear whether recycling can meet expected domestic mineral demands, particularly in the short term. Though global battery capacity available for recycling could grow by 560 percent by 2030, the mineral quantities needed to deploy that battery capacity in the first place are too significant to be fulfilled by today's available stockpile of recycled minerals.[62] This is especially true in the United States, where EV deployment has yet to truly scale, and significant quantities of key minerals will be required almost immediately for deployment to accelerate. Furthermore, while firms like Redwood Materials are offering case studies in the future business model for recycling EV batteries, the business model for a successful EV recycling program is largely undefined, which should give pause to proponents identifying recycling as a primary hedge against supply security. As it stands, strong, widespread recycling is less of a short-term solution than a sign of a healthy mineral supply chain over the long term.

60 Trevor Hunnicutt and Ernest Scheyder, "Biden's Electric Vehicle Plan Includes Battery Recycling Push," *Reuters*, June 4, 2021, https://www.reuters.com/article/us-usa-biden-mining-recycling-exclusive-idCAKCN2DG178.

61 Natalie Marchant, "5 Innovators Making the Electric Vehicle Battery More Sustainable," World Economic Forum, May 3, 2021, https://www.weforum.org/agenda/2021/05/electric-vehicle-battery-recycling-circular-economy/.

62 "Global EV Outlook 2020," IEA, June 2020, https://www.iea.org/reports/global-ev-outlook-2020.

RISKS, OPPORTUNITIES, AND POLICY PATHWAYS

The Biden administration's plans for EV deployment and the industry's current approach to securing the minerals necessary may be at odds with the scale and pace at which that prospective mineral demand growth will arrive to the market. This points to a number of mineral-related risks and opportunities that should remain in the forefront of the minds of policymakers and business leaders as pathways for EV deployment are put in place.

Risks:

- Aggressive plans for EV deployment will stimulate unprecedented, significant growth in minerals demand, placing even the most ambitious and well-meaning targets for transportation decarbonization at risk of disruption without additional mineral resources. Long lead times for the development of new mineral supplies add to the potential severity of these disruptions, which would be exacerbated by the additional amount of time it takes for the United States to set new domestic mining infrastructure in motion.

- The lack of sufficient mineral supplies for OEMs may place further manufacturing at risk for US automakers, as seen in the recent impact of a global semiconductor shortage in early 2021. So long as the administration wishes for transportation electrification to be "made in the USA," failing to ensure a healthy mineral supply chain will undermine those goals.

- Over the long term, a tight minerals market could result in significantly higher material and component prices, boosting the price for the EV consumer and potentially undermining goals for ambitious EV deployment and decarbonization overall.

- Left unchecked, rapid development of mineral supplies may run awry of the principle that the materials necessary for transportation electrification (as well as energy transition and decarbonization writ large) should not come at the expense of sustainability, especially in jurisdictions where environmental protection, labor rights, and good governance are more challenging to enforce.

Opportunities:

- The likely increase in the US share of global mineral demand that would result from a rapid electrification of the transportation sector would further empower Washington to ensure that the investment, governance, and environmental stewardship of minerals development is done in a sustainable way. A scrutinous, sustainability-minded approach to mineral supply chains can also be self-reinforcing, unlocking additional ESG investment to further develop new mineral supplies and spur innovation, as well as improving supply chain security by supporting diversity of supply and transparency.

- The US mining sector is well-positioned for such an escalation of minerals demand, both in terms of resource-development opportunities at home and abroad, as well as the expertise necessary to support OEMs as they aim to further understand their sensitivity to the minerals supply chain and seek to secure supply partnerships.

- An approach to transportation electrification by the US government that includes a strategy for sufficient minerals supplies will alleviate much of the concerns from within the automotive industry around appropriate levels of access to the mineral supply chain, perhaps incentivizing even more ambitious commitments to transportation electrification at home and abroad.

CONCLUSION AND RECOMMENDATIONS

Significant mineral demand growth will be a natural consequence of the energy transition as new, mineral-intensive technologies provide an ever-greater share of clean energy and decarbonized mobility. In this transition, the pace of transportation electrification, in particular, has accelerated even during periods of limited policy support, led by an automotive industry that sees electrification as a market for the taking. To this end, the Biden administration's ambitions for rapid electrification of the transportation sector will be a catalyst for a much faster, policy-enabled transition, accelerating mineral demand growth in a very short amount of time. Should the administration opt for an even more aggressive suite of policy measures to electrify the transportation sector than what has already been proposed as of this writing, such as a ban on internal combustion engines, these mineral demands would be decidedly greater, and would arrive in a much shorter period of time.

Even though stakeholders from the private sector and the policy-making community have begun to explore how to mitigate the risks and opportunities of increased mineral demands from the automotive sector, the Biden administration in particular would be wise to consider carefully how it can embed minerals-minded policies into its strategy for transportation electrification. This is especially true given the speed at which the administration hopes to achieve EV deployment targets. In doing so, the following principles will serve as valuable guideposts:

- **Aim for an overabundance of mineral supplies:** Given the scale of projected minerals demand, the rate at which that demand will grow, and the likely consequences of a tight minerals market on broader decarbonization goals and the cost curve for EVs in particular, policymakers will be better suited to pursue an overabundance of mineral supplies in their planning. Fulfilling the minerals demand growth that will accompany goals for an acceleration in EV sales will, therefore, require an approach to the mineral supply chain that is inclusive of new supply chain programs at home and abroad. This approach should embody two distinct, but closely linked strategies:

    - *Leverage best-in-class domestic mineral resources and expertise:* Significant domestic natural resources and a tradition of leadership in the mining sector represent crucial opportunities for policymakers to ensure sufficient mineral supplies are brought to market quickly. To leverage these resources, policymakers must have the courage to de-risk new domestic supply chain activity by reforming the regulatory environment to be more nimble and easily navigated; and establish a framework for direct government investment in key mining and processing activities.

    - *Collaborate with partner countries to grow capacity throughout the minerals supply chain:* Already, a number of countries such as Canada, Australia, and Japan have looked to the United States as a necessary partner in the expansion of the mineral supply chain. Building upon these partnerships across the supply chain, bilaterally and as a group, will continue to grow available pools of capital for investment in new supply chain capacity, improve mineral access and supply chain resiliency, and build the network of stakeholders committed to sustainable, transparent, and well-governed mineral supply chains.

- **Encourage cross-industry partnerships that add value to the effort:** Though many OEMs have begun to explore the value of direct partnerships with the mining industry to secure mineral supplies, policy support to further enable these partnerships will reinforce the EV value chain from mine to road with additional expertise and capital. Such efforts should also endeavor to expand the playing field of potential value-added collaboration, such as better understanding mineral needs throughout the supply chain, improving certainty for investment in additional EV and EV infrastructure, supporting innovation, and encouraging sustainable mineral development.

- **Place sustainability front and center:** The Biden administration must place the need for sustainable and resilient mineral supply chains at the core of its transportation electrification strategy, and explain that narrative externally. Doing so will provide two advantages to the administration's efforts to ensure sufficient and stable mineral supplies for its electrification goals. First, efforts to ensure verifiable environmental stewardship, sustainable investment practices, and good governance will allow automakers and the mining industry greater insight into the mineral supply chain, improving business certainty for OEMs and infrastructure providers seeking to scale their activities; and second, a sustainability-minded minerals policy might further unlock additional investment from fast-growing ESG funds, filling gaps in capital throughout the minerals supply chain.

The Biden administration's goals for EV deployment will have a transformative impact on the broader decarbonization and economic goals of the United States. Minerals will be critical to make that transformation successful, and policymakers should not forget their importance as the policy pathways for EV deployment fall into place.

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