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WHEN GOVERNMENT CHOOSES YOUR CAR

EXAMINING THE CHALLENGES AND COMPLEXITIES OF A TRANSITION TO ELECTRIC VEHICLES

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EXECUTIVE SUMMARY

This report provides a comprehensive analysis of the current landscape of electric vehicles (EVs) within the U.S. motor vehicle market, emphasizing the challenges and complexities surrounding a forced transition towards electrifying our transportation system.

Proponents of a forced transition to electric vehicles often present it as a universally beneficial scenario, overlooking various hidden costs. This analysis highlights the financial implications for individual owners, the economy, and society, emphasizing the need for a balanced assessment in public policy discussions.

Costs of EVs

- Electric vehicles typically have higher upfront costs than internal combustion engine (ICE) vehicles. In Q1 2024, the average price of an EV was 42% more than that of an ICE vehicle, a gap that persists even after taxpayer subsidies. This price difference is primarily due to the cost of batteries.
- Charging an EV can be complex and expensive. Electricity prices vary widely, influenced by factors such as time of day and regional utility rates. Home charging is cheaper than public charging, but the cumulative costs of charging infrastructure and potential future increases in electricity rates must be considered. The growing demand for electricity to support EVs may lead to higher rates for consumers.
- Installing and maintaining charging infrastructure involves significant expenses, which are often underestimated. While the federal government has allocated taxpayer subsidies for this purpose, progress has been slow, and the burden may ultimately fall on individuals and the private sector.
- While some claim EVs have lower maintenance costs due to fewer moving parts, the evidence is mixed. Electric vehicles can incur higher repair costs, primarily due to expensive battery replacements. Insurance premiums for EVs are also typically 20% higher than for ICE vehicles, reflecting perceived higher repair costs.
- EVs depreciate more rapidly than conventional vehicles, with some models losing up to 50% of their value within the first year. Battery replacement costs can reach

$30,000, further diminishing resale value. The high upfront cost and low resale value make EVs less financially attractive than ICE vehicles. Due to their heavier weight, EVs contribute to increased wear on roads and bridges, leading to higher maintenance costs for infrastructure that are not typically accounted for in EV ownership costs.

- While EVs eliminate tailpipe emissions, their heavier weight and faster acceleration may increase particulate emissions from tire wear. Studies suggest that tire emissions can significantly exceed tailpipe emissions, contradicting claims of overall environmental benefits from EV adoption.
- EVs require significantly more mineral inputs than conventional cars, leading to potential shortages and increased prices as demand rises. The environmental impact of mining these minerals is also considerable, adding another layer of cost to the transition.

Barriers to EV Adoption

- Furthermore, electric vehicle adoption faces significant barriers often overlooked in federal policy discussions.
- Surveys indicate limited interest in EVs, with concerns about cost, battery range, charging time, and infrastructure availability contributing to reluctance. The size and range of batteries are crucial, as larger batteries increase costs and range anxiety deters buyers.
- Battery lifespan is also a concern, as frequent fast charging can significantly degrade battery health over time.
- Unlike gas stations, building a robust charging network is complex and costly. The current infrastructure is inadequate, and new installations face challenges in terms of location and efficiency.
- Additionally, the electric grid is already struggling to meet peak demand and will face additional strain from increased EV charging. This situation is exacerbated by regulatory hurdles that limit the development of stable energy sources.
- EVs require significantly more minerals than traditional vehicles, complicating mass production. Mining and processing these materials are time-consuming, creating short-term supply limitations despite long-term availability. These factors suggest that achieving widespread EV adoption may be more challenging than often assumed.

Myths Fueling EV Policy

The discussion surrounding electric vehicle (EV) adoption is heavily influenced by organizations and companies advocating for a rapid transition, often promoting misleading claims.

- The fuel cost savings presented on EV EPA stickers are based on assumptions that don't reflect reality. For instance, the annual fuel cost calculation assumes an electricity rate of $0.12 per kWh, while rates in places like California are significantly higher. The purported five-year savings of $9,900 decreases substantially when compared to more efficient gasoline vehicles like the BMW 3 or hybrid models.
- Advocates often tout the energy efficiency of EVs using the misleading metric of MPGe (miles per gallon equivalent). However, when considering energy loss in the electrical power system, the Tesla's efficiency is overestimated. A more accurate energy balance shows that while EVs lose only 10% of energy during use, they suffer significant losses during electricity generation.
- Although EVs produce zero tailpipe emissions, their overall carbon footprint—including battery production and electricity generation—can be significant. Life Cycle Assessments reveal that EVs often have a higher production-related carbon footprint than conventional vehicles, with breakeven points varying based on driving distance and energy sources used for electricity.
- The notion that EVs enhance national security by reducing dependence on foreign oil is flawed. The U.S. is now a net oil exporter, while the supply chains for EVs, particularly batteries, are primarily dominated by China, potentially creating new dependencies.
- The belief that renewable energy sources can meet the electricity demands of widespread EV adoption is unrealistic. Current growth rates for wind and solar are insufficient to accommodate the added demand, and transitioning to EVs could lead to greater reliance on fossil fuels, contradicting the original environmental justifications for their adoption.

Proponents of a forced transition to EVs argue that an all-electric future would be beneficial; however, this report outlines the considerable costs and tradeoffs that are often overlooked. Policymakers must recognize that as consumer preferences and economic factors shape vehicle purchases, any aggressive regulatory push could impose substantial costs on individuals and the broader economy. History shows that top-down mandates often fail to achieve their intended outcomes, imposing significant costs and generating resentment among those most affected by the regulations. Instead, this report advocates for a market-driven approach to vehicle adoption, allowing consumers to choose the most suitable options for their needs.

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SECTION 1

ELECTRIC VEHICLES AND THE U.S. CAR MARKET

A threshold step to analyzing electric vehicles and electric vehicle policy is developing a baseline understanding of the U.S. motor vehicles market. There are electric vehicles in many market segments, and advocates for a forced transition to electric vehicles favor forcing all transportation to use electricity. For the consuming public, the Light Duty Vehicle (LDV) market is the focus of concern and public policy because this includes vehicles for personal use. The LDV category includes cars and light-duty trucks such as pickups,[1] sport utility vehicles, and vans.

There are three main types of vehicles included in electric vehicle counts depending on the source: battery-electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), and hybrid-electric vehicles (HEV). Both PHEVs and HEVs still use traditional liquid fuels in addition to their batteries.

HEVs have achieved significant sales for two decades and continue to outsell BEVs every year. When reviewing electric vehicle manufacturing and sales statistics, it is important to check what vehicles are being counted. BEV and PHEV sales are frequently grouped together in sales statistics, and all three can be combined to present an even more inflated impression of the electric vehicle market.

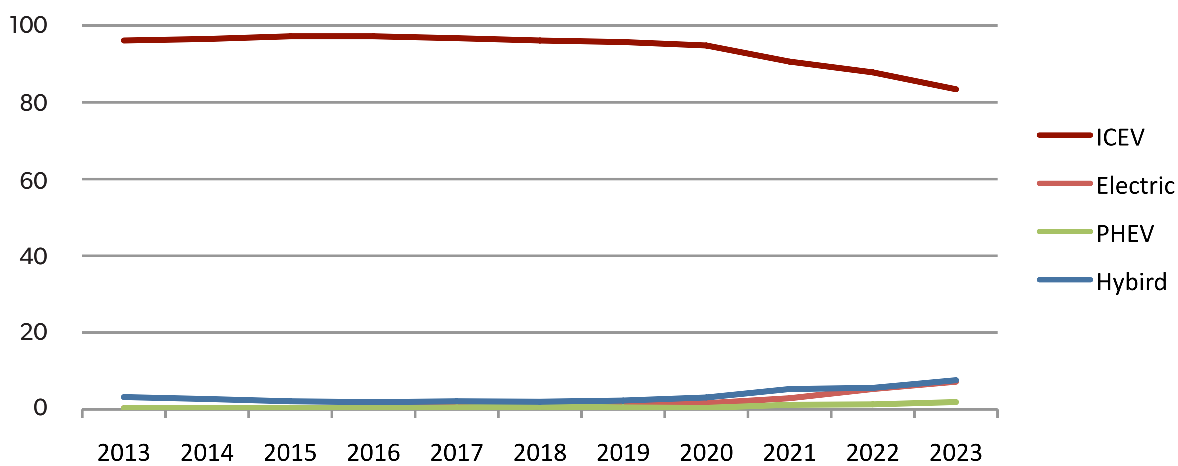
The most recent federal data from 2023 shows almost 1.15 million BEVs were sold, representing about 7.4% of the 15.5 million vehicles sold that year.[2] An additional 295,000 PHEVs and nearly 1.2 million HEVs were also sold. These were all significant increases in previous years' sales and represent record annual sales percentages for all three categories.

Total vehicle sales since the start of the pandemic have

1 Half-ton trucks, such as the Ford F-150, Chevy 1500, and Ram 1500 are light duty vehicles. The F-250, Chevy 2500, and Ram 2500 and above are medium duty vehicles.

2 "Light Duty Electric Drive Vehicles Monthly Sales Updates - Historical Data." Argonne National Laboratory, August 2024. https://www.anl.gov/esia/reference/light-duty-electric-drive-vehicles-monthly-sales-updates-historical-data.

FIGURE 1: 2023: LIGHT DUTY VEHICLES SALES CHART



Source: Transportation Energy Institute, "Share of U.S. Light Duty Vehicle Sales by Powertrain," https://www.transportationenergy.org/resources/blog-post/2023-light-duty-vehicle-market-the-data/

remained well below the typical average for various reasons, with the previous five years exceeding 17 million vehicles per year. These low sales give an inflated impression of electric vehicle market share growth, but by any estimate, electric vehicle sales have certainly grown significantly.

In the first half of 2024, however, there has been a noticeable slowing in the growth of BEV sales, even as HEV sales have continued to increase. HEVs in the second quarter of 2024 accounted for nearly 10% of sales, with BEVs falling to 7.1% of sales.[3]

BEVs are still relatively small as a percentage of total LDV vehicles in the U.S. The entire existing fleet of LDVs is extensive, as it represents all cars on the road, both new and old. Taking one estimate of 3.3 million EVs on the road at the end of 2023, EVs represent about 1% of the nearly 290 million vehicles in the U.S.[4] Electric vehicle prices remain consistently higher than prices for internal combustion (ICE) vehicles. While electric vehicle sales have increased, they are still a niche product in the motor vehicles market.

Many car companies have made many, often optimistic, claims and commitments about future BEV production.

- In 2020, GM announced that it would have 20 electric vehicles on the market by 2023 and 30 electric vehicles on the market by 2025.[5]
- In 2021, GM announced that it aspires to eliminate all gas and diesel light-duty vehicles by 2035.[6]

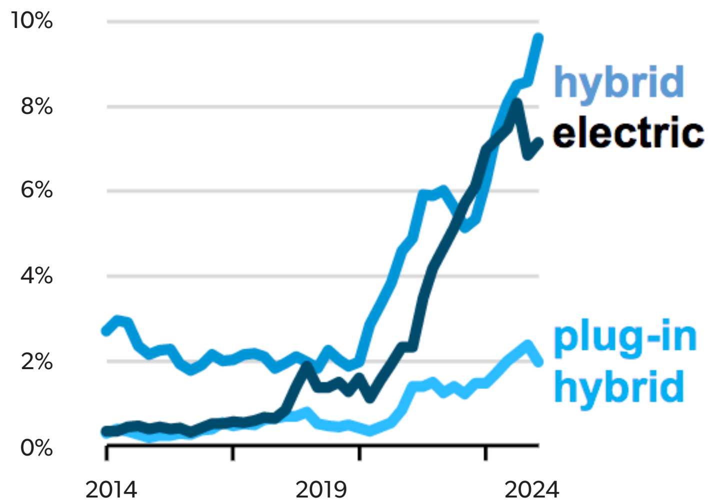
3 "U.S. Share of Electric and Hybrid Vehicle Sales Increased in the Second Quarter of 2024." U.S. Energy Information Administration (EIA), August 26, 2024. https://www.eia.gov/todayinenergy/detail.php?id=62924.

4 Montoya, Ronald, and Steven Ewing. "How Many Electric Cars Are There in the U.S.?" Edmunds, July 7, 2024. https://www.edmunds.com/electric-car/articles/how-many-electric-cars-in-us.html.

5 Beresford, Colin. "GM Accelerates Electrification Timeline, Plans 30 EVs by 2025." Car and Driver, November 19, 2020. https://www.caranddriver.com/news/a34730248/gm-accelerates-electrification-plans/.

6 Baldwin, Roberto. "Ford Makes $29 Billion Commitment to EVs and Self-Driving Cars." Car and Driver, February 5, 2021. https://www.caranddriver.com/news/a35432253/ford-ev-commitment-announced/.

FIGURE 2: EIA 2024 SALES



Source: U.S. Energy Information Administration, "Breakoutof EV and hybrid sales," https://www.eia.gov/todayinenergy/detail.php?id=62924

- In 2022, Ford stated it would sell 600,000+ EVs annually by 2026.[7]
- In 2021, Volvo committed to selling only EVs by 2030.[8]
- In 2022, Volkswagen committed to 55% of U.S. vehicle sales being fully electric by 2030.[9]
- In 2021, Mercedes targeted 50% of sales being electric by 2025.[10]

In late 2023 and into 2024, however, many of these companies began abandoning these projections and claims due to softening BEV sales.[11] Many car manufacturers, including Volvo, Ford, GM, and others, are reducing or halting their EV production.[12] Additionally, companies like Lucid Motors and Renault are falling short of their projected EV targets due to declining sales.[13] General Motors is set to miss its EV production targets for 2025, falling short of its

7 "Ford Takes Bold Steps Toward All-Electric Future in Europe; 7 New Connected EVs Support Plans to Sell 600K+ EVs Annually by 2026." Ford Media Center, March 14, 2022. https://media.ford.com/content/fordmedia/fna/us/en/news/2022/03/14/Ford-Takes-Bold-Steps-Toward-All-Electric-Future-in-Europe.html.

8 Mannes, Marie. "Volvo Cars Abandons 2030 EV-Only Target." Reuters, September 4, 2024. https://www.reuters.com/business/autos-transportation/volvo-cars-scales-back-electric-vehicle-ambition-2024-09-04/.

9 "Volkswagen Unveils $7.1 Billion Commitment to Boost Product Line-up, R&D, Manufacturing in North America." Volkswagen US Media Site, March 21, 2022. https://media.vw.com/en-us/releases/1668.

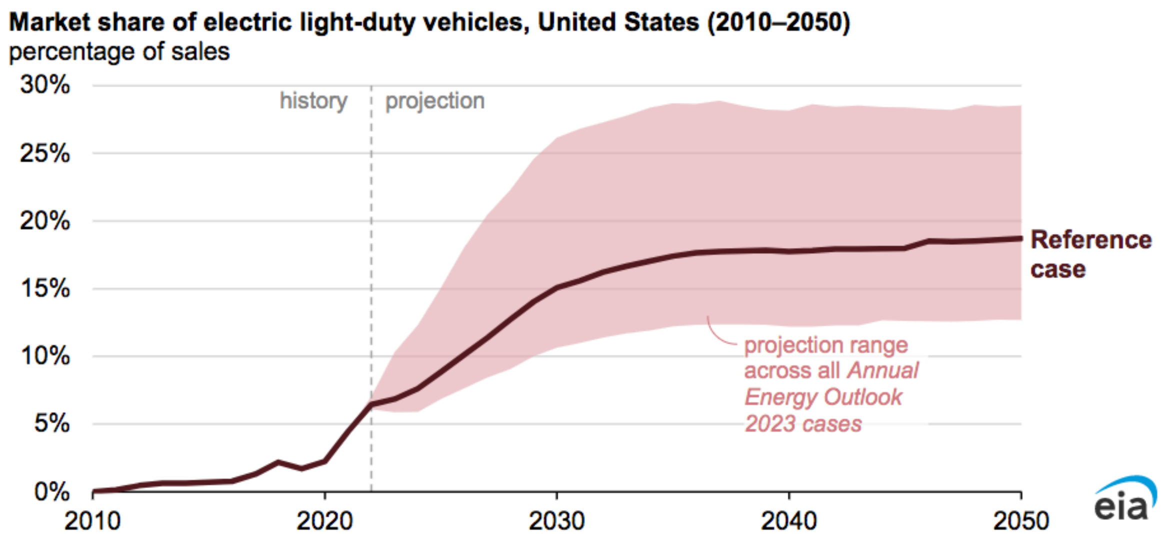
10 Waldersee, Victoria. "Mercedes-Benz Delays Electrification Goal, Beefs up Combustion Engine Line-Up." Reuters, February 22, 2024. https://www.reuters.com/business/autos-transportation/mercedes-benz-hits-cars-returns-forecast-inflation-supply-chain-costs-bite-2024-02-22/.

11 Chopping, Dominic. "Volvo, An Early Electric Car Adopter, Cuts Off Funding For Its EV Affiliate." *Wall Street Journal*, February 1, 2024. https://www.wsj.com/business/earnings/volvo-car-evaluating-potential-reduction-of-shareholding-in-polestar-85e29826.

12 Colias, Mike. "Ford Shrinks Its EV Rollout Plans as Demand Lags." *Wall Street Journal*, August 21, 2024. https://www.wsj.com/business/autos/ford-cancels-plans-for-electric-suv-44817367?mod=itp_wsj.

13 O'Kane, Sean. "Lucid Motors Will Only Build 9,000 EVs in 2024 after Once Predicting It Would Ship 90,000." TechCrunch, February 21, 2024. https://techcrunch.com/2024/02/21/lucid-motors-2024-guidance-2023-results-gravity-suv/.

FIGURE 3: EIA EV OUTLOOK



Source: U.S. Energy Information Administration, "Incentives and lower costs drive electric vehicle adoption in our Annual Energy Outlook, https://www.eia.gov/todayinenergy/detail.php?id=56480

goal to manufacture 200,000 EVs by that year.

These industry commitments are not actual projections of sales, as the abandonment of many of these targets has shown. The latest U.S. Energy Information Administration (EIA) projections estimate the electric vehicle share of new vehicle sales (including both BEV and PHEV) will not exceed 20% by 2050 in the reference scenario and not exceed 30% even in a high oil price scenario.[14]

Ultimately, consumer decisions drive vehicle purchases, not manufacturer commitments. However, there are various policy levers and mandates, discussed later in this paper, that electric vehicle supporters seek to use to alter this trajectory forcibly. When advocates for this forced transition refer to the electrification of transportation, they mean full electrification using BEVs. Thus, in this paper, unless specifically noted, the usage of the terms EV or electric vehicle refers to full-battery electric vehicles only.

The latest U.S. Energy Information Administration (EIA) projections estimate the electric vehicle share of new vehicle sales (including both BEV and PHEV) will not exceed 20% by 2050 in the reference scenario and not exceed 30% even in a high oil price scenario.

14 "Incentives and Lower Costs Drive Electric Vehicle Adoption in Our Annual Energy Outlook." U.S. Energy Information Administration (EIA), May 15, 2023. https://www.eia.gov/todayinenergy/detail.php?id=56480.

SECTION 2

THE COST OF ELECTRIC VEHICLES

Electric vehicle proponents argue that a forced transition to electric vehicles is a win-win scenario, with all upsides and no cost (except perhaps to industries they want to displace, like refiners). However, numerous costs are associated with a forced transition to electric vehicles, many of which are ignored in public policy discussions. These include costs to individual electric vehicle owners, the larger economy, and society. Adequately weighing these costs should be a crucial factor in informing government efforts to force an electric vehicle transition.

ELECTRIC VEHICLES ARE EXPENSIVE

Prices for electric vehicles are consistently above prices for comparable internal combustion engine vehicles. In the first quarter of 2024, Edmunds found a 42% gap in price for an average ICE vehicle and an average EV.[15] This price differential is one of the primary reasons consumers

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cite when considering the purchase of an electric vehicle. This price differential persists even when factoring in the additional taxpayer subsidies for electric vehicle purchases and battery manufacturing in the Inflation Reduction Act.

15 O'Dell, John. "Big Gap Remains in Average Price of Electric Car vs. Gas Car." Edmunds, May 8, 2024. https://www.edmunds.com/car-buying/average-price-electric-car-vs-gas-car.html.

This price differential is due primarily to the cost of an EV's battery module. While, at times, module prices have come down, in recent years, prices have also increased.[16] Past assumptions about continued declines in battery prices cannot be predictive. Even using optimistic assumptions about future declines in battery prices, continued regulatory support, and taxpayer subsidies, EIA still projects that EVs do not ever reach cost parity in some categories of LDV.[17] Even in those categories where the EIA thinks parity can be reached, most dates are more than ten years in the future. All this means that in the near term, electric vehicles can be expected to remain more expensive than comparable internal combustion vehicles.

Even these high sticker prices do not account for the total cost of electric vehicles. Most carmakers have consistently recorded losses on the sales of their electric vehicles.[18] Even where they have managed to move inventory, carmakers are selling electric vehicles for less than they cost to manufacture. In effect, profits from sales of internal combustion vehicles are subsidizing the manufacture of electric vehicles. Carmakers should begin to realize some economies of scale as more EVs are manufactured. However, as EV sales replace ICE sales, those vehicles' profits are no longer available for cross-subsidization. Eventually, carmakers will need to profit from electric vehicle sales, which may require even higher prices than today.

CHARGING COSTS

The cost of charging an electric vehicle is often treated as a minimal part of the expense of ownership. Simply plug in at home, and the vehicle will be ready to go in the morning with no money out of pocket for gas. But electricity costs money, and electricity rates can vary significantly. Daytime peak hours can be two to four times more expensive than nighttime off-peak hours. Public charging stations' prices vary widely and are much more costly than home charging, especially during peak hours. Additionally, each region of the country has different electric utility prices that can vary by a factor of two or three.

Because of the number of variables, estimating charging costs for EVs gets very complex. Electricity rates for homeowners differ from commercial rates; public charging stations have variable prices, and gas and electricity prices vary from state to state, to name a few significant factors.

There is also the impact of state-level policies. Many states have added taxes on liquid fuels, with some requiring unique fuel blends or mandating low-carbon fuel standards. All these increase ICE fueling costs artificially. The putative cost advantage of electric vehicles is significantly reduced in areas where government policy does not artificially increase the price of gasoline.

Additionally, there is an assumption that electricity prices will stay the same in the future. Electricity supplies are already tight in many parts of the U.S., with major blackouts in Texas and California, and other regional grid operators warning of near-term shortages.[19] More electric vehicles mean more electric load placed on an already strained grid. As discussed elsewhere in this paper, massive infrastructure and electric capacity investments are needed to meet this increased demand. Adding in efforts to eliminate the 60% of electricity generation currently derived from natural gas and coal means even more spending on new generation sources.

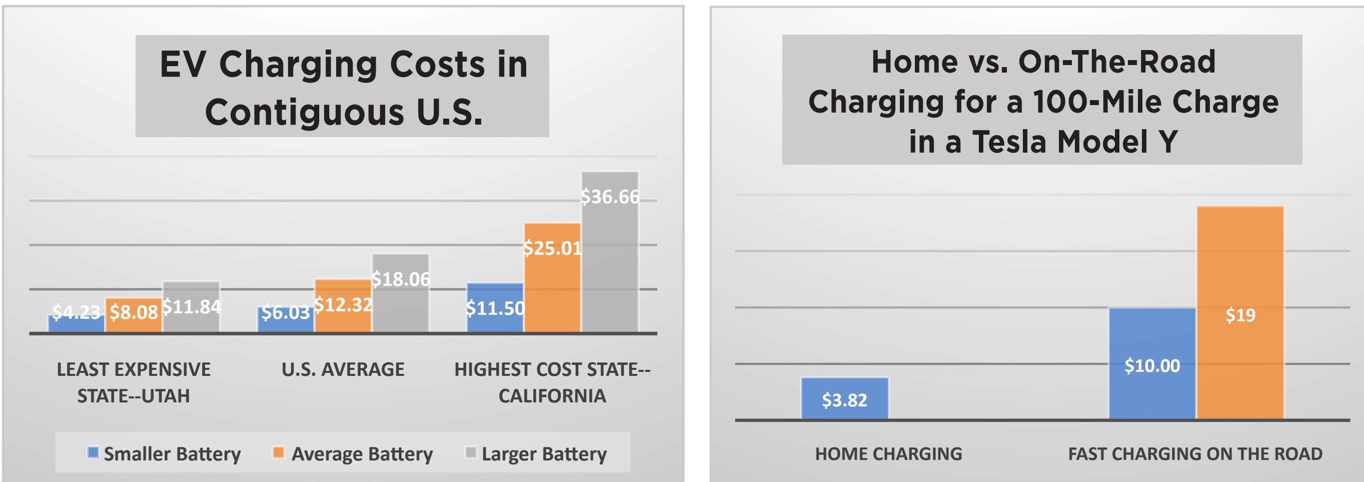
16 "Batteries: The Greenflation Challenge II." Goldman Sachs Research, June 22, 2022. https://www.goldmansachs.com/insights/goldman-sachs-research/batteries-the-greenflation-challenge-2.

17 U.S. Energy Information Administration, May 15, 2023.

18 Lutz, Hannah. "Automakers Lose about $6,000 on Every EV They Sell." Automotive News, March 20, 2024. https://www.autonews.com/mobility-report/every-ev-leads-6000-losses-automakers-bcg-says.

19 Howland, Ethan. "PJM, Miso, Others Warn of 'Significant Power Shortages' from EPA's Power Plant Carbon Rule." Utility Dive, August 10, 2023. https://www.utilitydive.com/news/pjm-miso-iso-ne-grid-operators-epa-power-plant-carbon-ghg-grid-reliability/690489/.

FIGURE 4: CHARGING COST ESTIMATES



Sources: https://www.kbb.com/car-advice/how-much-does-it-cost-to-charge-an-ev/, https://www.caranddriver.com/news/a45036169/electric-vehicle-ev-cost-to-charge/

All this transmission and generation spending must be paid for, and ultimately, utilities pass these costs on to their ratepayers. This transfer means higher electricity costs. The more generation is needed for electric vehicle load, and the more required spending on transmission and generation capacity, the higher the rates must go. Indeed, we have already seen electricity prices rise significantly in recent years.

Massive electric vehicle adoption, especially if powered by more expensive wind and solar generation and their backup costs, will accelerate this pace of price growth. As electricity prices rise, the cost of operating an electric vehicle also goes up.

COST OF CHARGING INFRASTRUCTURE

The cost of charging infrastructure must also be considered part of the cost of charging an electric vehicle because, ultimately, someone must pay for the installation, electric upgrades, and maintenance required to support chargers. Electric vehicles cannot be efficiently charged by simply plugging into a standard wall socket; additional infrastructure and upgraded grid connections are required.

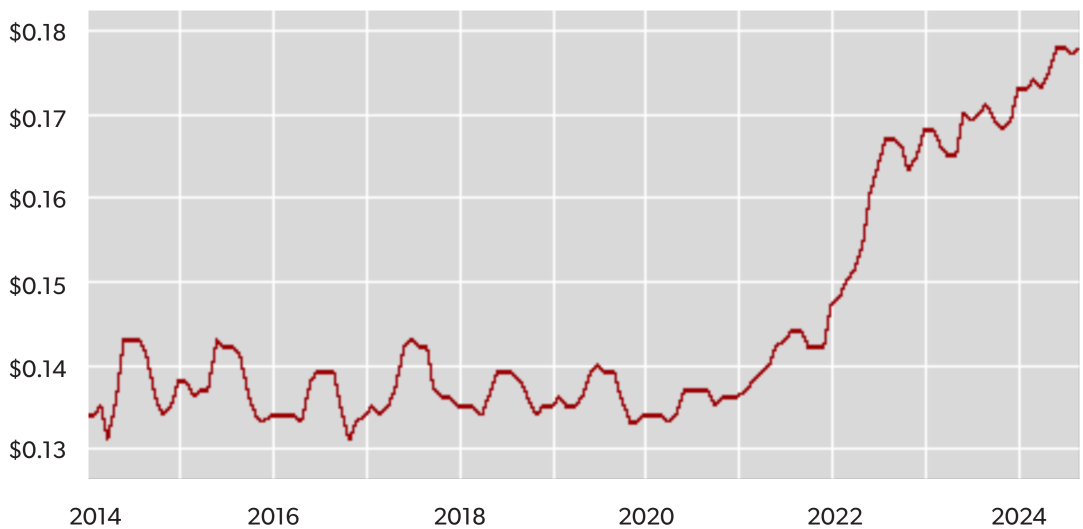
There is a wide range of cost estimates for infrastructure installation.

None of these infrastructure costs are cheap. While the federal government and states offer some taxpayer subsidies, ultimately, the buildout of electric vehicle charging infrastructure will have to come from individuals and the private sector. To emphasize this point, the bipartisan Infrastructure Investment and Jobs Act passed in 2022 appropriated $7.5 billion for EV charging infrastructure. However, as of the middle of 2024, only seven EV charging stations were operational using these taxpayer funds.[20]

Charger installation and maintenance costs will eventually need to be included in drivers' charging prices. This means

20 Institute for Energy Research. "Biden Spends $7.5 Billion for 7 EV Charging Stations." American Energy Alliance, June 21, 2024. https://www.americanenergyalliance.org/2024/06/biden-spends-7-5-billion-for-7-ev-charging-stations/.

FIGURE 5: BLS ELECTRICITY PRICE



Source: U.S. Bureau of Labor Statistics, "Consumer Price Index Average Price Data," https://data.bls.gov/timeseries/APU000072610?amp%253bdata_tool=XGtable&output_view=data&include_graphs=true

that charging prices at public chargers will be higher than standard market electricity prices. Projections of the cost to charge a vehicle based on market electricity rates thus underestimate the actual cost of charging an electric vehicle.

MAINTENANCE COSTS

Electric vehicle proponents claim that maintenance costs for electric cars are much lower than conventional cars. The basis of this claim is that electric cars have fewer moving parts, require fewer oil changes, and don't need replacement parts like spark plugs. The data supporting the claim that maintenance costs are lower is limited and based on sources with a strong incentive to promote electric vehicles. An example of higher-than-expected maintenance costs came from the Hertz auto rental company, which attempted to electrify its fleet but found costs much higher than expected.[21] Additionally, electric cars are only just making their way onto the market in significant numbers, so long-term maintenance costs are yet to be observed. However, some known factors about electric vehicles undermine the claims of maintenance savings.

Tires are one of the most expensive maintenance items for car owners. The tire replacement cost for electric vehicles is typically trivialized or misrepresented. Electric vehicles are much heavier and have faster acceleration and torque than conventional vehicles. These factors all have significant impacts on a vehicle's tires. The extra load and wear require special tires. Electric vehicle tires are 30% to 45% more expensive than conventional ones.[22]

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21 Gitlin, Jonathan M. "Hertz Is Selling 20,000 Used EVs Due to High Repair Costs." Ars Technica, January 11, 2024. https://arstechnica.com/cars/2024/01/hertz-is-selling-20000-used-evs-due-to-high-repair-costs/.

22 Goreham, John. "Electric Vehicles' Tire Cost Will Negate Maintenance Savings vs. ICE." Torque News, July 26, 2022. https://www.torquenews.com/1083/electric-vehicles-pushing-tire-costs-higher-consumers.

FIGURE 6: COST ESTIMATES OF CHARGING INFRASTRUCTURE

Cost Element	Study	Level 2	DCFC			
			50 kW	150 kW	350 kW	800 kW
Equipment cost	ICCT (2019)	$3,127	$28,401	$75,000	$140,000	
	NREL (2020)	$3,500	$38,000	$90,000		
	RMI (2020)	$2,500 - $4,900	$20,000 - $35,800	$75,600 - $100,000	$128,000 - $150,000	
	EDF & GNA (2021)			$136,540		$481,299
Installation Cost	ICCT (2019)	$2,837 - $4,148	$17,692 - $45,506	$18,577 - $47,781	$25,654 - $65,984	
	NREL (2020)	$2,500	$20,000	$60,000		
	RMI (2020)	$7,000	$62,700	$75,500	$138,200	
	EDF & GNA (2021)			$35,000		$175,000

Sources: ICF, https://www.icf.com/insights/transportation/electric-vehicle-charging-infrastructure-costs, https://futureenergy.com/incentives-programs/how-much-do-ev-charging-stations-cost-in-2024/#

The increased wear and tear associated with these extra load tires also decreases the tread life of tires.[23] The replacement cost for a set of electric vehicle tires is $300 to $500 more than for comparable ICE vehicles.[24] The extra maintenance cost of over 100,000 miles could offset other electric vehicle maintenance savings.

Recent studies also question the claims of considerable maintenance savings for EVs. For example, a Kelley Blue Book assessment estimates an electric vehicle's overall five-year maintenance cost is $4,246 vs. $4,583 for a

23 "Do EV Tires Wear out Faster?" Firestone Complete Auto Care, March 4, 2024. https://www.firestonecompleteautocare.com/blog/tires/ev-tire-wear/.

24 Goreham 2022

FIGURE 7: TABLE -TIRE COST COMPARISON[25]

RAV4 17-inch tire Model TOYO OPEN COUNTRY A38 Price = $160.44 each	Tesla Model 3 18-inch HANKOOK KINERGY GT Price = $257.99	Chevy Bolt 17-inch MICHELIN ENERGY SAVER A/S Self-Seal Price = $242.96
bZ4X 18-inch tire Model BRIDGESTONE TURANZA EL450 = $276.29	Honda Civic 17-inch HANKOOK KINERGY GT Price = $175.99	Nissan Kicks 16-inch FIRESTONE FT140 Price = $131.45

conventional car.[26] But this is a negligible difference, especially considering that there are some caveats regarding the potential for greater tire replacement cost in this comparison. According to data from Mitchell, a software provider to the car insurance and auto repair industries, EVs cost about 30% more to repair than the average ICE vehicle.[27] A large part of that difference is EVs require nearly double the labor hours for repairs.

There are many ways to calculate estimates of maintenance costs, but if there is a minimal cost difference in maintenance or if EVs even cost more to repair or maintain, the consumer rationale for purchasing an electric vehicle becomes even more tenuous. With little or no maintenance savings, the larger upfront cost of an electric vehicle looks even more daunting.

INSURANCE

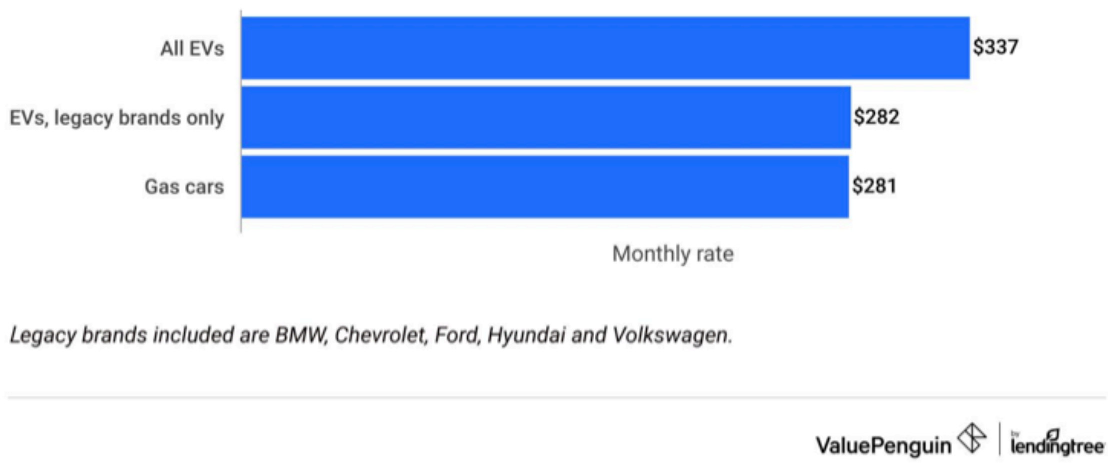
A review of the insurance cost for electric vehicles can also provide some insight into the maintenance cost of these vehicles. Insurance companies are in the business of evaluating the financial risk of car ownership and use. Electric vehicle insurance is, on average, 20% higher vs. an ICE model, based on the rate data from Quadrant

25 *Ibid.*

26 St. John, Alexa, and Matthew DeBord. "Teslas and Other Evs Don't Need as Much Maintenance as Gas-Powered Cars. Here Are Key Differences in Upkeep and Repairs." Business Insider, June 27, 2023. https://www.businessinsider.com/tesla-differences-between-gas-and-electric-vehicles-maintenance-2020-4.

27 Tucker, Sean. "Study: EVS Cost 30% More to Repair." Kelley Blue Book, June 4, 2024. https://www.kbb.com/car-news/study-evs-cost-30-percent-more-to-repair/.

FIGURE 8: ELECTRIC VEHICLE INSURANCE COST



Source: **https://www.valuepenguin.com/how-having-electric-car-affects-your-auto-insurance-rates**

Information Services.[28] The main reasons referenced were that electric vehicles are more expensive to repair due to the high battery replacement cost. Repairing electric vehicles will also require specialized equipment and highly trained technicians. Insurance companies appear to believe that electric vehicle repair and parts are more expensive than conventional vehicles.

VALUE, DEPRECIATION, AND BATTERY REPLACEMENT

Although depreciation is not a maintenance cost per se, it is an essential factor in the cost of ownership. Electric vehicles depreciate at a much faster rate than conventional cars. There is a wide range in value loss from one EV to another, but some EVs can lose as much as 50% of their value in just the first year.[29] Kelley Blue Book estimates that the average five-year depreciation for an electric vehicle is $43,515 vs. $27,883 for a conventional car.[30] The high depreciation cost is due to both the high purchase price and the relatively low estimated value at resale.

Electric vehicle resale values may change over time depending on demand and the condition of vehicles at resale. However, battery deterioration will be a dominant factor in resale value. Battery replacement can cost anywhere from $7,000-$30,000, depending on the type of vehicle and battery module.[31] For example, J.D. Power

28 Timmons, Matt. "How Much Does Electric Car Insurance Cost?" ValuePenguin, May 24, 2024. https://www.valuepenguin.com/how-having-electric-car-affects-your-auto-insurance-rates.

29 Charlton, Alistair. "EVs Are Losing up to 50 Percent of Their Value in One Year." Wired, August 16, 2024. https://www.wired.com/story/evs-are-losing-up-to-50-percent-of-their-value-in-one-year/

30 Horn, Greg."Electric Vehicles vs. Internal Combustion: The Real Cost Comparison." PartsTrader, April 14, 2023. https://www.partstrader.com/electric-vehicles-vs-internal-combustion-the-real-cost-comparison/.

31 Stern, Perry. "How Much Does It Cost to Replace an EV Battery?" U.S. News & World Report, January 26, 2024. https://cars.usnews.com/cars-trucks/advice/ev-battery-replacement-cost.

estimates that the cost to replace a Tesla Model 3 battery starts at $13,000, which is already over 30% of the list price of a new Model 3.[32] At such high battery replacement costs, the value of a used electric vehicle would remain very low.

Electric vehicles are facing notable depreciation rates.[33] For example, a Tesla Model 3 is expected to lose 45% of its value after three years, while a gas-powered Toyota RAV4 depreciates only 22% over the same timeframe. After just one year, the resale value of a Tesla Model 3 is approximately 64.38% of its original price.

Recent data from CarEdge indicates that Teslas may depreciate at double the rate of gas-powered vehicles. Specifically, the Tesla Model Y, Model S, and Model X are projected to lose 57% of their value after five years, compared to the RAV4's expected 28% depreciation. Tesla could be approaching a saturation point, where the increasing number of Teslas on the road diminishes their desirability, reminiscent of the Toyota Camry in the 1990s. In 2021, Hertz announced plans to buy 100,000 electric vehicles from Tesla but faced disappointing rental demand and higher-than-expected costs. By January, Hertz decided to sell 20,000 of these vehicles, dropping prices to as low as $25,000. This depreciation resulted in a $588 million loss for Hertz in the first quarter of this year compared to the last quarter of 2023. This "EV nightmare" also led to the CEO's dismissal.

Simply buying a new vehicle is more practical than paying for a new battery. If there is little resale value, the higher upfront cost is even harder to justify compared to a conventional internal combustion engine vehicle, which can be expected to last for decades and be resold multiple times.

Recent data from CarEdge indicates that Teslas may depreciate at double the rate of gas-powered vehicles. Specifically, the Tesla Model Y, Model S, and Model X are projected to lose 57% of their value after five years, compared to the RAV4's expected 28% depreciation. Tesla could be approaching a saturation point, where the increasing number of Teslas on the road diminishes their desirability, reminiscent of the Toyota Camry in the 1990s

32 Yantakosol, Matt. "How Often Do Tesla Batteries Need to Be Replaced?" J.D. Power, June 21, 2024. https://www.jdpower.com/cars/shopping-guides/how-often-do-tesla-batteries-need-to-be-replaced.

33 "Depreciation crushes EV resale values." Institute for Energy Research, September 26, 2024. https://www.instituteforenergyresearch.org/regulation/depreciation-crushes-ev-resale-values/

INFRASTRUCTURE WEAR

There are indirect costs of electric vehicles as well that, while not included in the cost an individual owner pays, are borne by the country. The most significant of these is the additional wear on infrastructure from EVs. Heavier vehicles on roads have negative consequences, and EVs are far heavier than their conventional vehicle counterparts because of their battery modules. Heavier vehicles cause more damage to roads and bridges. Road damage leads to accidents, injuries, and sometimes deaths. A 2021 American Society of Civil Engineers study estimated that extra vehicle cost from damage caused by deteriorating infrastructure is $130 billion.[34] The environmental, safety, and consumer costs associated with road damage and repair are rarely considered when analyzing the impact of EVs.

A study conducted by the U.S. General Accountability Office (GAO) of overweight trucks determined that road damage was related to the fourth power of the relative vehicle weight on the road.[35] This means that the road damage caused by a vehicle that is two times heavier creates sixteen times as much damage. In 2022, the average weight of cars increased to over 4,300 pounds, more than 1000 pounds heavier than they were in 1980,[36] causing increased damage to U.S. roads. Electric vehicles will significantly increase the average weight of cars, SUVs, and pickups.

A recent study of the vehicle population of Scotland applied this relationship between vehicle weight and wear and tear to Scotland's roads.[37] This relationship applied to the U.S. would differ but more than likely be worse because drivers in the U.S. have heavier vehicles and drive more miles. The study introduces the concepts of Road Wear Potential (RWP) for an individual vehicle and Road Wear Impact Factor (RWIF). The RWIF considers the RWP, the number of vehicles in each class, and the average miles driven. This study estimates that the RWIF is approximately 20-40% higher when transitioning to an all-battery electric vehicle fleet, including both cars and heavy trucks. The impact is much greater for trucks due to the heavier weight. This directly impacts road maintenance costs, which are estimated to increase by approximately 30%.

Heavier vehicles cause more damage to roads and bridges. Road damage leads to accidents, injuries, and sometimes deaths. A 2021 American Society of Civil Engineers study estimated that extra vehicle cost from damage caused by deteriorating infrastructure is $130 billion.

It is important to point out that the Scotland study does not consider the condition of the roads. Roads in poor condition

34 "Roads." ASCE's 2021 Infrastructure Report Card. https://infrastructurereportcard.org/cat-item/roads-infrastructure/#.

35 "Excessive Truck Weight: An Expensive Burden We Can No Longer Support." U.S. Government Accountability Office, July 16, 1979. https://www.gao.gov/products/ced-79-94.

36 Randall, Tom. "American Cars Are Developing a Serious Weight Problem." Bloomberg.com, August 8, 2023. https://www.bloomberg.com/news/articles/2023-08-08/american-cars-are-developing-a-serious-weight-problem#.

37 Low, John M., R. Stuart Haszeldine, and Gareth P. Harrison. "The Hidden Cost of Road Maintenance Due to the Increased Weight of Battery and Hydrogen Trucks and Buses—a Perspective." *Clean Technologies and Environmental Policy* 25, no. 3 (December 5, 2022): 757–70. https://doi.org/10.1007/s10098-022-02433-8.

FIGURE 9: PARTICULATE EMISSIONS STUDY – TIRE WEAR VS. TAILPIPE

	Particulate mass emissions (mg/km)	As proportion of tailpipe limit value
Tire wear - aggressive legal driving	5,760.00	1,280.000
New tire wear - normal driving	73.00	16.222
Used tire wear - normal driving	36.50	8.111
Airborne tire particles - normal driving, new tires	8.03	1784
Additional tire wear - +500 kg vehicle mass	7.67	1703
Tailpipe particulates - legal maximum	4.50	1000
Tailpipe particulates - real world	0.02	0.004

Source: https://www.emissionsanalytics.com/news/gaining-traction-losing-tread

would be impacted to a greater extent. It is estimated that 40% of U.S. roads are in poor or mediocre condition.[38] U.S. road maintenance costs were estimated to be $206 billion in 2021, with 50% for capital projects.[39] Fuel taxes currently pay 25% of the maintenance cost of U.S. roads, and these funds would no longer be available if we fully transitioned to an all-electric vehicle fleet.

Of course, these infrastructure impacts will be gradual and not fully felt until the car and truck fleets are fully transitioned, and roads and bridges begin to crumble prematurely. However, some early examples of this wear are perhaps already being seen, with collapsing parking garages being blamed on increasing vehicle weights.[40] As EVs grow more common, the cost of this wear will only increase.

PARTICULATE EMISSIONS

A second indirect cost of electric vehicles that is not considered is the potential impact on particulate emissions. The EPA has determined that particulate matter, including in the 2.5-micron size range (PM 2.5), is sufficiently hazardous to be a criteria pollutant under the National Ambient Air Quality Standards. The EPA has promulgated regulations to reduce particulate emissions (PM 2.5 and PM 10) from conventional cars and trucks.[41] Indeed, one of the most significant societal benefits electric vehicle boosters claim is that electrifying the vehicle fleet will substantially reduce PM emissions from transportation because it eliminates tailpipe emissions. However, this claim does not tell the whole story.

Emission Analytics did an exhaustive and detailed study comparing the particulate emissions from the tailpipe of

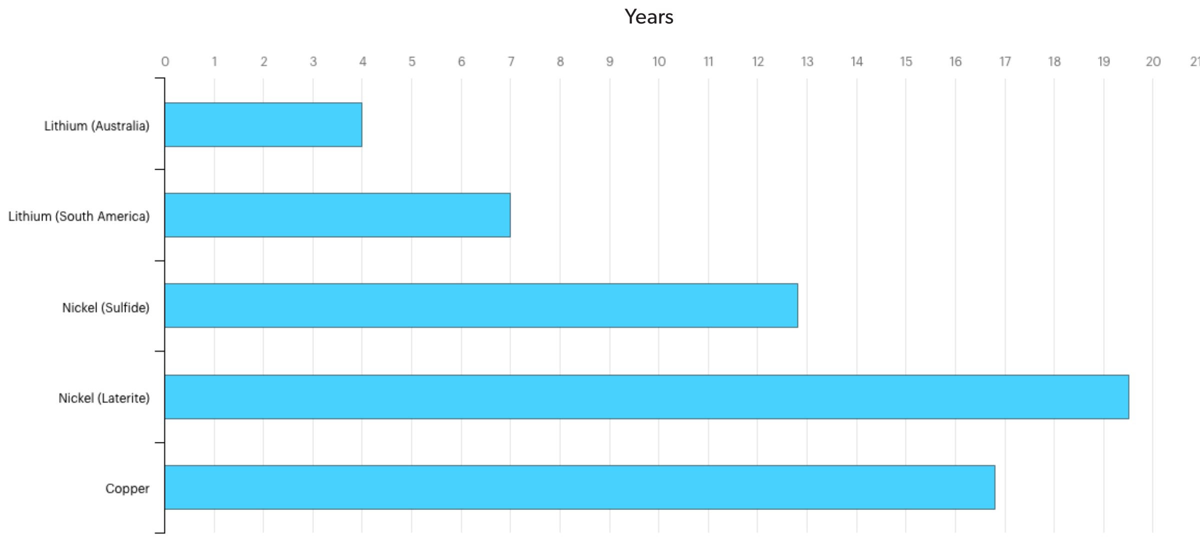
38 ASCE's 2021 Infrastructure Report Card

39 "Highway and Road Expenditures." Urban Institute. https://www.urban.org/policy-centers/cross-center-initiatives/state-and-local-finance-initiative/state-and-local-backgrounders/highway-and-road-expenditures.

40 Day, Lewin. "Heavy EVs Could Collapse Old Parking Garages: Report." The Drive, April 10, 2023. https://www.thedrive.com/news/heavy-evs-could-collapse-old-parking-garages-report.

41 "Health and Environmental Effects of Particulate Matter (PM)." Environmental Protection Agency, July 16, 2024. https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

FIGURE 10: MINE LEAD TIMES



Source: https://www.iea.org/data-and-statistics/charts/average-observed-lead-times-from-discovery-to-production-for-selected-minerals-2010-2019

new conventional vehicles and their tires.[42] The surprising results were that tire wear particulate emissions were much greater than the particulate emissions from the tailpipe. In fact, tire wear particulate emissions were over a thousand times greater over the life of the car vs. tailpipe particulate emissions.

Vehicle weight and aggressive driving (which can be associated with instantaneous acceleration) were found to be important contributing factors in particulate emissions. According to the study, a 500-pound increase in vehicle weight can result in tire emissions 400 times greater than real-world tailpipe emissions.

Since EVs have a heavier weight and greater acceleration, there will be greater tire wear emissions than from conventional cars. Another study by Emissions Analytics confirms this relationship: a Tesla Model Y recorded tire PM emissions 26% larger than a comparable hybrid vehicle.[43]

The emissions profile for volatile organic compounds was even worse, with the Tesla tires emitting at more than double the rate of the compared vehicle.

Given the ultra-low tailpipe levels of PM emissions achieved by modern ICE vehicles, forcing the replacement of those new ICE vehicles with new EVs would likely increase overall PM emissions due to higher tire emissions.

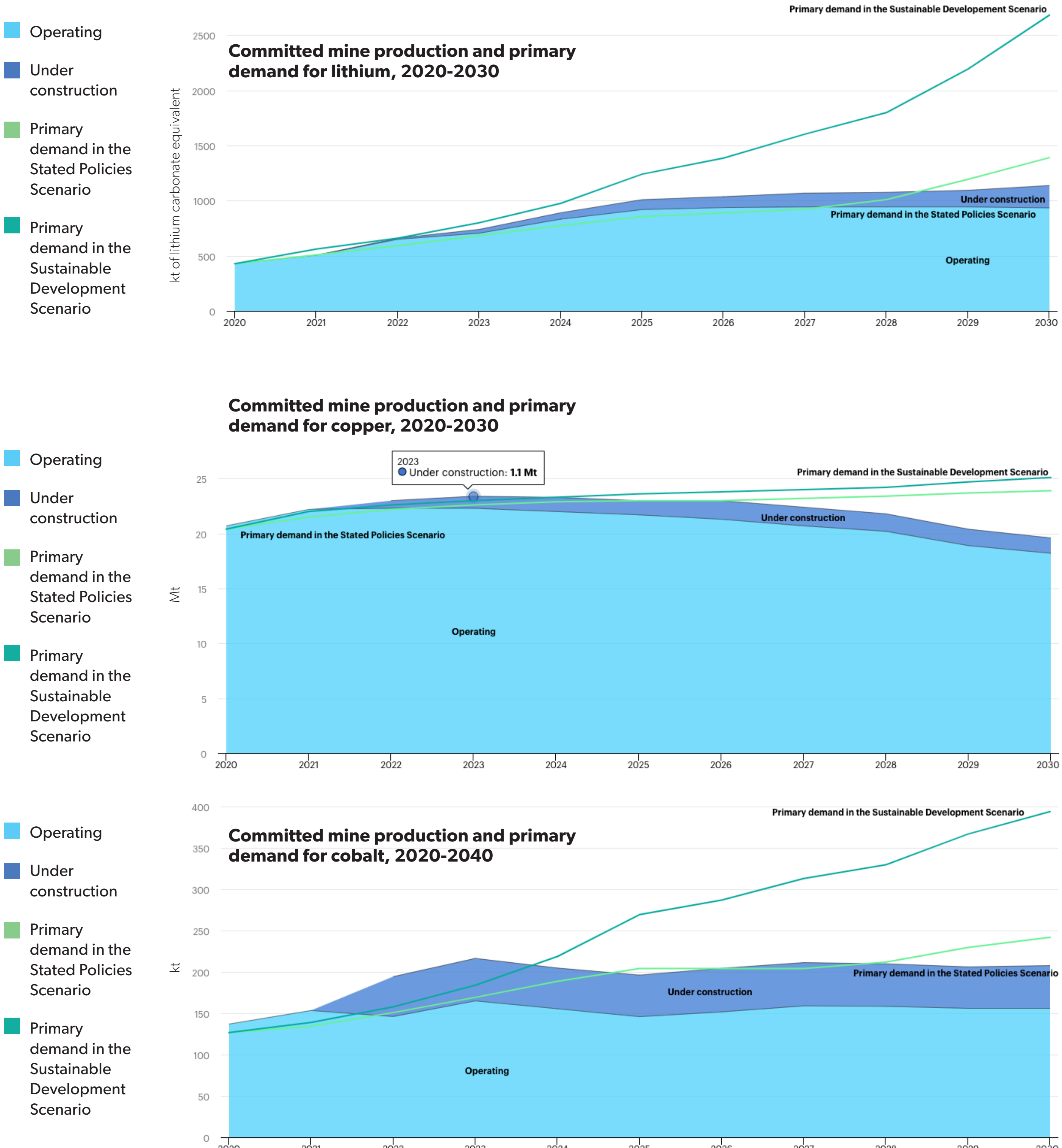
MINERAL SOURCING

A final cost of electric vehicles that is somewhat hidden is the cost of mining and processing or purchasing the mineral inputs for electric vehicles. While electric vehicles do not require oil to operate, that does not mean that they have no mineral supply demands. Electric vehicles are very resource-intensive to manufacture, requiring six times the

42 "Gaining Traction, Losing Tread Pollution from Tire Wear Now 1,850 Times Worse than Exhaust Emissions." Emissions Analytics. https://www.emissionsanalytics.com/news/gaining-traction-losing-tread.

43 "Do No Harm." Emissions Analytics. https://www.emissionsanalytics.com/news/do-no-harm.

FIGURE 11: PROJECTED NEW MINERALS SUPPLY



Sources: https://www.iea.org/data-and-statistics/charts/committed-mine-production-and-primary-demand-for-lithium-2020-2030, https://www.iea.org/data-and-statistics/charts/committed-mine-production-and-primary-demand-for-copper-2020-2030, https://www.iea.org/data-and-statistics/charts/committed-mine-production-and-primary-demand-for-cobalt-2020-2040

CHILE MINES LITHIUM FROM SALT FLATS OF ATACAMA DESERT

mineral inputs of conventional cars.[44] These resources must be mined from the ground and processed. The current world capacity for nearly all relevant minerals is insufficient to supply a rapid short-term ramp-up in EV manufacturing. While new mines are in the planning stages, bringing a new mine into production takes many years, and often decades, to complete. These shortages will inevitably drive up prices, especially if governments continue to try to force electric vehicle demand adoption beyond what the market organically desires.

On top of the dollar cost of minerals, which a customer will likely pay much of in the form of more expensive vehicles, mining and processing minerals has an environmental cost. Mining is an emissions-intensive process that produces large amounts of waste rock and toxic byproducts. Refining and processing minerals likewise produce toxic waste and significant emissions. Both mining and processing are also energy intensive, whether fueled by oil and gas or electricity. All these environmental costs are part of the electric vehicle transition, even if they don't always have a specific dollar amount attached.

44 Hillberg, Patrick, and Sawyer Hall. "Global Boom in Electric Vehicles Will Strain Mineral Supply." World Economic Forum, June 25, 2021. https://www.weforum.org/agenda/2021/06/carmakers-switch-to-electric-vehicles-strain-supply-of-battery-minerals/.

SECTION 3

THE LIMITATIONS TO ELECTRIC VEHICLE ADOPTION

There are several significant barriers to the adoption and spread of electric vehicles. These limitations are often fundamental issues, not subject to being fixed by government fiat, no matter how enthusiastically a government may force a transition. In discussions of federal electric vehicle policy, these limitations are frequently ignored, or if acknowledged, it is assumed that they can be overcome at some unspecified point in the future. However, these limitations are very real brakes on both the short-term pace of adoption and set a potential ceiling on the possibility or desirability of achieving anything close to 100% electric vehicle adoption.

CONSUMER ACCEPTANCE IS LOW

One of the most prominent limitations on the spread of electric vehicles is a simple question of demand. For several reasons, surveys consistently find limited interest in purchasing electric vehicles.[45] Consumers consistently continue to express reservations about purchasing an electric vehicle as their next car.[46] The cost of electric vehicles, battery range, the time it takes to charge an electric vehicle, and the availability of charging infrastructure are just a few of the reasons commonly cited for reluctance to purchase. These issues are discussed in more detail elsewhere in this paper, but the cumulative impact is that demand for electric vehicles is not increasing at the pace

45 "2024 Global Automotive Consumer Study." Deloitte Global, January 2024. https://www.deloitte.com/global/en/Industries/automotive/perspectives/global-automotive-consumer-study.html.

46 "New Survey, Same Results: Voters Prefer Affordable Energy over Climate Agenda." American Energy Alliance, June 1, 2023. https://www.americanenergyalliance.org/2023/06/new-survey-same-results-voters-prefer-affordable-energy-over-climate-agenda/.

that many electric vehicle boosters have projected.[47] Many large automakers have reduced their forecasts for sales recently due to limited demand, often absorbing huge losses in the process.[48]

Many of the issues that currently deter consumers do not have near-term solutions.[49] Among electric vehicle boosters, there is optimism that innovation and economies of scale will continue to lower costs and improve battery life, but this is a hope, not a certainty. On the flip side, the regulatory authority of federal or state governments to force consumers to accept electric vehicles is limited. Some states are attempting to ban internal combustion vehicles, but those rules are subject to litigation. At the federal level, there is some regulatory authority to force automakers to make more electric vehicles and fewer internal combustion vehicles. Still, there is no authority to force consumers to purchase said vehicles. The Biden administration has aggressively sought to deploy those regulatory authorities, but the further they are stretched, the more vulnerable they become to legal challenges.

A recent survey by McKinsey & Company revealed that globally, 30% of electric vehicle owners are likely to switch back to gas-powered vehicles for their next purchase.[50] Absent new laws, which could force purchases of electric vehicles, consumers must be persuaded that electric vehicles are a better purchase than the internal combustion vehicles they have long known. While some parts of the country, and certain populations, have been enthusiastic about electric vehicles, it is far from a universal sentiment. For electric vehicles to become more than a niche product, broader consumer sentiments must change.

BATTERY SIZE AND DRIVING RANGE

Electric vehicle batteries are a primary limitation of the adoption of electric vehicles. In particular, both battery size and driving range have a major impact on the adoption of electric vehicles. Battery size directly impacts the cost of a car since the battery module is the vehicle's most expensive component. Driving range is directly related to the size of the battery, and as discussed above, range anxiety is one of the biggest reasons given for consumer reluctance to purchase an electric vehicle. However, basic physical factors mean no easy fixes exist for these limitations. We can illustrate some of these issues with calculations and estimates for various electric vehicles.

Range is measured in a standardized EPA test. Larger batteries provide longer driving ranges. The following table summarizes the battery sizes for several different electric vehicles and the corresponding range.

Most car companies guarantee 100,000 miles and an eight–to–ten–year battery life.[51] They also guarantee 70% or more of the charge capacity. Note that constant charging and recharging gradually degrade the battery. Additionally, running the battery down to empty and recharging to 100% also has a negative impact on the battery—effectively reducing the battery size, EPA range, and mileage efficiency over time.

47 "Why Are EV Sales Slowing?" Goldman Sachs, May 21, 2024. https://www.goldmansachs.com/insights/articles/why-are-ev-sales-slowing.

48 Catenacci, Thomas. "Ford Abruptly Axes Electric SUV Plans over Slowing Demand, despite Billions from Biden-Harris Admin." Washington Free Beacon, August 21, 2024. https://freebeacon.com/biden-administration/ford-abruptly-axes-electric-suv-plans-over-slowing-demand-despite-billions-from-biden-harris-admin/.

49 "GM Not Reiterating 2025 1 Million EV Production Capacity Forecast." Reuters, July 15, 2024. https://www.reuters.com/business/autos-transportation/gm-not-reiterating-2025-1-million-ev-production-capacity-forecast-2024-07-15/.

50 "McKinsey Mobility Consumer Pulse." McKinsey & Company, June 2024. https://executivedigest.sapo.pt/wp-content/uploads/2024/06/Mobility-Consumer-Pulse-2024_Overview.pdf.

51 Fischer, Justin. "The Best Electric Vehicle Battery Warranties in 2024." CarEdge, January 9, 2024. https://caredge.com/guides/ev-battery-warranties.

FIGURE 12: BATTERY SIZE, RANGE

Examples	Battery Size (KwH)	EPA range (mi)
Mini Cooper	32.6	114
Nissan Leaf	40	149
Chevy bolt EV 1lt	65	259
Mercedes EQS:	108.4	345

Source: Select vehicles from https://insideevs.com/reviews/344001/compare-evs/

FIGURE 13: EV MILAGE EFFICIENCIES – DIFFERENT MODELS

Examples	Milage Efficiency
Mini Cooper	31kwh/100 miles
Nissan Leaf	30kwh/100 miles
Chevy bolt EV 1lt	28kwh/100 miles
Mercedes EQS:	35kwh/100 miles

Source: Select vehicles from https://ecocostsavings.com/electric-car-kwh-per-mile-list/

Real-world conditions can have a significant impact on EVs. For example, an EV driven during the wintertime in the areas of the country that experience cold temperatures can temporarily lose anywhere from 10-36% of its range.[52]

All batteries degrade based on calendar time. Geotab, the world leader in fleet tracking and management, reports an average degradation of 1.8% per year.[53] Frequency of charging, fast charging, and high-temperature exposure all accelerate the loss in battery capacity.

Mileage efficiency is measured by the amount of electricity in kilowatt-hours (kWh) consumed to drive one hundred miles. The lower the electricity consumption, the better the mileage efficiency. This measurement is based on a standard EPA test, similar to the test that measures miles per gallon (mpg) in a conventional car. The above table lists the variation of mileage efficiency for several different EVs.

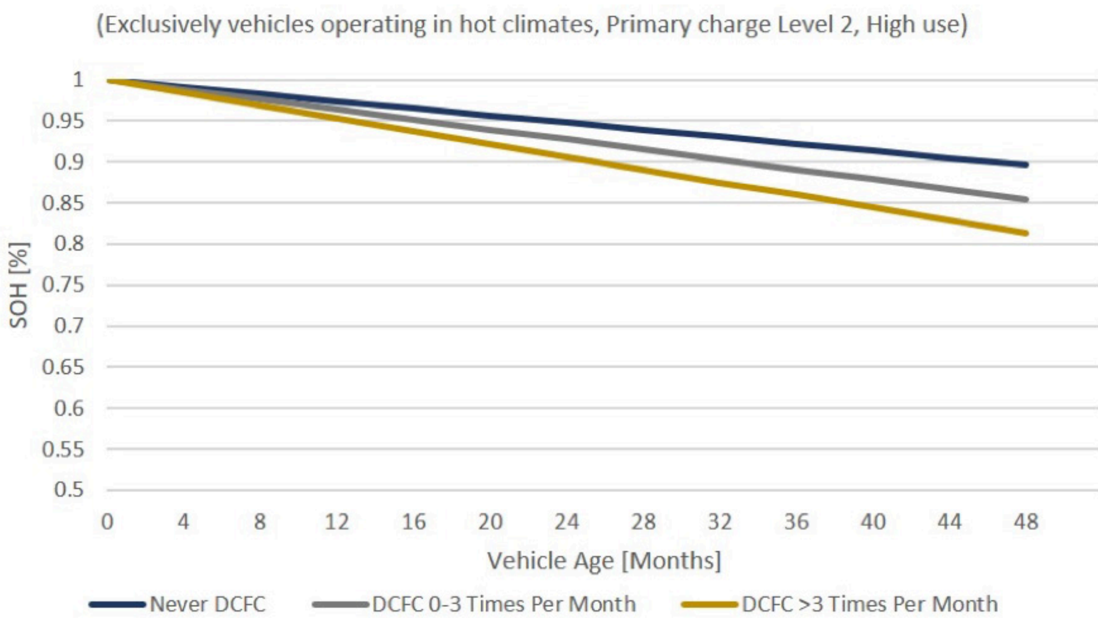
The mileage efficiency has an important effect on the electric cost of an EV. The following examples illustrate the impact of two different EVs driven for 1000 miles:

The Chevy Bolt's mileage efficiency is 28 kWh/100 miles, so it would utilize 280 kWh of electricity. Assuming an average unit electricity cost in California of $.34/kWh, the electric

52 Krisher, Tom. "Cold Weather Can Cut Electric Vehicle Range and Make Charging Tough. Here's What You Need to Know." Public Broadcasting Service, January 19, 2024. https://www.pbs.org/newshour/economy/cold-weather-can-cut-electric-vehicle-range-and-make-charging-tough-heres-what-you-need-to-know.

53 Argue, Charlotte. "How Long Do Electric Car Batteries Last?" Geotab, September 3, 2024. https://www.geotab.com/blog/ev-battery-health/.

FIGURE 14: BATTERY DETERIORATION VS. TIME



Source: https://www.geotab.com/blog/ev-battery-health/

cost would be $95.20. Due to its smaller battery size (60 kWh), it would also have to be refilled approximately five times.

Mercedes has a mileage efficiency of 35 kWh/100 miles and, therefore, would utilize 350 kWh of electricity. Assuming an average electricity cost in California of $.34/kWh, the electric cost would be $119.00, 25% higher than the Chevy Bolt. However, due to its larger battery size (107 kWh), it would only have to be filled approximately three times.

It's important to remember that the EPA test doesn't measure efficiency under real-world conditions. The actual mileage efficiency will be worse than what the EPA test values show. For example, the test does not include road friction, passengers, or climate control (A/C or heat). It is also conducted at room temperature. It measures a fresh battery and does not consider its degradation.

Even if new battery technologies are developed, there will always be a fundamental connection between battery size and the range of a vehicle. And because of the need for charging, the range is a more significant issue for electric vehicles than internal combustion vehicles, which can be refueled in minutes. Larger batteries make electric vehicles heavier and take up more space, which is also a major factor in the cost of the vehicle. This is a tradeoff that electric vehicles will always face and shows the limits on the extent to which electric vehicles can displace other vehicle types.

BATTERY LIFE

Battery life is another battery-related limitation inherent to electric vehicles. All batteries deteriorate over time – cell phones, laptops, and EVs. Frequent level three charging (DCFC) negatively affects the battery's state of health (SOH). Figure 14 shows that the SOH after four years can decrease to 85% of the original power rating for the battery with occasional fast charging and even further with frequent fast charging. Although this figure is based on battery deterioration in hot climates, it is indicative of the impact of recharging on battery life. Higher charging rates reduce the time to recharge the battery and cause it to deteriorate more quickly.

These numbers fit very well with car companies' current policies, which typically guarantee 70% battery capacity after 8-10 years or 100,000 miles. For example, a Chevy Bolt with a 60-kWh battery and an EPA-rated range of 238 miles could effectively have a capacity of only 42 kWh and a range of 166 miles, depending on the extent of DCFC charging and the climate. Car companies recommend that drivers do not charge above 90%, and most drivers will recharge at 20% or higher. Therefore, the real-world range before recharging could be closer to 116 miles. If this 5–10-year-old car is used on cold winter days in Chicago, the range would be further reduced.

Battery life also becomes the overwhelming factor for the resale of electric vehicles. The state of health of the battery matters far more than the car's age in miles. Replacing a battery is usually prohibitively expensive; if a new battery costs more than the car's value, why even buy a used electric vehicle? Clever software can mitigate some of these battery life issues, but the fundamental problem of degradation over time will always be there. This will limit the uses and applications of electric vehicles over time. Additionally, if battery life issues make resale of electric vehicles difficult or valueless, that could further deter consumers from purchasing at the outset.

CHARGING INFRASTRUCTURE

The availability of charging infrastructure is a crucial limitation on the penetration of electric vehicles. Because electric vehicles take significantly more time to charge than competing conventional vehicles take to refuel, charging infrastructure is a concern in the way that the availability of gas stations is not. However, building a charging infrastructure is not straightforward. Besides the cost discussed above, the physical location needs for charging are significant and far more burdensome than for a simple liquid fuel gas station. Charging infrastructure barely exists, and even what chargers are in place are often deficient, making this a problem for electric vehicle growth.

The availability of charging infrastructure is a crucial limitation on the penetration of electric vehicles. Because electric vehicles take significantly more time to charge than competing conventional vehicles take to refuel, charging infrastructure is a concern in the way that the availability of gas stations is not.

Installation of chargers is a complex matter. While Level 1 charging can be done on standard household outlets, it is incredibly slow. Perhaps it would work if you have a garage and only drive to work and back. Still, the availability of faster charging is required for electric vehicles to truly replace internal combustion engines in the way advocates call for. Both Level 2 and Level 3 charging require the installation of additional infrastructure. This infrastructure is not just the charger but often requires electric line upgrades. A rural gas station cannot suddenly install ten Level 3 fast chargers on their existing power line. Upgrades to power lines and connections take time and can be subject to supply limitations of critical components like transformers.

The time that electric vehicles take to charge also increases the need for chargers at any given location. A gas station with four pumps can get through many customers when each fill takes five minutes or less, but even a fast charger can require 30 minutes or more per vehicle.[54] This means far more ports are required to serve similar numbers of vehicles. This problem grows more acute as more electric vehicles come on the road. More chargers require greater peak electric supply capacity, even if that full capacity is rarely utilized, and adding that greater peak capacity takes upgrades.

Charging at home is not a solution to this infrastructure problem. Not all homes have garages where a charging port could be installed. Residents of multifamily buildings or renters must charge their vehicles somewhere. Many cities now mandate charging stations in apartment buildings, parking garages, shopping centers, etc., but as electric vehicles grow more common, that will be far from sufficient. The question of who covers the cost also becomes more relevant; two cars charging in an apartment complex garage is a negligible expense, but if 100 cars are charging, rent will probably need to be raised.

The scale of building out sufficient charging infrastructure to make electric vehicle charging even reasonably convenient is massive. The few billions of dollars pledged by the federal government and some carmakers is far short of what would be required. Even when money is available, building rapidly is not assured. For example, the bipartisan Infrastructure Investment and Jobs Act, passed in 2022, appropriated $7.5 billion for EV charging infrastructure. Still, as of the middle of 2024, only seven EV charging stations had begun operating.[55] If electric vehicles remain a niche product, charging infrastructure would likely be able to meet requirements, but infrastructure needs represent a significant barrier to a mass market in electric vehicles.

GENERATION CAPACITY AND SHORTAGES

Even if a buildout of charging infrastructure were possible, there are other infrastructure challenges facing an electric vehicle future. Because electric vehicles charge from the grid and will overwhelmingly continue to do so, the health and stability of the larger electric grid are significant factors. Unlike the liquid fuels supply chain, which has numerous refineries, pipelines, tanker trucks, etc., the electric grid is a single interconnected system.

The U.S. electric grid is already struggling to meet peak demand today. In just the last few years, both California and Texas have had significant outages, and multiple regional transmission operators have warned of generation shortfalls soon.[56] These shortfalls are due to policy and regulatory action outside the electric vehicles space. However, the rapid growth of electric vehicles envisioned by advocates will represent a large load addition to this system that is already struggling to handle existing loads. Coupling this with growing demands for electricity from things like artificial intelligence, data centers, and a broader push for

The U.S. electric grid is already struggling to meet peak demand today.

54 Cowell, K.C., and Jacob Kurowicki. "How Long Does It Take to Charge an Electric Car?" Car and Driver, March 14, 2024. https://www.caranddriver.com/shopping-advice/a32600212/ev-charging-time/.

55 Institute for Energy Research 2024

56 Howland 2023

electrification will make it difficult for generation capacity to keep up with demand.[57]

Meeting this increased demand will be difficult. Due to regulatory bias against dispatchable generation sources like coal and nuclear power at both the state and federal levels, the construction of new stable dispatchable generation sources like coal and nuclear power is unlikely. Nuclear power is enjoying a resurgence, but still unlikely in the short term. Dispatchable natural gas generation faces some of those regulatory challenges as well, which slows the development of such generation.

The generation sources favored through regulation, especially wind and solar, face significant constraints on growth. Wind and solar energy require large amounts of land, a massive increase in transmission construction, and a large amount of material inputs for construction. Because wind and solar are intermittent, capacity must be overbuilt in the hope that there will be enough wind blowing or sun shining somewhere on the grid. This overbuilding increases costs and increases land needs for generation and transmission. These factors are already slowing the growth of these sources to the point that they are barely replacing capacity (mainly from coal generation) that is now being retired. The increased load required for electric vehicles would require a vast wind and solar construction acceleration. Absent wholesale changes to permitting, eminent domain laws, and regulations, such an acceleration is unlikely in the near term. It also must be noted that many advocates for electric vehicles are also fighting hard to eliminate coal and natural gas electric generation, which provide about 60% of electric generation today.[58] This means that forced transition advocates are simultaneously seeking to reduce reliable electricity supply while advocating a for a large increase in electricity use.

Meeting this increased demand will be difficult. Due to regulatory bias against dispatchable generation sources like coal and nuclear power at both the state and federal levels, the construction of new stable dispatchable generation sources like coal and nuclear power is unlikely.

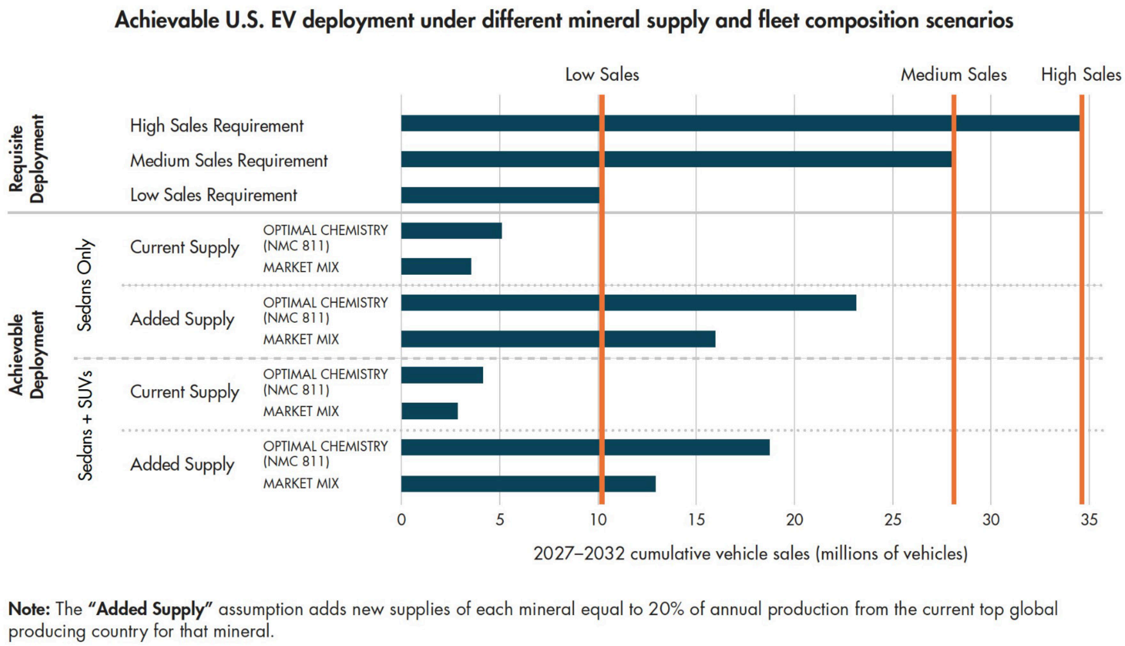
Electric vehicle charging will be one of the first uses curtailed when there is insufficient available generation. We have already seen these types of warnings in California and Europe.[59] The possibility of not being allowed to charge one's vehicle adds yet another hesitation point for consumers.

57 Goldman Sachs. "AI Poised to Drive 160% Increase in Power Demand." Accessed October 21, 2024. https://www.goldmansachs.com/insights/articles/AI-poised-to-drive-160-increase-in-power-demand.

58 "What Is U.S. Electricity Generation by Energy Source?" U.S. Energy Information Administration (EIA), February 29, 2024. https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

59 Albeck-ripka, Livia. "Amid Heat Wave, California Asks Electric Vehicle Owners to Limit Charging." The New York Times, September 1, 2022. https://www.nytimes.com/2022/09/01/us/california-heat-wave-flex-alert-ac-ev-charging.html.; Institute for Energy Research. "Europeans Plan on Banning EV Charging to Avoid Blackouts." American Energy Alliance, December 6, 2022. https://www.americanenergyalliance.org/2022/12/europeans-plan-on-banning-ev-charging-to-avoid-blackouts/.; Kurmayer, Nikolaus J. "EV Chargers, Heat Pumps May Be Curtailed in Germany as of 2024." Euractiv, November 29, 2023. https://www.euractiv.com/section/electricity/news/ev-chargers-heat-pumps-may-be-curtailed-in-germany-as-of-2024/.

FIGURE 15: PROJECTED MINERAL SUPPLY VS PROJECTED DEMAND NEEDS



Source: https://arxiv.org/abs/2309.15368

MINERALS SOURCING

Yet another limitation on electric vehicle growth is the amount of material inputs required to manufacture an electric vehicle. Electric vehicles are six times more mineral-intensive than comparable internal combustion vehicles.[60] This is a problem for the mass production of electric vehicles because the sourcing and supply chains of these minerals are not the same as those in the traditional auto industry.

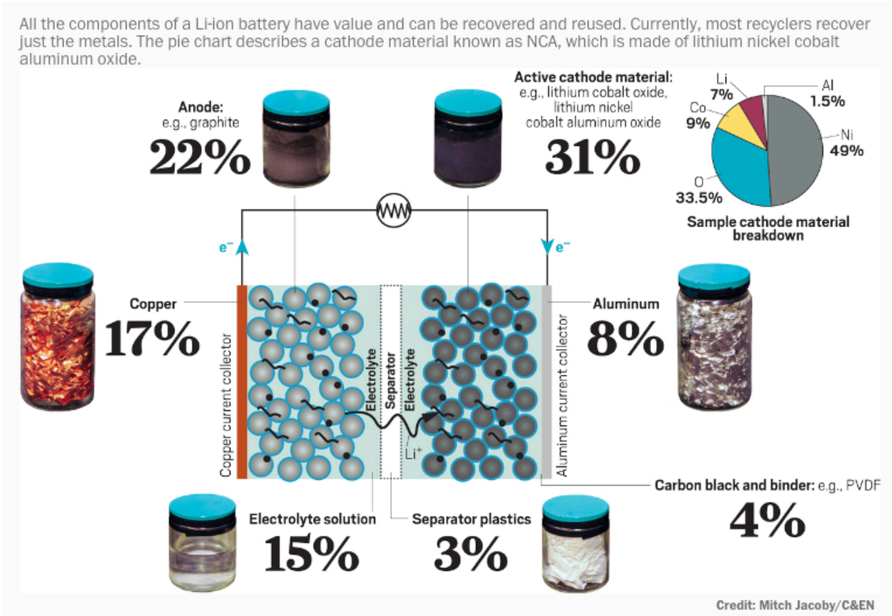
While the supply of most battery materials is, in theory, plentiful in the earth's crust, it all must still be mined and processed. However, bringing a new mine into production takes years or even decades, assuming no environmental permitting delays. Irrespective of prices, there is only a finite capacity to produce the mineral inputs required for an electric vehicle, particularly for a vehicle's battery. In the long term, supply is likely not a problem, but in the short term, it is very much a limitation on the number of electric vehicles that can be produced.

Figure 15 illustrates this supply problem for U.S. electric vehicle production. The current supply is far below what is required, even for a low EV sales scenario. The study even models an "Added Supply" scenario where an increase equivalent to 20% of the annual production of the top global producer of each mineral is assumed. But even with such a theoretical immediate supply boost, mineral requirements for assumed higher sales targets fall far short of requirements.

This would not matter as much in a normal market because as demand slowly grows over time, supply could be expanded to meet it. However, in an industry where

60 Hillberg and Hall 2021

FIGURE 16: BATTERY RECYCLE COMPONENTS



Source: Argonne National Laboratory, https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28

governments are aggressively subsidizing and mandating electric vehicles to force the pace of adoption, short-term supply constraints will have an impact. If carmakers cannot secure the supplies they need, they simply will not be able to produce as many cars as governments may want.

The national security element, discussed more extensively elsewhere in the paper, also deserves mention. China dominates the supply chains for electric vehicle battery minerals and has already shown a willingness to use this dominance as a weapon.[61, 62] In the event of abrupt supply cuts, the manufacture of electric vehicles would have to halt as it is impossible to simply open new mines the next day.

BATTERY RECYCLING IS LIMITED

Some electric vehicle advocates have presented the recycling of batteries as a solution to this problem of mineral sourcing. However, recycling lithium-ion batteries is very marginal economically. Most of the value from recycling is extracted from other metals, like cobalt. Today, it is estimated that 1-2% of lithium-ion batteries are recycled. McKinsey developed a model for the World Economic Forum that assumes 54% of lithium-ion batteries will be recycled by 2030. This would cover only 7% of lithium demand, and recycling capacity would need to increase by a factor of 25.[63] Based on the technical and economic hurdles, even this mere 7% recycled target seems unrealistic.

61 Bradsher, Keith. "Amid Tension, China Blocks Vital Exports to Japan." The New York Times, September 23, 2010. https://www.nytimes.com/2010/09/23/business/global/23rare.html.

62 Benson, Emily, and Thibault Denamiel. "China's New Graphite Restrictions." CSIS, October 23, 2023. https://www.csis.org/analysis/chinas-new-graphite-restrictions.

63 "A Vision for a Sustainable Battery Value Chain in 2030." World Economic Forum, September 2019. https://www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf.

Recycling lithium-ion batteries is a very complex technical and economic challenge. Lithium batteries combine many different minerals and chemicals, such as cobalt, nickel, lithium, aluminum, manganese, copper, graphite, and various polymers.

Recycling a lithium-ion battery can be dangerous and create other environmental issues. Some components of the used battery are flammable, which can cause safety issues. End-of-life lithium batteries represent a significant environmental risk, and used lithium-ion batteries are considered hazardous waste.

First, the battery must be discharged at the recycling center. There are several methods, but the most cost-effective solution is to utilize a brine bath, creating a waste stream that needs to be treated. The next step is to shred and grind the discharged battery to prepare it for further treatment to extract the individual components. The extraction process creates several different environmental issues. The pyrometallurgical extraction method utilizes high temperatures, producing carbon dioxide and harmful gases. The hydrometallurgical method of extraction utilizes acid liquification and creates water pollution.

Extended Producer Responsibilities (ERP) policies place the ultimate responsibility for end-of-life (EOL) batteries on the car company. As a result, car companies are developing a strategy involving partnerships with recycling companies. EOL batteries still have 60-70% capacity, so there are also efforts to develop outlets for secondary use for less demanding applications. However, recycling used batteries to recover the primary minerals will be challenging economically and create a new environmental challenge – water pollution, toxic air pollution, and greenhouse gas emissions.

It is clear that, at least in the near term, battery recycling cannot hope to meet the resource needs of a rapid forced transition to electric vehicles. In the future, new processes may be developed to improve the recycling process, but that does not address today's needs. On the timelines envisioned by electric vehicle advocates, mineral sourcing issues, with their attendant national security concerns, will be a major issue hanging over electric vehicle manufacturing.

It is clear that, at least in the near term, battery recycling cannot hope to meet the resource needs of a rapid forced transition to electric vehicles. In the future, new processes may be developed to improve the recycling process, but that does not address today's needs.

SAFETY LIMITATIONS AND QUESTIONS

There are open safety questions about electric vehicles that have the potential to place limits on adoption. The most prominent of these issues relates to fire safety, but there are also concerns about road safety for electric vehicles. Roads, bridges, and barriers are not designed with heavier EVs, whose fires may be difficult to extinguish, in mind.

The data regarding vehicle fires from EVs and conventional cars is incomplete. Many stories in the media sensationalize EV fires, while other sources claim that, statistically, EV fires are less likely. While we cannot say definitively that EVs are more or less prone to fires, EV fires do occur and are much different from conventional car fires. The nature of an EV fire makes them more dangerous when they do occur. The root cause of an EV fire is the lithium-ion battery. A lithium-ion battery fire is a chemical fire. It creates a thermal runaway that gets extremely hot and difficult to extinguish. These fires can happen spontaneously and reignite. To extinguish these fires involves flipping the car and flooding the battery with water for up to 24 hours, which might be difficult in a garage setting. Total immersion of the car or battery is recommended to prevent re-ignition. EV battery fires can last for hours or even days. These battery fires can be started by puncturing the battery (accident) or a recharging mishap. There have also been incidents of EVs with saltwater damage from floods igniting.[64] The "spontaneous" nature of these fires makes it challenging to predict when the car might ignite.

The potential hazards from lithium-ion battery fires might be best exemplified by the fire on the cargo ship "Felicity Ace." In February 2022, the ship was transporting 4,000 vehicles from Germany to the U.S., many of which were electric vehicles with lithium-ion batteries. A fire that could not be extinguished (lasting 13 days) broke out, and the cargo ship sank.

The captain of the ship claimed the fire was ignited by the EVs. Volkswagen claimed it was too early to know. However, the EV lithium-ion batteries played a role in the propagation of the blaze and the inability to extinguish it.[65]

Electric vehicle fires may or may not occur more often than conventional cars. However, the fire is much more dangerous and difficult to extinguish when they do occur. Manufacturers will undoubtedly add more safety features to the design of the battery, but the nature of the lithium-ion battery will never change. This risk will always exist as long as lithium-ion batteries are the battery technology of choice. Safety mitigation measures to reduce the risk for real-world applications that could result in catastrophic fires need to be implemented, especially where EVs are in dense proximity to each other – i.e., parking lots or transporting on trucks and ships.

The potential hazards from lithium-ion battery fires might be best exemplified by the fire on the cargo ship "Felicity Ace." In February 2022, the ship was transporting 4,000 vehicles from Germany to the U.S., many of which were electric vehicles with lithium-ion batteries. A fire that could not be extinguished (lasting 13 days) broke out, and the cargo ship sank.

Road safety is another area where the growth of electric vehicles is exposing problems. In a previous section, infrastructure wear from heavier electric vehicles was discussed. This wear on roads and bridges can lead to safety problems for all vehicles, including tire flats or accidents caused by degraded roadways. Current roadways are simply not designed or built for the weight of electric vehicles. But it's not just roadways not intended for heavy electric vehicles; safety infrastructure around roadways, like

64 Cerullo, Megan. "As Hurricane Idalia Caused Flooding, Some Electric Vehicles Exposed to Saltwater Caught Fire." CBS News, September 1, 2023. https://www.cbsnews.com/news/hurricane-idalia-electric-car-caught-fire-tesla/.

65 "Burning Ship Carrying Lithium EV Cars Sank Outside of the Azores." CTIF, March 12, 2022. https://www.ctif.org/news/burning-ship-carrying-lithium-ev-cars-sank-outside-azores.

guardrails, are likewise not designed with electric vehicles in mind. Recent preliminary testing recorded heavy electric vehicles breaking through representative guardrail systems due to their greater weight and lower centers of gravity as compared to conventional vehicles.[66] Upgrading or redesigning roads and guardrails will take time as well as funding.

In addition, the extra weight of EVs heightens the safety risk regarding crash fatalities. Especially in the case that a heavier EV crashes into a conventional car, which is much lighter. A 2011 study from the National Bureau of Economic Research estimated that a 1,000 lb. increase in vehicle weight resulted in a 47% increase in fatality risk.[67] While some experts have raised this safety issue, the long-term impacts are still highly uncertain.[68]

While these risks may be mitigated over time with improved battery compartment shielding, more efficient batteries, and upgrades to road infrastructure, these safety questions could limit the public appeal of electric vehicles and leave open the potential for limitations on electric vehicle use or storage.

A 2011 study from the National Bureau of Economic Research estimated that a 1,000 lb. increase in vehicle weight resulted in a 47% increase in fatality risk. While some experts have raised this safety issue, the long-term impacts are still highly uncertain.

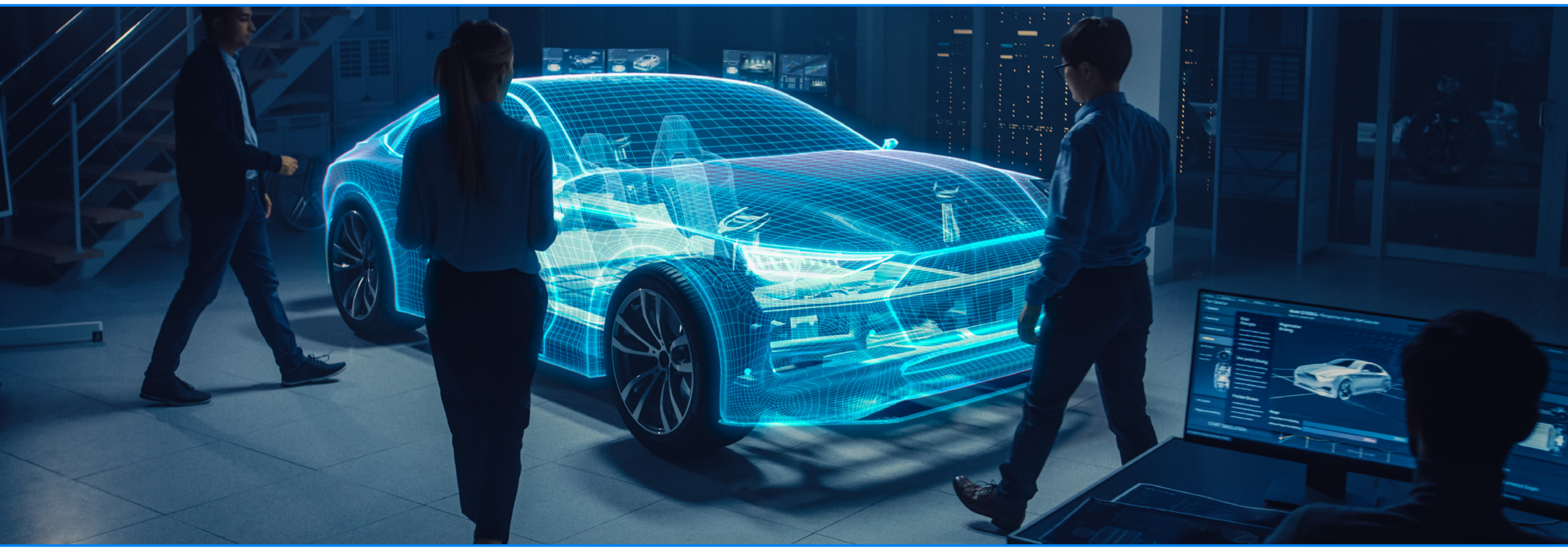
66 Beck, Margery A. "Crash Tests Indicate Nation's Guardrail System Can't Handle Heavy Electric Vehicles." AP News, January 31, 2024. https://apnews.com/article/electric-vehicles-crash-test-guardrails-nebraska-3ec299a7ad87d0f63a6dd9357f663fce#.

67 Anderson, Michael, and Maximilian Auffhammer. "Pounds That Kill: The External Costs of Vehicle Weight." National Bureau of Economic Research, June 23, 2011. https://www.nber.org/papers/w17170.

68 Proskow, Jackson. "Why the 'significant' Weight of Electric Vehicles Is Sparking New Safety Fears - National." Global News, April 12, 2023. https://globalnews.ca/news/9587791/electric-vehicle-weight-safety-risk/.

SECTION 4

THE MYTHS FUELING ELECTRIC VEHICLE POLICY



Much of the discussion around electric vehicle adoption is fueled by talking points from organizations advocating for it and companies hoping to profit from a forced transition. It is worth examining some of the most prominent claims about electric vehicles more closely because they are seemingly more myth than fact.

EV FUEL COST SAVINGS ARE OFTEN MISLEADING

Every new car sold includes an EPA window sticker on the fuel efficiency of the vehicle. Electric vehicles have their own EPA window sticker claiming significant fuel cost savings, but these calculations are misleading. The stickers read more as advocacy, pushing the narrative that electric vehicles are better for consumers. Although the calculations themselves are correct, the assumptions in the small print led to an unfair comparison.

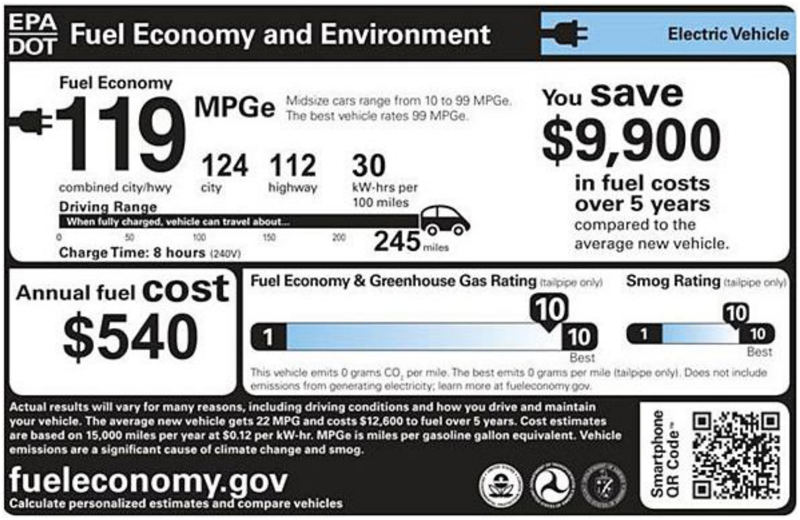
The following summarizes some of the assumptions in the small print:

Annual Fuel Cost ($540) – In the small print, this is based on an electricity cost of $0.12 per kWh. Electricity prices can vary, but in California, for example, average residential electric prices are $.34 per kWh.[69] Utilizing the California average would increase the annual fuel cost almost threefold to $1,530. U.S. household average electric prices in 2024 were $.16 per kWh,[70] significantly higher than the price used for the sticker calculation.

69 "Rankings: Average Retail Price of Electricity to Residential Sector, June 2024 (Cents/kWh)." U.S. Energy Information Administration (EIA). https://www.eia.gov/state/rankings/?sid=US#/series/31.

70 "Average Prices of Electricity to Ultimate Consumers." U.S. Energy Information Administration (EIA). https://www.eia.gov/totalenergy/data/monthly/pdf/sec9_11.pdf.

FIGURE 17: TESLA – MODEL 3 EPA WINDOW STICKER



Source: https://upload.wikimedia.org/wikipedia/commons/6/68/EPA_Label_Tesla_Roadster-2_5_119mpge.jpg

Five-Year Savings ($9,900)—This calculation assumes 15,000 miles per year for five years. In the small print, the average gasoline vehicle with a mileage efficiency of 22 mpg is used as a comparison. A more comparable gasoline car (BMW 3) has a mileage efficiency of 30 mpg. Hybrid cars in this category have even better mileage efficiency (50 mpg). Yet the EPA sticker deliberately chooses a less efficient vehicle for comparison.

The $9,900 savings for an EV vs. a conventional car drops to $6,540 compared to a car in the same class as a BMW 3. It drops even further to $2,844 compared to the Hyundai Sonata Hybrid. In the case of the California five-year electric cost ($.33/kWh vs. $.12/kWh), the savings of $9,900 dropped to $5,175. The hybrid is even $1,881 cheaper when a realistic electric cost is used.

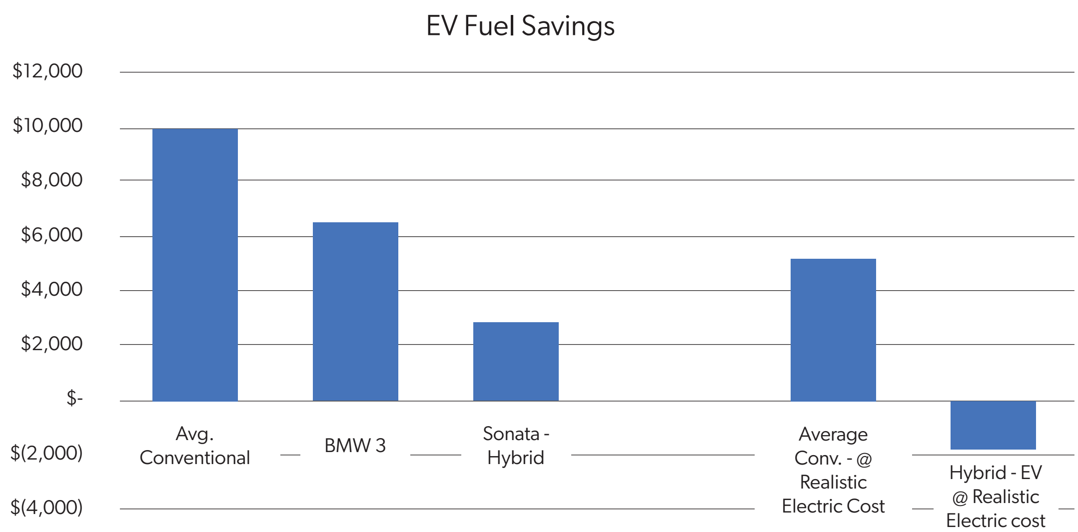
MPGe (112 MPGe) - Miles Per Gallon Equivalent (MPGe) is a term developed by the EPA to compare the mileage efficiency of an electric vehicle to a conventional vehicle. To make this mileage comparison, the electric energy efficiency of the EV needs to be converted. The conversion factor is that one gallon of burned gasoline produces the same amount of heat energy as 33.7 kWh of electricity (33.7 kWh/gallon gasoline). Therefore, an EV that can travel 100 miles on 33.7 kWh of electricity would be rated at 100 MPGe.

This Tesla can travel 100 miles on 30 kWh of electricity, equivalent to 112 MPGe highway. These sky-high MPGe numbers would seem to indicate that an EV's energy efficiency, based on this sticker, is approximately five times better than that of a conventional vehicle (112 MPGe vs. 22 MPG).

This characterization leaves out an important factor. Although the Tesla utilizes 30 kWh of electric output, it consumes 73 kWh of power input. Only about 41% of the energy input in electric power plants is converted to electric output.[71] Electric power plants lose 59% of the energy input

71 "U.S. Energy Consumption by Source and Sector, 2023." U.S. Energy Information Administration (EIA). https://www.eia.gov/energyexplained/us-energy-facts/images/consumption-by-source-and-sector.pdf.

FIGURE 18: COMPARING THE EV FUEL COST SAVINGS VS. BMW 3 AND A HYUNDAI SONATA HYBRID, EPA WINDOW STICKER - MISLEADING FUEL COST SAVINGS



due to heat, mechanical, and transmission losses. Based on 73 kWh of power input, the MPGe for the Tesla would be about 46 MPGe (vs. 112 MPGe). This is a much more accurate reflection of the milage efficiency compared to conventional and hybrid vehicles.

In concert, these three misleading numbers present electric vehicle ownership as a substantial financial winner. Using more realistic assumptions and comparisons, the cost savings are limited or even nonexistent.

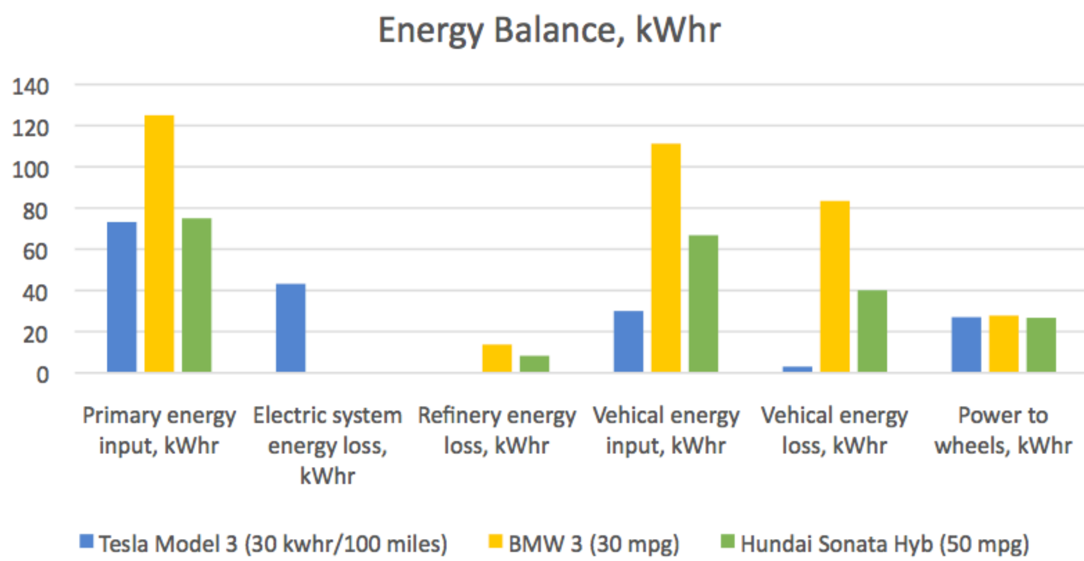
THE ENERGY EFFICIENCY OF ELECTRIC VEHICLES IS DEBATABLE

Electric vehicle advocates frequently proclaim how "energy efficient" electric vehicles are. Often, they use the misleading concept of MPGe, which is discussed above. However, energy balance is a better standard for comparing the energy efficiency of electric vehicles vs. conventional vehicles. Energy balance is a fundamental engineering concept where the energy into a system must equal the energy out of the system. This concept can be used to evaluate the energy efficiency of electric, conventional, and hybrid vehicles.

The figure below applies this concept to three vehicles: a Tesla Model 3, a BMW 3, and a Hyundai Sonata Hybrid. It assumes that each vehicle will need approximately the same amount of energy applied to the wheels to drive 100 miles. The EPA conversion factor of 33.7 kWh/gallon of gasoline is used to compare each vehicle.

The energy balance analysis punctures the claim that an electric vehicle is much more efficient than a conventional or hybrid vehicle. The electric vehicle itself only loses 10% of the energy that goes into the vehicle during use because it is very efficient in delivering power to the wheels. This comparison is most often expressed in journals, magazines, and government literature promoting electric vehicle efficiency. However, most of the energy loss (59%) for an electric vehicle is in the electrical power system and is often

FIGURE 19: ENERGY EFFICIENCY OF ELECTRIC VEHICLES VS. CONVENTIONAL & HYBRID VEHICLES



overlooked. The electrical power system loses energy due to heat and mechanical energy used to generate electricity.

Conventional and hybrid vehicles do not utilize the electrical power system and have no losses due to the electrical system. The gasoline is delivered directly to the vehicle with a slight energy loss in the refinery (11%). Since these vehicles use an internal combustion engine, most of the energy is lost in the vehicle itself. The conventional ICE vehicle loses 75% of the energy that goes into the vehicle compared to only 10% for the EV. The hybrid is more efficient than the conventional ICE vehicle but still loses 60%.

When the energy balance is based on primary energy input, the Tesla energy efficiency is 53% better than the BMW at 30 mpg. However, the Hyundai Sonata Hybrid mpg and Tesla are virtually the same.

THE SIZE OF THE EV CARBON FOOTPRINT IS DEBATABLE

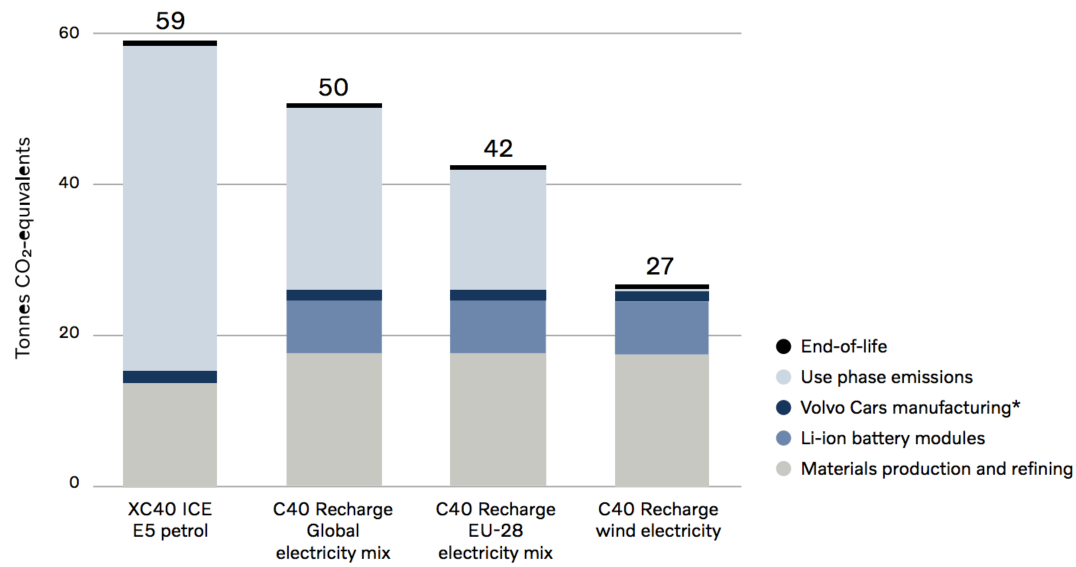
Electric vehicles still have a significant carbon footprint. Although the tailpipe emissions of an electric vehicle are zero, the carbon dioxide emissions related to the production of an electric vehicle battery and the electricity produced to power an electric vehicle are significant. A Life Cycle Assessment (LCA) is a methodology used by car companies and industry consultants to calculate the carbon footprint from materials used in production to end-of-life.

An example comes from Volvo, which performed a Life Cycle Assessment (LCA) comparing its C40 electric vehicle to the XC40 conventional vehicle. The results of this study for several different scenarios are shown below.[72]

The study does show that the C40 EV has an advantage over the conventional XC 40 in all cases. However, this advantage

72 "Carbon Footprint Report – Volvo C40 Recharge." Volvo. https://www.volvocars.com/images/v/-/media/Market-Assets/INTL/Applications/DotCom/PDF/C40/Volvo-C40-Recharge-LCA-report.pdf.

FIGURE 20: VOLVO'S LIFE CYCLE ASSESSMENT - C40 RECHARGE (EV) VS. XC40 ICE (CONVENTIONAL VEHICLE)



** Volvo Cars manufacturing includes both factories as well as inbound and outbound logistics.*

Figure ii. Carbon footprint for C40 Recharge and XC40 ICE, with different electricity mixes.
Results are shown in tonnes CO_2-equivalents per functional unit (200,000km total distance, rounded values).

Source: https://www.volvocars.com/images/v/-/media/Market-Assets/INTL/Applications/DotCom/PDF/C40/Volvo-C40-Recharge-LCA-report.pdf

is very different depending on how the electricity is produced. The global electricity mix reflects that much of the electricity worldwide is coal-based (40%). In fact, regions with higher proportions of coal-based electricity, such as China and India, have no advantage over electric vehicles.

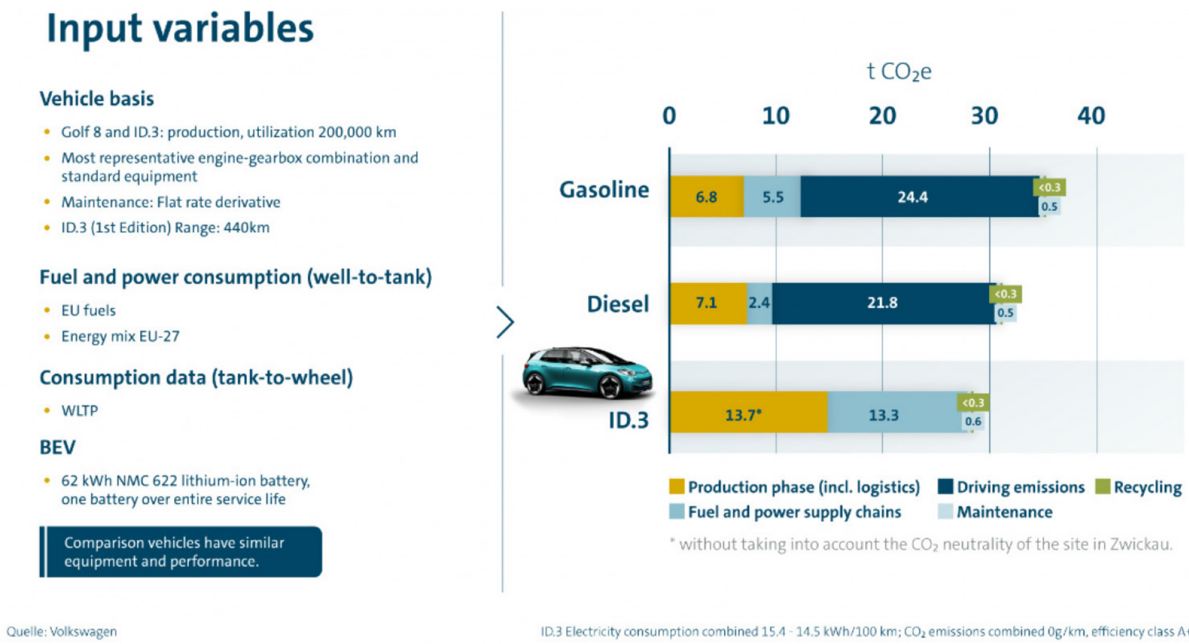
The EU-28 electricity mix is more like the electricity mix in the U.S. (20% coal-based). In this case, an electric vehicle has approximately a 25% lower carbon footprint than a conventional car. The wind electricity mix shows the most optimistic scenario since there are no CO2 emissions from electricity generated from a renewable resource. There are cases, such as Norway, that use a high percentage of hydropower that approach this case. But for most places in the world, this is unrealistic.

The study also shows that emissions from the production phase of an EV (mining, metal refining, chemical precursors, and battery modules) are significantly higher than a conventional car. The C40 EV has approximately 70% higher carbon footprint vs. a conventional car. The XC 40 conventional car carbon footprint breaks even with the C40 EV carbon footprint at 68,400 miles. In other words, the XC 40 conventional fossil fuel car must drive 68,400 miles (approximately 4-5 years of everyday driving) before it overcomes the carbon footprint penalty to manufacture the C 40 EV.

A similar LCA study was performed by Volkswagen (comparing the ID 3 to Golf gasoline and diesel models).[73] The ID 3 (EV) had 20% lower carbon footprint vs. the Golf

73 "E-Mobility Is Already This Climate Friendly Today." Volkswagen Newsroom, February 8, 2021. https://www.volkswagen-newsroom.com/en/stories/e-mobility-is-already-this-climate-friendly-today-6805.

FIGURE 21: VOLKSWAGEN'S LIFE CYCLE ASSESSMENT ID.3 (EV) VS. GOLF (CONVENTIONAL)



gasoline vehicle, but only 10% vs. Golf diesel vehicle.

The study also confirms the high carbon footprint associated with the production phase of an electric vehicle (mining, metal refining, chemical precursors, and battery modules). The ID3 C40 electric vehicle has approximately double (100%) higher carbon footprint vs. a conventional car.

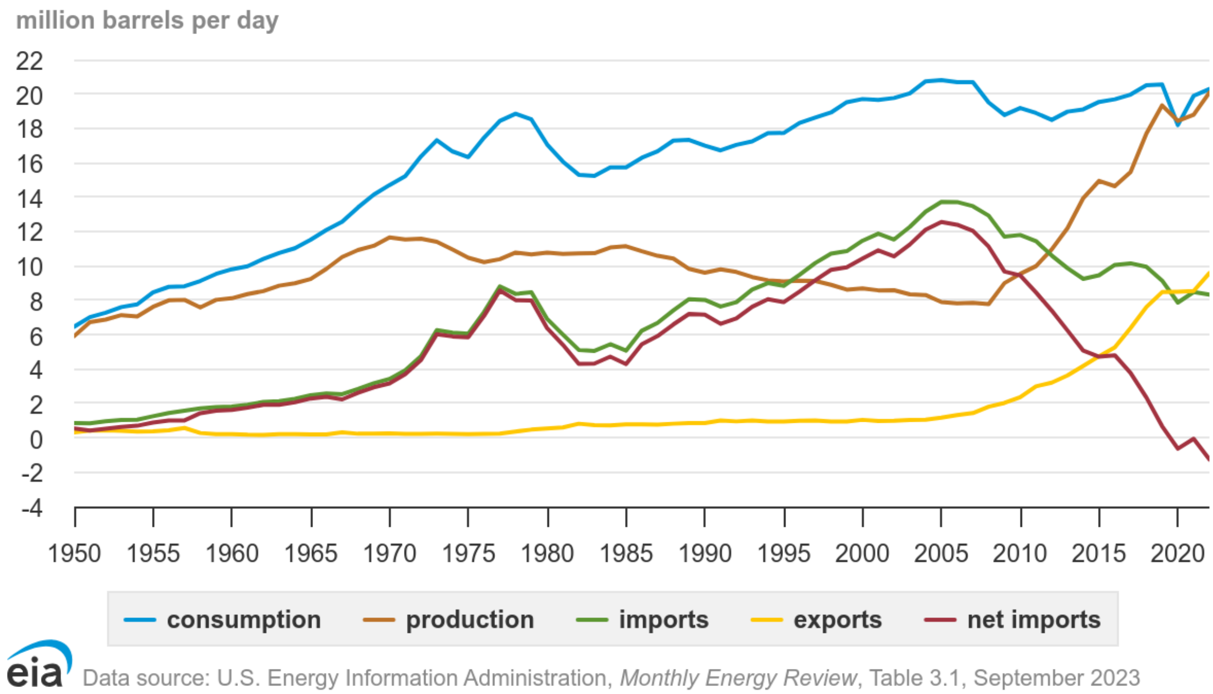
All sources agree that there is a carbon footprint penalty in the production of an electric vehicle versus a conventional ICE vehicle. The breakeven point varies – a Ford & Michigan University study reported 1.5 to 2 years to break even compared to a conventional car (18,000 – 24,000 miles) and 3 to 4 years to break even (36,000 – 48,000 miles) with a hybrid vehicle.[74] The CEO of Stellantis, Carlos Tavares, stated that an electric vehicle needs to be driven 44,000 miles to break even with the added footprint from manufacturing.[75]

Life Cycle Assessments are very sensitive based on the assumptions used in the analysis. For example, battery size and design can affect this calculation. Trends toward larger batteries and batteries with more nickel content would negatively impact the comparison of an EV to a conventional car. The trend towards sourcing and producing nickel from Indonesia (80% coal-based power) would also negatively affect the comparison. The amount of battery precursor and battery manufacture in China (60% coal-based power) would also have a negative effect. The MIT Climate Portal affirmed this large variation in October 2022, reporting that

74 Woody, Maxwell, Parth Vaishnav, Gregory A. Keoleian, Robert De Kleine, Hyung Chul Kim, James E. Anderson, and Timothy J. Wallington. "Corrigendum: The Role of Pickup Truck Electrification in the Decarbonization of Light-Duty Vehicles." *Environmental Research Letters* 17 (July 15, 2022). https://doi.org/https://iopscience.iop.org/article/10.1088/1748-9326/ac7cfc.

75 Unrau, Jason. "Stellantis CEO Carlos Tavares on EV Push: 'Chosen by Politicians, Not by Industry.'" CBT News, January 20, 2022. https://www.cbtnews.com/stellantis-ceo-carlos-tavares-on-ev-push-chosen-by-politicians-not-by-industry/.

FIGURE 22: U.S. DOMESTIC OIL PRODUCTION VS EXPORTS



Source: https://www.eia.gov/energyexplained/oil-and-petroleum-products/imports-and-exports.php

production of an 80-kWh battery can vary from 2.5 to 16 metric tons of CO2 equivalent.[76]

Given the large body of research, it is clear the CO2 reduction for electric cars is not nearly as great as advertised. There is no, or minimal, advantage in the cases where electricity is primarily produced from coal power plants. The advantages may even be smaller if other factors are considered – destruction of the rainforest or increased tire replacements. Tire raw materials and production are very energy and material intensive. For example, one tire is estimated to consume seven gallons of oil to produce.[77]

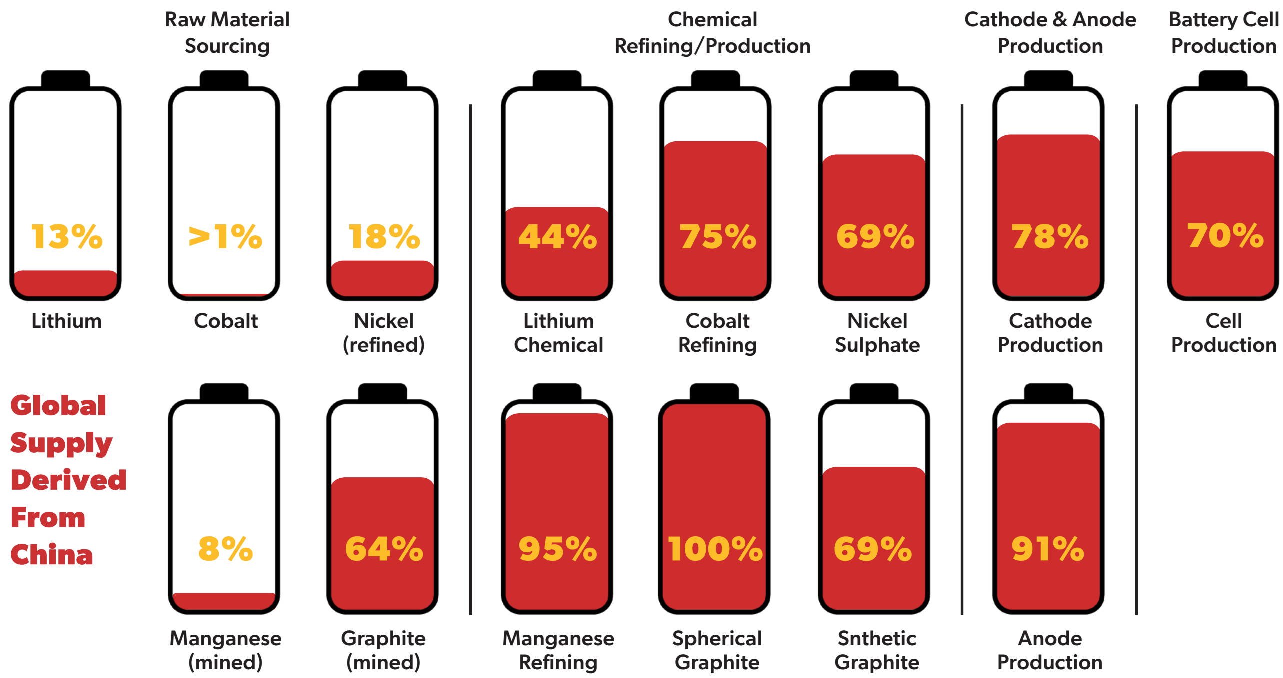
ELECTRIC VEHICLES ARE NOT BETTER FOR NATIONAL SECURITY

A myth that has become a frequent talking point in recent policy debates is that electric vehicles are better for national security. A prominent example of this was during the debate on the misleadingly named Inflation Reduction Act, which includes large taxpayer subsidies for electric vehicles and electric vehicle battery manufacturing. The claim goes that cars that run on oil harm national security because of "dependence" on foreign oil, while electricity is made in America. But this claim is ill-informed on two counts: the U.S.

76 Moseman, Andrew. "Are Electric Vehicles Definitely Better for the Climate than Gas-Powered Cars?" MIT Climate Portal, October 13, 2022. https://climate.mit.edu/ask-mit/are-electric-vehicles-definitely-better-climate-gas-powered-cars.

77 Szabo, Agota. "How Much Oil Is Needed to Make One Car Tire?" TireMart.com, July 13, 2022. https://blog.tiremart.com/how-much-oil-make-one-car-tire/.

FIGURE 23: U.S. BATTERY MODULES SUPPLY CHAIN



Source: https://www.greencarcongress.com/2022/10/20221009-benchmark.html

is no longer dependent on foreign oil, and while electricity may be generated in the U.S., the electric vehicle supply chain is very much not located in the U.S.

In the last 15 years, the U.S. has massively increased domestic oil production, setting new records and becoming a net oil exporter in 2019. Even of the remaining imports that still come into the country, a majority come from Canada and Mexico, and much of that imported crude oil is simply refined and reexported. Domestic production capacity shows no signs of falling anytime soon as the shale revolution has opened vast deposits of domestic oil supplies. The U.S. is energy secure when it comes to oil, so efforts to reduce its use actually undermines national security.

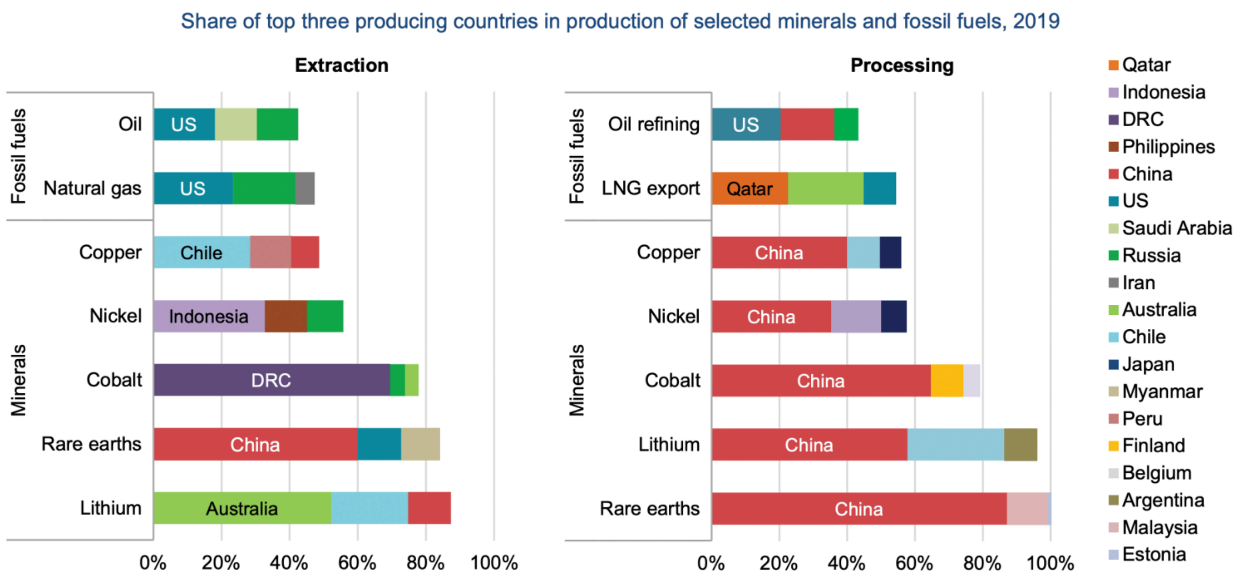
In contrast, the supply chain for electric vehicles is overwhelmingly located outside the U.S. While much of the final assembly of vehicles occurs domestically, the inputs for that assembly come from overseas. China currently dominates these supply chains.

China also dominates the mineral supply chains for electric vehicles.

To the extent that electric vehicles operate on electricity from wind and solar generation, the supply chains of those industries are likewise dominated by China.[78] In theory, this could change if the U.S. elected to mine and process more minerals domestically, but in the near term, a rapid transition to electric vehicles is a rapid transition to a greater dependence on China.

78 Institute for Energy Research. (2023). *The economic and strategic importance of domestic mineral production.* Retrieved from https://www.instituteforenergyresearch.org/wp-content/uploads/2023/04/The-Economic-and-Strategic-Importance-of-Domestic-Mineral-Production.pdf

FIGURE 24: MINERAL PRODUCTION SUPPLY CHAIN



Notes: LNG = liquefied natural gas; US = United States. The values for copper processing are for refining operations.

Source: International Energy Agency World Energy Outlook Special Report

RENEWABLES WILL NOT MEET EV ELECTRICITY DEMAND

Another myth in the electric vehicle discussion is that renewable electricity generation, by which most advocates mean wind and solar, can and will provide all the electricity generation the U.S. needs going forward. This is often presented as a response to the bursting of some of the other myths in this paper, such as the CO2 emissions myth or the national security myth. However, it is entirely unrealistic to believe that wind and solar generation will meet the increased electricity demand from the forced adoption of electric vehicles.

As discussed in this paper, the U.S. electric grid is already struggling to meet current demand. Wind and solar advocates claim that wind and solar can meet most U.S. electricity demand within mere decades. However, wind and solar must meet unprecedentedly high growth targets simply to account for that existing electricity demand. Electric vehicle electricity demand will be on top of existing demand.

The cost of this massive increase in generation is vast, and trillions of dollars more in transmission investment would also be required to make a wind and solar-heavy grid work.[79] Even if the money is found, there are limitations to the pace

79 Institute for Energy Research. (2023). *The challenges and costs of net zero and the future of energy.* Retrieved from https://www.instituteforenergyresearch.org/wp-content/uploads/2023/08/THE-CHALLENGES-AND-COSTS-OF-NET-ZERO-AND-THE-FUTURE-OF-ENERGY.pdf

of growth due to land use and mineral availability. Balancing this intermittent load as wind and sun come and go is an enormous technical challenge. Wind and solar growth have not even been able to keep pace with the retirements of firm generation in recent years.[80]

In the near term, absent massive policy and political changes in the U.S., it is simply not possible for wind and solar generation capacity to grow at the pace required to support a rapid transition to electric vehicles fully. If then, as is likely, increased electricity demand from EVs is met by coal or natural gas generation, it ultimately undermines a fundamental justification for forcing that transition on American consumers in the first place.

In the near term, absent massive policy and political changes in the U.S., it is simply not possible for wind and solar generation capacity to grow at the pace required to support a rapid transition to electric vehicles fully.

80 Howland, Ethan. "Up to 58 GW Faces Retirement in PJM by 2030 without Replacement Capacity in Sight: Market Monitor." Utility Dive, March 18, 2024. https://www.utilitydive.com/news/pjm-coal-gas-power-plant-risk-retirement-market-monitor/710518/.

SECTION 5

ADDITIONAL POLICY CONSIDERATIONS

ELECTRIC VEHICLES ARE NOT NEW

Former Senator and Secretary of State John Kerry once remarked that Thomas Edison would have praised government-led electrification, noting that "an energy revolution he envisioned is actually happening."[81] However, Edison was acutely aware of the limitations of battery power for transportation, as shown in a notable 1896 conversation with a budding automobile inventor.

Henry Ford recalled, "He asked me countless questions, and I sketched everything for him. I've always found that drawing conveys an idea more effectively than words." Edison's response was emphatic, accompanied by a fist on the table:

"Young man, that's it—you've got it. Stay the course. Electric cars need to be close to power stations. The storage battery is too cumbersome. Steam cars won't work either; they require a boiler and fire. Your vehicle is self-sufficient—it carries its own power source—no fire, no boiler, no smoke, no steam. You have the solution. Keep at it."

Ford later reflected, "That bang on the table meant everything to me."

Edison, the foremost authority on electricity, believed that for long-distance travel, the gas engine was superior to any electric motor—it could travel great distances, with stations ready to supply hydrocarbon fuel. This was during a time when electrical engineers widely accepted that nothing new or significant could exist without electricity as its power source. They envisioned it as the universal energy solution.

The rise of the internal combustion engine ultimately disrupted the electric vehicle market.[82] Historian David Hirsch noted in The Electric Vehicle and the Burden of History (2000) that in the late 1890s, steam, gasoline, and electric cars all vied for dominance in the emerging

81 Master Resource, "Edison and Kerry: Wrong on Electric Vehicles," https://www.masterresource.org/edison-to-enron-bradley/edison-kerry-wrong/.

82 Institute for Energy Research, "Electric Vehicles: Continued Government Dependency," https://www.instituteforenergyresearch.org/renewable/electric-vehicles-continued-government-dependency/.

FIGURE 25: CO_2 TAILPIPE EMISSIONS – HYBRIDS VS. CONVENTIONAL VEHICLES

	Average hybrid battery size	Average non-hybrid	Average hybrid CO_2	CO_2 reduction from hybrid
	kWh	**g/km**	**g/km**	**%**
EU	1.2	184	143	-23%
US	1.2	214	141	-34%
Average	1.2	203	142	-30%

Source: https://www.emissionsanalytics.com/news/hybrids-are-better

automobile industry. By the early 1900s, the competition had concluded, and internal combustion had solidified its position as the primary driving force of the twentieth century. Hirsch concluded, "Since 1902, no electric car—regardless of battery or drivetrain—has been able to compete effectively with its internal combustion rivals."

BETTER TRADE-OFF VALUE OF HYBRIDS

Most studies and media attention today compare EVs to conventional gasoline or diesel-powered cars. The push towards pure EVs has crowded the discussion on other power trains, such as hybrids. We can look to the Toyota Prius, launched in 1997, as an example of how hybrid technology is mature, widely available, and constantly improving.

Mild and full hybrids both recharge the battery through regenerative braking and through the engine. Since they don't need to be plugged in, they don't require a charging network. Additionally, they don't require a buildout of electric power plants or an expansion of the electric grid, all of which provides a tremendous advantage in terms of infrastructure cost savings. Also, there are no worries for apartment and condo dwellers and renters, who don't often have easy access to overnight recharging facilities.

Hybrids utilize batteries that are ten-to-100 times smaller than an EV. Making many one to two-kWh batteries is a more efficient use of scarce mineral resources vs. making a few 60-kWh batteries. Sixty hybrid vehicles can reduce more CO2 than one electric vehicle.

The CO2 reduction per unit of battery size is a crucial metric. A full hybrid reduces CO2 by only 65 g/km vs. 210 g/km for the EV. However, the CO2 reduction per unit of battery size shows the full hybrid to be much more efficient at 50.5 g/km/kWh vs. 3.5 g/km/kWh. The full hybrid is 14 times more efficient in reducing CO2 per unit of power output (kWh). Based on the limitations of the availability of batteries and battery materials discussed above, hybrid vehicles offer an attractive option if the goal is to reduce tailpipe emissions.

The adoption rate of hybrids would likely be much faster than that of EVs. Hybrids are a mature technology that is already widely accepted in the marketplace. There is no concern regarding vehicle range and refueling. There are no shortages of raw materials. There is no need to destroy the environment in developing regions through massive mining expansion. There is no need for child labor. There is no need to rely on China. There is no need to build renewable power plants or charging stations.

FIGURE 26: CO_2 TAILPIPE EMISSIONS – HYBRIDS, EVS VS. CONVENTIONAL VEHICLES

	Vehicle tested	Average of battery size	Average CO_2 reduction	CO_2 reduction per unit of battery size
	#	kWh	g	g/km/kWh
Mild hybrid	7	0.4	25	73.9
Full hybrid	59	1.3	65	50.5
Plug-in hybrid - most engine	29	10.5	43	4.0
Plug-in hybrid - 50% engine	29	10.5	126	12.0
Plug-in hybrid - mostly battery	29	10.5	210	19.9
Battery electric vehicle*	n/a	60.0	210	3.5

Source: https://www.emissionsanalytics.com/news/hybrids-are-better

If most cars on the road were as clean as a Prius, tailpipe emissions would be slashed by a third worldwide. This could be accomplished faster than transitioning to 100% EVs. EVs' full, positive supposed impact will not be realized for many years, if ever. The primary energy source to produce electricity today is fossil fuels (60%). Reducing this to 0% fossil fuels could take until the end of the century. Improving EV battery efficiency by 100 – 200% will take a paradigm shift in battery technology. Realizing gains from hybrid requires no such massive, speculative shifts.

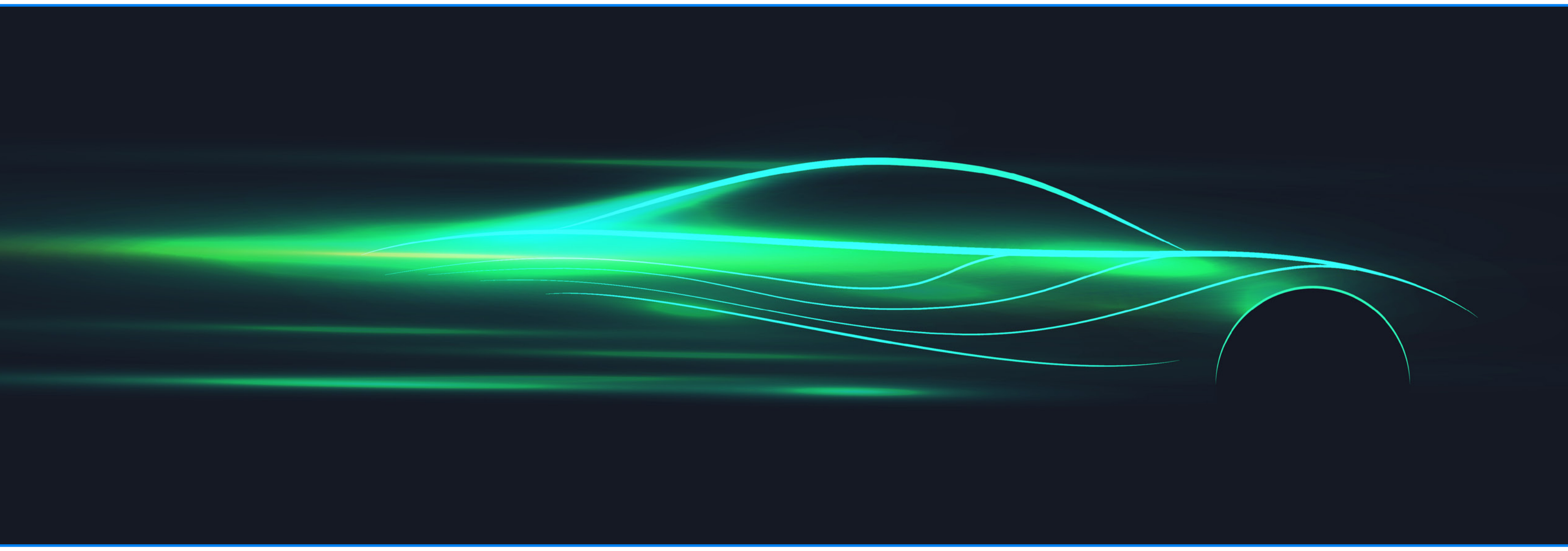
CONSUMER PREFERENCE, NOT GOVERNMENTS, SHOULD DRIVE THE FUTURE OF THE AUTOMOBILE MARKET

As the future of technological change is uncertain, public policy must prioritize consumer sovereignty as the guiding principle that should shape the automobile market. Consumers, with their diverse set of preferences and needs in automobiles, should be free to choose the type of vehicle that best suits their needs, and we should rely on the market process to determine the exact make-up of the automobile market. Consumer choices serve as signals to producers about what to supply. High demand for a product indicates its desirability, prompting businesses to produce more, while low demand can lead to reduced production and further innovation.

When consumers express their preferences, businesses are incentivized to innovate and improve product quality to attract customers. This drives competition and leads to better products and services. In a market driven by consumer choice, businesses must be accountable to their customers. If a company fails to meet consumer needs, it risks losing market share to competitors, encouraging firms to prioritize consumer satisfaction. Ultimately, consumer sovereignty ensures that the market responds to the needs and desires of individuals. It empowers consumers to make choices that reflect their values and preferences. Under this system, consumers can choose between ICE, hybrid, electric vehicles, or whatever the future holds with respect to transportation. This ensures that everyone maintains access to mobility, a feature of American life that has been fundamental to our dynamism and growth for over a century.

SECTION 6

CONCLUSION



Electric vehicle sales have been growing, and the product has established itself in the vehicle market. EVs can be an attractive choice for certain users and uses, such as a suburbanite with a garage and a regular daily commute to work. EVs as a market segment offer a valuable additional choice for those customers for whom the tradeoffs work. The policy question, though, is not whether EVs as a category are here to stay. The policy question is whether governments can force a 100% EV transition on the transportation market, and even if it is possible to achieve, whether such a forced transition would be beneficial.

As this report clearly shows, at least in the near term, a forced transition to 100% EVs is not possible. Consumer resistance in the United States is widespread, and the factors that cause that resistance, such as cost and range anxiety, are not subject to near-term solutions. Even if Congress were to create new legal authority to allow the government to override consumer choice, there are still practical limitations on the pace of growth that EVs can achieve in areas like mineral production and charging infrastructure. Those limitations are independent of the costs of an EV transition. Still, the high costs of a transition discussed in the paper also

As this report clearly shows, at least in the near term, a forced transition to 100% EVs is not possible. Consumer resistance in the United States is widespread, and the factors that cause that resistance, such as cost and range anxiety, are not subject to near-term solutions.

limit the pace of EV adoption because, ultimately, someone must pay for all those costs, whether it's consumers or governments. This near-term inability to achieve an EV transition in the U.S. should be more prominent in the policy and media discussion. It is frequently assumed that a rapid transition is already happening and inevitable.

In the longer term, there is at least the possibility that EVs can come to dominate the vehicle market. If the cost issues and physical limitations can be overcome, perhaps by hard-to-predict technological innovations, or at least mitigated, EVs might grow organically to dominate. Over long enough periods, consumer sentiments have the potential to change. Of course, EV competitors will also be innovating over the longer term, so it is impossible for policymakers today to know whether a new powertrain or transportation option may arise. A long-term potential for success, though, does not establish certainty today. Policies being put in place today that assume an all-EV future impose significant costs and distort markets negatively, all in support of an all-EV future that may never come.

Even if an all-EV future might be possible at some distant point, policymakers must grapple with whether such a future would be desirable. Despite how most media covers this question, there are tradeoffs involved with growing EV adoption. Far too often, climate change is the only consideration for EV supporters, though, as discussed in this paper, even by emissions measures, the case for EVs is not as strong as assumed. However, climate change is just one component of the policy discussion. Cost, flexibility, safety, reliability, national security, and many other factors covered in this paper are also part of the discussion. While EV boosters may believe that climate change outweighs all these other considerations, in a democratic system, the people also get a say, and for average Americans, the tradeoff calculation obviously is not working. This is not due to misinformation; indeed, as discussed in this paper's myth sections, there is plenty of pro-EV misinformation. It is simply that, as chronicled in this report, there are negative tradeoffs to EVs. In designing policy, these negative factors must be considered rather than simply ignored.

A better course would be to simply let markets work. Allow consumers and businesses to choose the best vehicles for their needs. Maintain safety and pollution standards, but within that framework, allow vehicle use and adoption to operate organically. By providing Americans with the most utility from vehicles, we will also derive the most societal benefit. Top-down directives have a long history of failure to achieve the desired goals while imposing large costs and creating resentment and harm to the regular people who bear the brunt of the regulations.

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