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Final Project Report

Identifying Targets for Electric Vehicle Industry Improvement: Infrastructure, Policy and Technological Solutions for a Sustainable Future

BY

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Electric vehicles (EVs) are globally recognized as a key strategy for reducing greenhouse gas emissions and decarbonizing the transportation sector. Regions have made significant progress in electrifying mobility; despite global momentum, adoption remains inconsistent. High upfront costs, insufficient charging infrastructure, battery performance concerns, and limited public awareness continue to present major challenges. This report presents a comprehensive review of these barriers based on a research effort drawing from global, national, and state-level studies. The findings are contextualized for the United States transportation ecosystem using international and national comparisons to identify scalable, effective policy and technology interventions. The research integrates global trends to ensure contextual relevance and broader applicability. The research is a behavioral study of vehicle choice to addresses the question of what characteristics of the electric vehicle environment should be identified for change to motivate people to adopt electric vehicles.</td></tr>
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EXECUTIVE SUMMARY

Electric vehicles (EVs) are globally recognized as a key strategy for reducing greenhouse gas emissions and decarbonizing the transportation sector. From Europe's ambitious bans on internal combustion engines to California's Zero Emission Vehicle (ZEV) mandates and Norway's aggressive tax exemptions, various regions have made significant progress in electrifying mobility. Yet, despite this global momentum, adoption remains inconsistent across regions. High upfront costs, insufficient charging infrastructure, battery performance concerns, and limited public awareness continue to present major challenges. This report presents a comprehensive review of these barriers based on a research effort drawing from global, national, and state-level studies. The goal is to contextualize these findings for the United States transportation ecosystem, using international and national comparisons to identify scalable, effective policy and technology interventions. The research integrates global trends to ensure contextual relevance and broader applicability. The research is a behavioral study of vehicle choice. The research addresses the question of what electric vehicle environment characteristics should be identified for change to motivate people to adopt electric vehicles.

INTRODUCTION

Electric vehicles (EV) are increasingly seen as the cornerstone of the global transition toward sustainable transportation. Governments around the world are enacting aggressive policies and investing in infrastructure to support widespread EV adoption. In Europe, Norway, the Netherlands, and the United Kingdom are leading the charge, offering substantial tax incentives and infrastructure rollouts that have pushed EV market shares above 70% in some regions. In the United States, California, New York, and Washington have implemented strong Zero Emission Vehicle (ZEV) mandates, incentivizing both consumers and manufacturers to accelerate the shift to electric mobility.

Despite this encouraging progress, significant challenges persist in the United States. As of 2023, EVs accounted for less than 10% of total vehicle sales nationwide, placing the country behind global leaders such as Norway, China, and several European Union nations. The U.S. landscape presents a diverse mix of opportunities and challenges due to its vast geography, varied climate zones, dependence on fossil fuel industries, and growing investments in renewable energy. Urban centers have shown promising growth in EV uptake, but many rural and underserved areas continue to lag due to infrastructure and affordability gaps. This research draws on global and national data to provide a comprehensive understanding of the key barriers impeding EV adoption across the U.S., with the goal of proposing scalable, policy-driven, and technological solutions to accelerate the nation's transition toward a sustainable, zero-emissions transportation system.

BACKGROUND

History of Electric Vehicles

The history of electric vehicles (EVs) in the United States spans over a century, reflecting cycles of innovation, decline, and resurgence. EVs were among the earliest automobiles introduced to the market, enjoying remarkable popularity in the late 1800s and early 1900s due to their quiet operation, ease of use, and the absence of the hand-crank starter that gasoline cars required (Santini, 2011). By 1900, electric cars made up approximately one-third of all vehicles on U.S. roads, particularly favored in urban environments where short-range travel was common.

However, the invention of the electric starter by Charles Kettering in 1912 eliminated the need to manual crank gasoline engines, significantly boosting the appeal of internal combustion engine (ICE) vehicles. Mass production innovations introduced by Henry Ford dramatically lowered the cost of gasoline cars, and the discovery of cheap, abundant oil further cemented the ICE dominance. By the 1930s, EVs had all but disappeared from American roads.

The oil crises of the 1970s sparked renewed interest in electric mobility as fuel prices surged and national security concerns around energy dependence intensified. Several prototypes and limited-production EVs were introduced, yet these efforts were hampered by limited battery range, high production costs, and a lack of charging infrastructure. This wave, much like the first, faded by the 1980s.

The modern EV renaissance began in earnest in the early 21st century, driven by mounting concerns over climate change, technological advancements, and stronger government support. The development and commercialization of lithium-ion batteries in the 1990s provided the breakthrough needed for practical EV range and performance. The release of the Tesla Roadster in 2008 and subsequent mainstream models like the Nissan Leaf and Chevrolet Bolt reshaped public perception, marking the true arrival of EVs as a viable alternative to gasoline-powered cars.

The research underscores that the combination of environmental policy mandates, such as Corporate Average Fuel Economy (CAFE) standards and state-level Zero Emission Vehicle (ZEV) programs, were pivotal in accelerating EV development and market readiness in the United States. Public-private partnerships and incentives further contributed to an increasingly supportive ecosystem for EV growth.

Global Leadership and Comparative Trends

Globally, several nations have emerged as leaders in EV adoption. Norway, through a combination of tax exemptions, free tolls, and expansive public charging, reached an EV market share of over 80% by 2023 (European Commission, 2023). The European Union has implemented aggressive policies, including a commitment to ban the sale of new internal combustion vehicles by 2035 and significant investments in high-speed charging corridors across member states.

China dominates the EV landscape both in manufacturing and consumer adoption. Leveraging state-led investments, China has built the largest EV market in the world and leads in battery production capacity. The country has also pioneered battery-swapping infrastructure and integrated EVs into public transportation at a massive scale (IEA, 2023).

The United States has made substantial progress but remains behind global leaders in terms of market share and infrastructure density. Electric vehicles accounted for less than 10% of new vehicle sales nationwide as of 2023 (Statista, 2024). Adoption patterns are geographically uneven. California remains the clear frontrunner, responsible for over 40% of national EV sales, as a result of strong ZEV mandates, rebate programs, and its expansive network of over 40,000 public chargers. Other states, to include New York, Washington, and Colorado, have introduced ambitious policies, combining purchase incentives with aggressive infrastructure expansion.

The federal government has put in place transformative initiatives. The Bipartisan Infrastructure Law allocates $7.5 billion to build a nationwide network of 500,000 EV chargers by 2030. The Inflation Reduction Act provides enhanced tax credits to support EV purchases and domestic battery production. The National Electric Vehicle Infrastructure (NEVI) program establishes minimum standards for public chargers and offers funding assistance to states for deployment.

However, substantial gaps remain. Many rural areas lack adequate charging coverage, and public fast-charging infrastructure remains limited outside of coastal urban centers. The U.S. also faces challenges in battery supply chain security, relying heavily on imports for critical minerals such as lithium, cobalt, and nickel.

A key insight from the research highlights that public-private partnerships, standardization of charging equipment, and domestic battery manufacturing are essential pillars for closing these gaps and enhancing national resilience.

BARRIERS TO EV ADOPTION IN THE UNITED STATES

The electric vehicle (EV) market across the United States is expanding steadily but falls short of the pace needed to meet national and global climate goals. The federal government has set ambitious targets, including the deployment of 500,000 public EV chargers nationwide by 2030, as part of its broader strategy to achieve significant reductions in transportation-sector emissions. Despite substantial funding allocations and rapid technological advancements, actual EV adoption rates and public readiness remain uneven across regions, with significant disparities between states that have implemented aggressive EV policies and those that have not (U.S. Department of Transportation, n.d.).

Charging Infrastructure Gaps

Electric vehicle adoption across the United States is characterized by significant regional disparities. Urban centers, such as Los Angeles, New York City, and San Francisco, boast relatively high charger availability, while many suburban and rural regions continue to face critical deficits in public charging infrastructure. One persistent national challenge is the limited reach of fast-charging networks along interstate highways and in smaller towns, creating range anxiety for potential EV buyers in less densely populated areas. Charging speed remains a critical factor. Level 1 chargers (standard 120-volt home outlets) can take over 24 hours to fully charge an EV, making them impractical for anything beyond overnight residential use. Level 2 chargers, which operate on 240 volts, significantly reduce charging time to approximately 6 to 8 hours but require dedicated hardware installation, often unavailable in multi-unit dwellings or older buildings. Direct Current (DC) Fast Chargers, capable of replenishing 80% of a battery's capacity in under an hour, are essential for long-distance travel but remain scarce and expensive to deploy. Installation costs for DC fast chargers range from $50,000 to $200,000 depending on factors such as site preparation, labor, utility upgrades, and permitting (SparkCharge, n.d.). Bridging these infrastructure gaps nationwide is vital to enable seamless EV adoption and foster consumer confidence in the practicality of electric mobility. The data summarized in Table 1 provides a comparative view of charging times for Level 1, Level 2, and DC Fast Charging options.

Table 1 Comparison of Level 1, Level 2, and DC Fast Charging Times

Source: ChargeHub. (n.d.). Electric car charging guide. Retrieved from https://chargehub.com/en/electric-car-charging-guide.html

Level	Charge Hub Markers	Power (kW)	Approximate Charging Time (Empty Battery)
1		1	200 km: +/- 20 hours 400 km: +/- 43 hours
2		Typically, 7kW, but can vary between 3kW et 20kW	200 km: +/- 5 hours 400 km: +/- 11 hours
3 (DCFC)		Typically, 50kW, 100kW 150kW, 180kW or 350kW, but can vary between 20kW and more than 350kW	80% +/- 15 to 60 minutes according to the power of the charger and the battery capacity of the car

Additionally, charging standard incompatibility adds to user frustration. CHAdeMO, CCS, and Tesla NACS (now SAE J3400) are not universally compatible, limiting access for many EV drivers (Wikipedia contributors, n.d.). This technological fragmentation discourages investment in multi-standard public chargers and confuses first-time buyers. Figure 3 illustrates EV charging connector types, including CCS, and Tesla NACS.

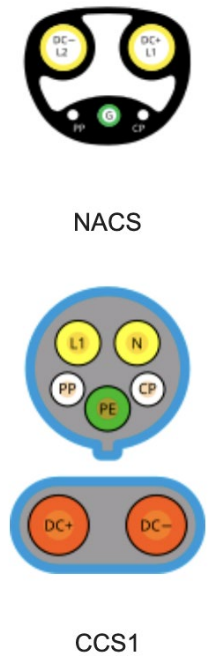

Figure 1 EV Charging Connector Types (CCS, Tesla NACS)

Source: Wikipedia contributors. (n.d.). North American Charging Standard. Retrieved from https://en.wikipedia.org/wiki/North_American_Charging_Standard

Battery Technology Limitations and Environmental Concerns

Even in cases where access to charging is not an issue, concerns about battery performance and sustainability persist. Lithium-ion batteries, which currently dominate the EV market, are known to degrade over time, especially when subjected to extreme temperatures or frequent fast charging. Research indicates repeated use of DC fast charging can cause lithium plating on the anode, reducing capacity and increasing internal resistance, thus shortening the overall lifespan of the battery (Qu et al., 2022). This is particularly relevant where high summer temperatures can reach well above 100°F and intensify battery degradation.

Cold weather presents another major concern. In colder regions of United States, EV batteries can lose between 30% to 40% of their range in winter conditions. Low temperatures slow down the electrochemical processes in the battery, making it less efficient at discharging energy (Power-Sonic, n.d.). The unpredictability of battery performance under various climate conditions remains a key deterrent for many potential buyers.

In addition to performance issues, environmental concerns around battery production also influence consumer sentiment. Research found that lithium mining operations, particularly in Chile's Salar de Atacama, consume more than 65% of the region's freshwater resources, severely affecting local agriculture, biodiversity, and indigenous communities (Green Cars, n.d.). These ethical and ecological implications complicate the narrative that EVs are universally "green" and highlight the importance of supply chain transparency.

To mitigate these concerns, emerging battery technologies, such as sodium-ion, lithium-sulfur, and solid-state batteries, are being explored. Sodium-ion batteries are less expensive and more environmentally friendly due to the abundance of sodium; however, they are heavier and less energy-dense than lithium-ion batteries, making them less viable for long-range travel (Greenly, 2023). Lithium-sulfur and solid-state batteries promise improved efficiency, safety, and environmental performance but remain in experimental stages, with scalability and cost being the biggest roadblocks to commercial adoption (Habib & Butler, 2022). Figure 4 illustrates lithium mining water use in Chile's Salar de Atacama region.

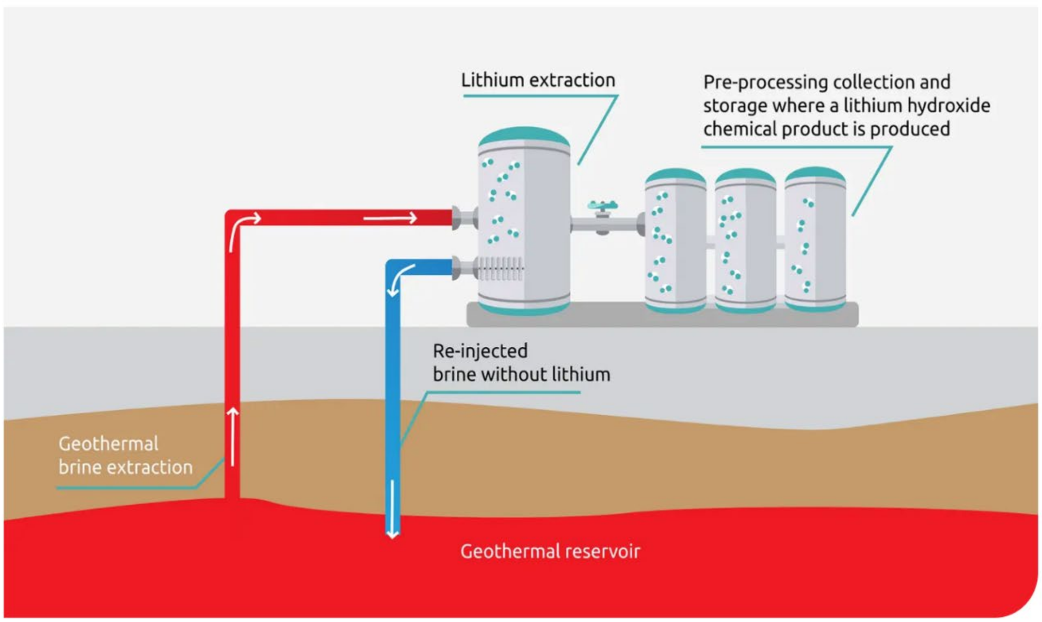

Figure 2 Lithium Mining Water Use - Chile's Salar de Atacama

Source. Adapted from Environmental Impact of EV Batteries, by GreenCars, n.d. Retrieved from https://www.greencars.com/greencars-101/environmental-impact-of-ev-batteries

High Upfront Costs and Affordability Issues

Another critical barrier is the affordability of EVs. Despite long-term savings from lower fueling and maintenance costs, the initial price of electric vehicles remains significantly higher than traditional gasoline-powered vehicles. According to Gibson (2023), even after applying the federal $7,500 tax credit, EVs can still cost $10,000 to $15,000 more than their combustion-engine counterparts.

Furthermore, installing a home charger typically costs between $1,000 and $2,000. Many renters and those living in apartment buildings lack access to home charging altogether, increasing reliance on the already overburdened public network. These compounded expenses make EVs impractical for large segments of the population, particularly students, young professionals, and families in lower-income brackets.

Depreciation is a major financial concern for EV buyers, particularly in markets where resale value plays a critical role in purchase decisions. According to a 2025 report by iSeeCars, EVs have one of the highest five-year depreciation rates among all vehicle categories—averaging a loss of 49.1% of their value. In contrast, internal combustion engine (ICE) vehicles depreciate at a slower pace, with small Sport Utility Vehicles (SUVs) averaging only 41.2%, and pickup trucks retaining even more value. The rapid technological evolution of EVs, combined with limited demand in the used EV market and concerns about battery life, contribute to this sharp decline in trade-in value. As a result, prospective EV buyers, especially in cost-sensitive regions, remain hesitant due to concerns over long-term economic feasibility. Table 2 identifies vehicle depreciation rates, and Figure 3 visually compares average depreciation of vehicle types.

Table 2 Five-Year Depreciation Rates of Vehicle Types in the U.S.

Source. Adapted from The Top 25 Cars That Hold Their Value Best – and the 25 Worst, by iSeeCars. (2025). Retrieved from https://www.iseecars.com/cars-that-hold-their-value-study

5-Year Depreciation for Notable Vehicle Segments - iSeeCars Study

iSeeCars

Segment	2019	2023	2025
Overall	49.6%	38.8%	45.6%
Hybrids	56.7%	37.4%	40.7%
EVs	67.1%	49.1%	58.8%
SUVs	51.6%	41.2%	48.9%
Trucks	42.7%	34.8%	40.4%

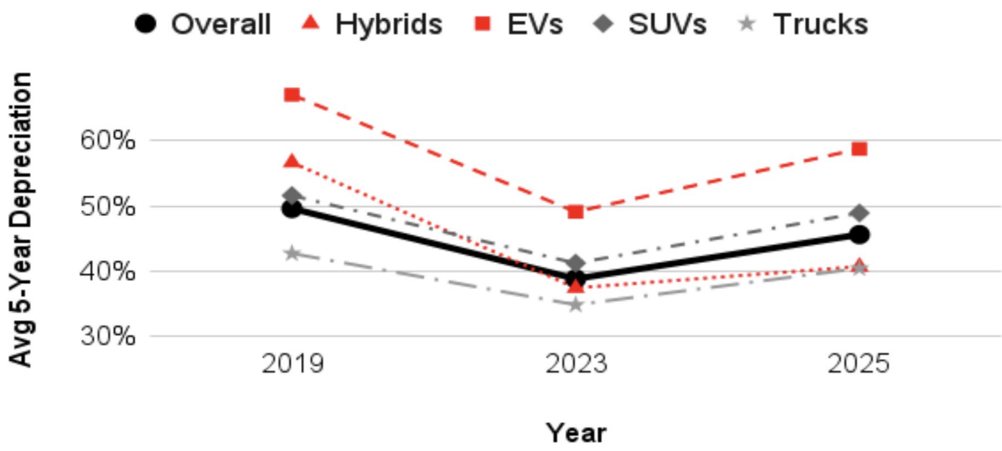

Figure 3 Visual Comparison of Depreciation by Vehicle Type (EVs, Hybrids, SUVs, Pickups)

Source. Adapted from The Top 25 Cars That Hold Their Value Best – and the 25 Worst, by iSeeCars. (2025). Retrieved from https://www.iseecars.com/cars-that-hold-their-value-study

Range Anxiety and Public Charging Costs

Range anxiety, the fear an electric vehicle (EV) may not have sufficient battery range to complete a journey, remains one of the most persistent and psychologically significant barriers to EV adoption across the United States. While global leaders in the Netherlands, Norway, and Germany have effectively mitigated this challenge through dense networks of fast-charging stations and integrated urban planning, the United States is beginning to develop a nationwide charging infrastructure that instills consumer confidence. Many rural, suburban, and even peri-urban areas lack reliable access to public chargers, particularly Direct Current (DC) fast-charging stations, creating substantial regional disparities in EV readiness and usability (U.S. Department of Transportation, n.d.).

Compounding the issue are the inherent limitations of current EV battery technology. While premium models can deliver ranges exceeding 300 miles per full charge, the more affordable, mass-market EVs, critical for achieving equitable adoption, typically provide between 150 and 220 miles of range under optimal conditions. Real-world variables, such as extreme cold, air conditioner and heater use, elevation changes, and high-speed highway driving, can reduce effective range by as much as 20% to 40% (Power-Sonic, n.d.). For consumers in regions with harsh winters or long commuting distances, these limitations raise practical concerns about reliability and convenience, particularly in long-distance or emergency travel situations.

Adding to the challenge is the rising cost of public charging. Recent nationwide data indicate that DC fast-charging prices have surged across multiple states, with some regions now exceeding $0.40 per kilowatt-hour, a price point that, in certain cases, rivals or surpasses gasoline in terms of cost-per-mile for comparable vehicles (AAA, 2024; Axios, 2024). Without transparent pricing, standardized payment systems, and competitive regulation of charging networks, EVs may begin to lose their cost-advantage appeal among budget-conscious consumers. This underscores the urgent need for federal and state policymakers to implement robust oversight, promote fair market practices, and ensure equitable access to affordable charging infrastructure nationwide. Public charging cost trends in the U.S. are shown in Figure 4, including year-over-year increases across major states.

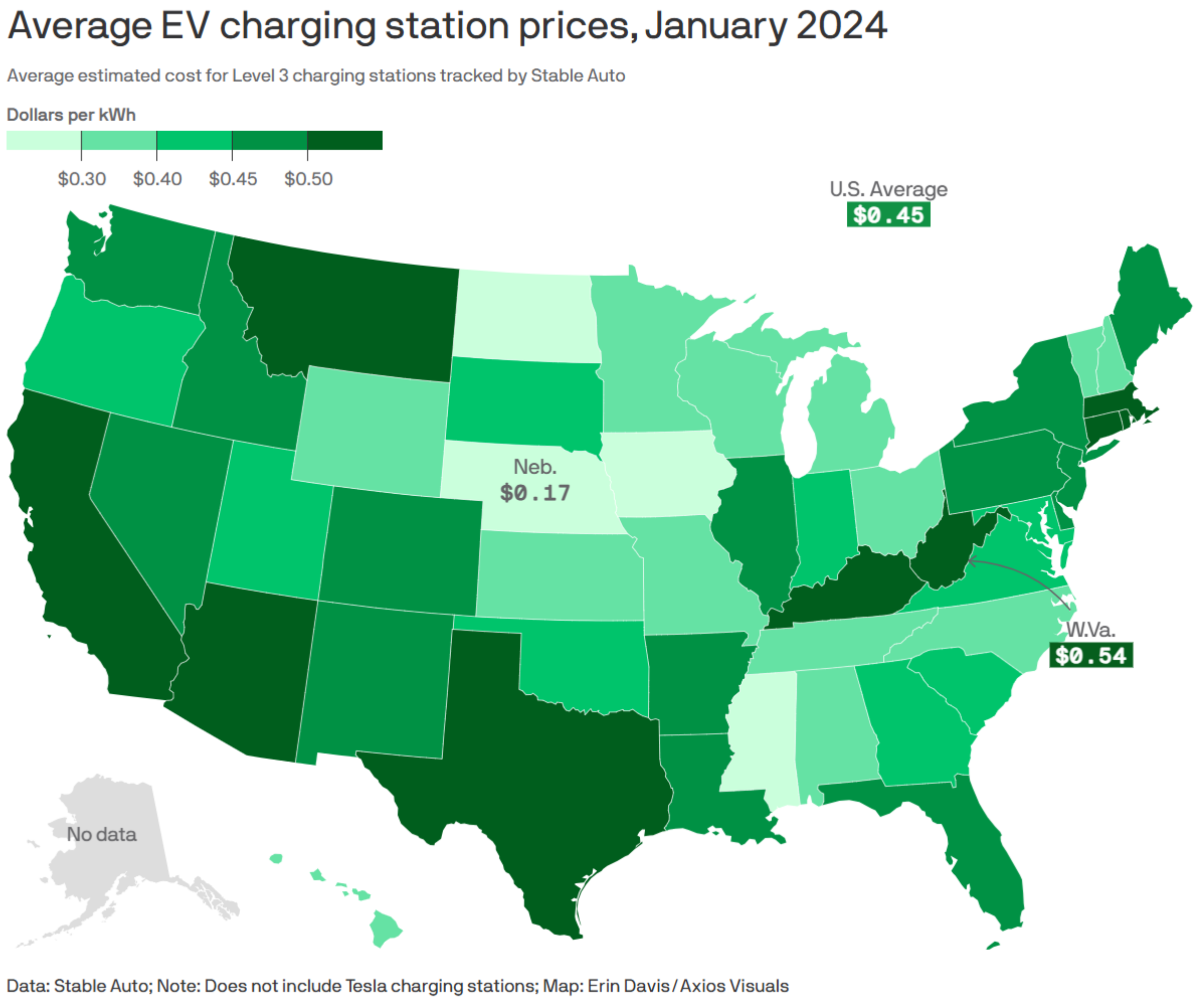

Figure 4 Public EV Charging Cost Trends in the U.S. (2023 - 2024)

Source. Adapted from Axios. (2024). EV charging costs are rising in Texas. Retrieved from https://www.axios.com/local/houston/2024/03/14/ev-charging-cost-texas-electric-vehicle

Consumer Hesitancy and Misinformation

Consumer perception remains one of the most complex and deeply rooted challenges in accelerating EV adoption. According to a 2024 AAA survey, only 18% of U.S. adults reported being "very likely" to consider purchasing an electric vehicle, a decline from 23% the previous year (AAA Newsroom, 2024). This drop is attributed to a combination of misinformation, limited public education, and market uncertainty.

Misconceptions include assumptions that EVs are prone to battery fires, require frequent and expensive repairs, have poor resale value, and cannot operate in cold weather. Although data shows EVs generally require less maintenance than ICE vehicles, this narrative has not yet reached mass awareness. Furthermore, a shortage of trained EV repair technicians, particularly in rural areas, amplifies the fear of owning a high-maintenance vehicle with limited support.

Another factor is a psychological resistance to change. Many potential buyers remain emotionally attached to traditional gasoline vehicles due to familiarity, perceived reliability, or skepticism about emerging technology. This is especially true among older demographics, as evidenced by survey data showing that over 50% of respondents aged 65 and older said they were "not at all likely" to consider an EV (Statista, 2024). Figure 5 presents consumer EV interest trends in the U.S. from 2022 to 2024.

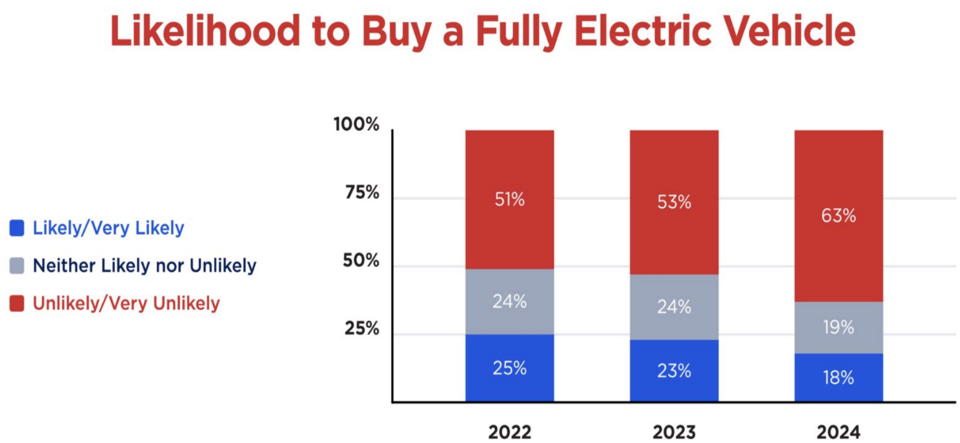

Figure 5 EV Purchase Interest in the U.S. (2023 - 2024)

Source. Adapted from AAA Newsroom. (2024). Is the EV hype over? Retrieved from https://newsroom.aaa.com/2024/06/is-the-ev-hype-over

Grid Load and Renewable Integration

A critical systemic challenge for the United States is ensuring the national electric grid can absorb the increasing energy demands of widespread EV adoption. Countries, to include Germany and the United Kingdom, have pioneered the integration of vehicle-to-grid (V2G) technologies, offering incentives for off-peak charging and enabling EVs to serve as distributed energy resources that can feed power back into the grid during high-demand periods. In contrast, the U.S. grid remains in the early stages of adapting to the unique challenges posed by large-scale EV deployment.

The aging and decentralized nature of the U.S. electric grid poses substantial risks. While some regions, such as California and New York, have made strides in modernizing grid infrastructure and expanding renewable energy capacity, many states still rely on outdated transmission systems vulnerable to overloads and blackouts. Recent grid strain events, including the California rolling blackouts of 2020 and severe winter storms in the Midwest and South, have exposed structural weaknesses that could be exacerbated by the added demand from millions of EVs.

Nationwide, approximately 20% of electricity generation comes from renewable sources (U.S. Department of Energy, 2023), but this share must grow substantially to ensure that EV adoption genuinely reduces carbon emissions. Without parallel investments in grid modernization and renewable energy integration, the environmental benefits of EVs may be diluted by continued reliance on fossil-fuel-powered electricity.

Furthermore, a lack of coordinated efforts between utility companies, local governments, and automakers limits the deployment of smart grid technologies. These include real-time energy balancing systems, time-of-use pricing models, and grid-interactive EV charging, all essential for optimizing electricity use and preventing peak-load issues. Pilot programs for V2G integration, such as those underway in California, have shown the potential to transform EVs into active components of the energy ecosystem, but nationwide adoption remains minimal.

To prepare the U.S. energy system for the future, federal and state policymakers must prioritize investments in renewable-powered charging infrastructure, battery storage systems, and nationwide V2G capability. Developing a coordinated framework that bridges utilities, technology providers, and transportation agencies will be essential for building a resilient, flexible, and clean grid capable of supporting mass EV adoption.

PROPOSED SOLUTIONS FOR EV ADOPTION

The successful nationwide adoption of electric vehicles requires a comprehensive, multi-pronged strategy that combines infrastructure investment, forward-thinking policies, advanced technological research, and robust public engagement. Drawing from best practices in global leaders such as Europe, China, and progressive U.S. states like California and New York, this chapter outlines actionable solutions designed to address the diverse geographic, economic, and infrastructural challenges facing the United States.

Expanding National EV Charging Infrastructure

The federal government, through the National Electric Vehicle Infrastructure (NEVI) program, has allocated significant funding, $7.5 billion nationwide, to expand public EV charging capacity (U.S. Department of Energy, 2021). This investment presents a pivotal opportunity to address geographic disparities in charging accessibility across urban, suburban, and rural regions. To ensure seamless coast-to-coast EV travel, a strategic nationwide plan is essential; chargers should be installed every 50 miles along major highway corridors and no more than 70 miles apart in less dense regions, mirroring the European Union's corridor electrification model.

Public-private partnerships are vital to scaling up infrastructure efficiently. Incentivizing private firms to install and maintain charging stations, particularly in underserved regions, can achieve more equitable access while reducing the burden on public funds. The integration of smart grids and Vehicle-to-Grid (V2G) solutions is equally critical. These technologies enable two-way energy flow, allowing EVs to serve as mobile energy storage units that can feed electricity back into the grid during peak demand periods, thus enhancing grid stability and resilience.

Standardization is another key focus. The U.S. must streamline charger compatibility by promoting universal adoption of common connectors (e.g., Combined Charging System, CCS), while also addressing Tesla's North American Charging Standard (NACS) to ensure interoperability across all vehicle models. Uniform payment systems, real-time charger availability data, and robust maintenance protocols will further enhance user confidence.

Policy and Financial Incentives

While federal incentives like the $7,500 tax credit have bolstered EV adoption, state-level support remains inconsistent. To accelerate nationwide uptake, states should introduce complementary incentives such as direct purchase rebates, registration discounts, toll exemptions, and utility-based charging rebates. As examples, Colorado and New Jersey offer up to $5,000 in additional rebates, providing a proven model that other states can replicate to make EV ownership more affordable.

In addition to consumer-focused incentives, fleet electrification mandates should be expanded. Federal and state policies can require public-sector fleets, including government vehicles, school buses, and municipal services, as well as private-sector fleets (e.g., rideshare services) to transition to at least 50% electric by 2030. Early success stories, such as New York City's electrified bus pilot and California's Advanced Clean Fleets regulation, provide valuable templates for scaling nationwide.

Innovative approaches, like battery-swapping pilot programs, can complement traditional charging solutions. In China, Nio automated battery-swapping stations have demonstrated the feasibility of replacing depleted batteries with fully charged units in under five minutes. The U.S. could explore partnerships with automakers, startups, and research institutions to pilot similar systems in densely populated urban centers and along high-traffic corridors.

Further, EV-ready building codes should be standardized nationally to ensure all new residential and commercial developments are equipped with the necessary infrastructure, such as conduit for future chargers or pre-installed EV charging equipment. This approach reduces costly retrofits and ensures infrastructure growth keeps pace with vehicle adoption.

Affordability must also consider operational costs. Public charging prices vary significantly across the U.S., with states like California and Alaska exceeding $0.40 per kilowatt-hour, while other regions remain closer to the national average of $0.346 (AAA, 2024). To address equity concerns, utilities and policymakers should introduce tiered pricing models that offer reduced rates for low-income households and expand public utility rebate programs to offset installation costs. Figure 6 represents the national and state daily average per kilowatt hour cost for all commercial/public charging (Level 1, Level 2, and Level 3/DC Fast Charging).

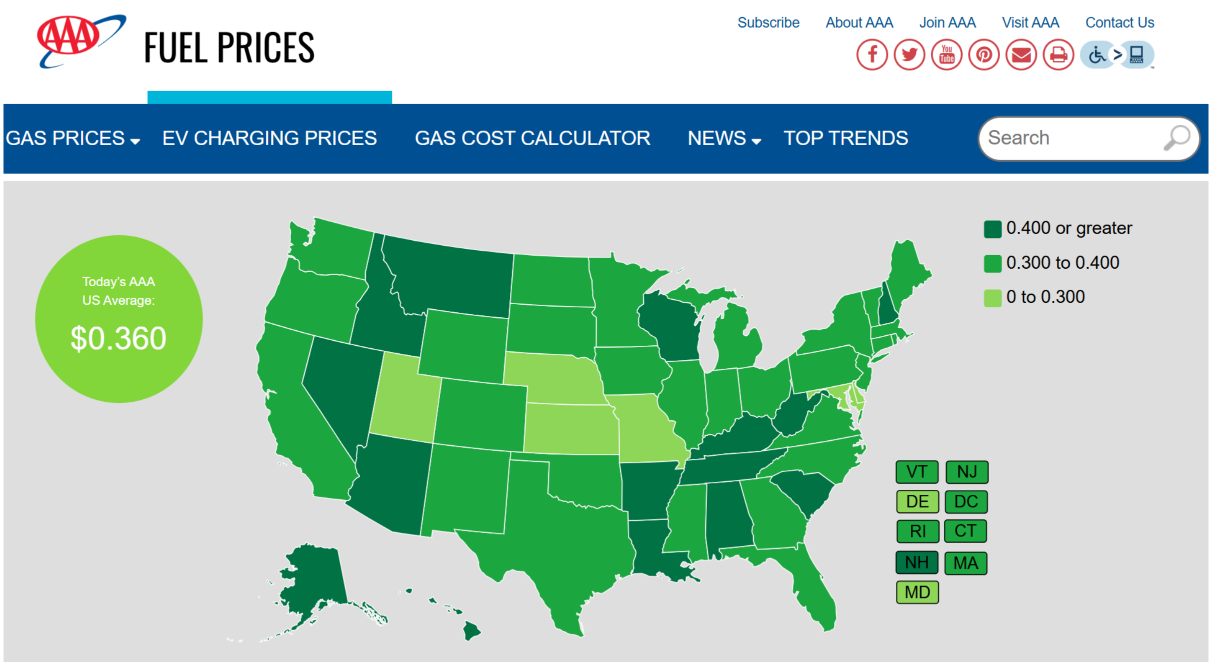

Figure 6 National and State Daily Average Per Kilowatt Hour Costs

Source. Adapted from AAA. (2024). EV Charging Prices Map. Retrieved from https://gasprices.aaa.com/ev-charging-prices/

Adopting Alternative Battery Technologies

To strengthen domestic energy security and reduce environmental dependency on lithium extraction, the United States must accelerate research and development of next-generation battery technologies. While lithium-ion batteries remain dominant today, diversification is essential for long-term sustainability, cost reduction, and enhanced safety. Among the alternatives, solid-state batteries have emerged as the most promising candidate for revolutionizing EV performance and reliability.

Solid-state batteries replace the flammable liquid electrolyte found in lithium-ion batteries with solid materials, offering significant safety advantages by reducing risks of thermal runaway and battery fires (Kanellakis & Kanakas, 2023). In addition to enhanced thermal stability, solid-state batteries boast higher energy density, which could extend EV driving range by 50% or more compared to current lithium-ion models. They also offer faster charging capabilities and potentially longer lifespans, key factors that address consumer concerns over range anxiety and battery degradation.

However, scaling solid-state technology for mass-market EVs presents formidable challenges. Current hurdles include dendrite formation, which can compromise battery integrity, high manufacturing costs, and difficulties in identifying solid electrolytes that balance conductivity with mechanical strength. Leading companies such as Toyota, QuantumScape, and U.S.-based Solid Power are conducting extensive R&D and pilot production, aiming to achieve commercial viability within the next decade.

The U.S. Department of Energy has prioritized solid-state research through funding initiatives and collaborations with national laboratories and universities. Institutions such as Argonne National Laboratory, Oak Ridge National Laboratory, and the University of Michigan are advancing critical breakthroughs in electrolyte design, interface stability, and scalable manufacturing techniques.

While sodium-ion and lithium-sulfur batteries also hold potential, particularly in reducing costs and minimizing environmental impact, they are generally viewed as supplementary to the transformative promise of solid-state technology. Sodium-ion batteries, despite their affordability and abundance of raw materials, face limitations in energy density, making them less suitable for long-range EVs. Lithium-sulfur batteries offer high theoretical capacity but remain in earlier stages of development with durability concerns.

For the U.S. to maintain technological leadership and achieve its zero-emission transportation goals, a national strategy focused on solid-state battery innovation is crucial. This includes increasing research and development investments and also developing domestic supply chains for critical materials, creating pilot production hubs, and fostering partnerships between government agencies, research institutions, and private industry. Advancing solid-state technology will be a cornerstone of the next-generation EV ecosystem, addressing key barriers of range, safety, and consumer confidence. Table 3 provides a comparative analysis of lithium-ion and solid-state batteries.

Table 3 Comparison of Lithium-ion and Solid-State Batteries

Source. Adapted from Laserax. (2024). Solid State Batteries vs. Lithium-Ion: Which One is Better?https://www.laserax.com/blog/solid-state-vs-lithium-ion-batteries

Key Comparisons

FEATURE	LITHIUM-ION BATTERIES	SOLID STATE BATTERIES
Energy Density	160-250 Wh/kg	250-800 Wh/kg
Safety	Risk of overheating and flammability due to liquid electrolyte	Significantly reduced fire risk, non-flammable solid electrolyte
Lifespan	Degrades over time due to chemical reactions from high temperature, deep discharge cycles, high recharge rate, etc.	Potential for longer lifespan, but currently faces challenges with crack formation
Charging Speed	Moderate to fast, sensitive to temperature	Potential for ultra-fast charging
Current Availability	Widely available, established manufacturing infrastructure	Primarily in laboratories and small-scale production and prototypes
Production Status	Mature technology with ongoing improvements	High production costs, crack formation when charging/discharging. Need to be solved before going large-scale production
Commercialization	Currently used in EVs and other applications	Expected around 2026-2027 for EVs
Key Advantages	Established technology, currently more robust and available	Higher energy density, improved safety, faster charging potential
Main Challenges	Safety concerns, limited energy density	High production costs, technical issues in scaling up

Another key strategy is to incentivize U.S.-based battery production. The Unites States, with its manufacturing potential, could attract gigafactories to reduce reliance on global supply chains. Complementing this, the states should invest in battery recycling facilities and promote second-life applications (e.g., grid storage), minimizing waste and maximizing lifecycle efficiency.

CASE STUDIES AND GLOBAL BEST PRACTICES

To better contextualize the United States' position in the EV landscape, it is important to examine global and national models that have successfully accelerated EV adoption. This section presents case studies from California, China, and the European Union, regions that have implemented best practices in policy, infrastructure, and innovation.

California EV Infrastructure Model

California continues to lead the United States in electric vehicle (EV) adoption and infrastructure development. As of February 2025, the state has deployed over 152,000 public and shared private Level 2 and DC fast charging ports serving light-duty EVs. This marks significant progress toward California's goal of installing 250,000 chargers.

In the first half of 2024 alone, approximately 24,000 new chargers were installed, reflecting the state's commitment to expanding its charging network. The Consumer Electronics Control (CEC) has enhanced its tracking methods by incorporating data from PlugShare, grant recipient reports, and voluntary surveys from electric vehicle service providers (EVSPs) and public agencies. This comprehensive approach ensures a more accurate representation of the state's charging infrastructure.

California's success is also attributed to robust public-private partnerships. Collaborations with companies like Tesla, ChargePoint, and Electrify America have facilitated the rapid deployment of charging stations across urban centers and along major transportation corridors. Additionally, the state's building codes mandate EV-ready infrastructure in new residential and commercial constructions, further supporting EV adoption. Figure 7 maps the distribution of public and private EV chargers across California counties, showing disparities in coverage.

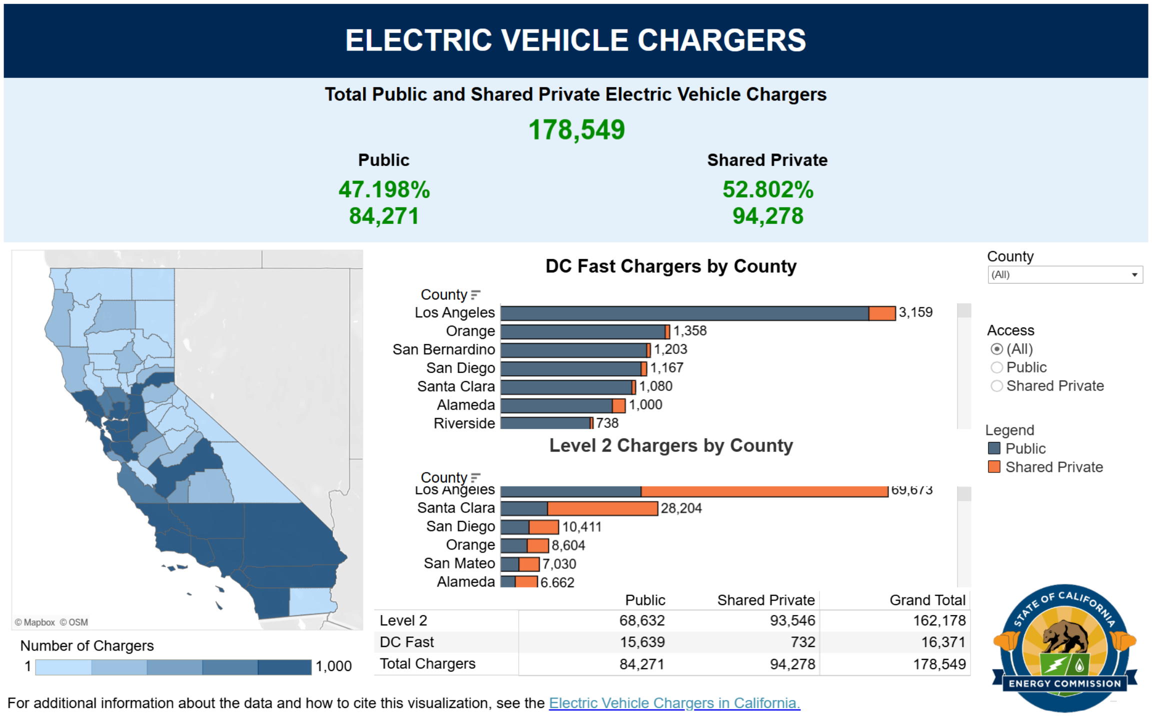

Figure 7 Public and Shared Private EV Chargers Distribution in California by County (2025)

Source. Adapted from California Energy Commission. (2025). Electric Vehicle Charger Dashboard. Retrieved from https://www.energy.ca.gov/data-reports/energy-almanac/zero-emission-vehicle-and-infrastructure-statistics-collection/electric

China Battery-Swapping Model

China has made significant strides in reducing range anxiety through the implementation of battery-swapping technology. Led by companies like Nio, the country has deployed more than 1,400 battery-swapping stations as of 2024. These stations can replace a depleted EV battery in under 5 minutes, addressing one of the key deterrents of EV adoption of long charging times (EVBox, 2023).

Beyond infrastructure, China's policy-driven approach has been instrumental. Regulations now require new residential and commercial buildings to be EV-ready, ensuring integration of electric mobility. Cities such as Beijing and Shanghai offer EV-specific license plates, tax exemptions, and subsidies that make electric vehicles a preferred option for urban commuters. Figure 8 presents battery-swapping station growth in China, particularly by Nio, from 2022 to 2024.

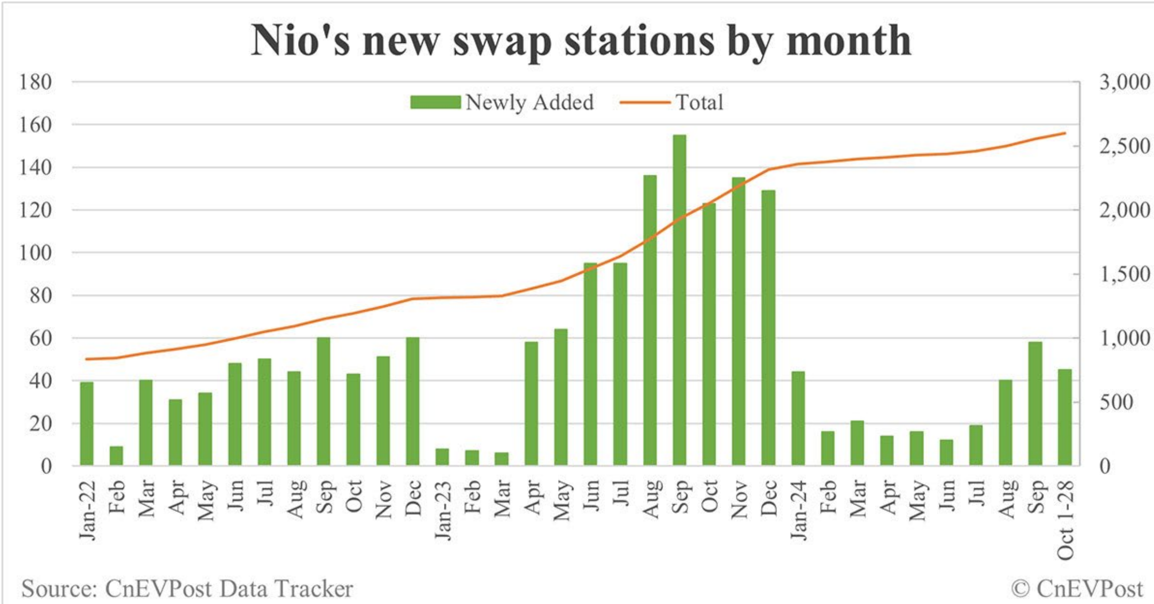

Figure 8 Nio Battery-Swapping Station Growth by Month (2022 - 2024)

Source. Adapted from CnEVPost. (2024). Nio adds 1,292 battery swap stations in 2023. Retrieved from https://cnevpost.com/2024/01/01/nio-battery-swap-station-growth-2023/

Europe Standardization and Regulation Framework

The European Union has created one of the most harmonized policy environments for EV adoption. The EU has mandated that all new cars sold by 2035 must be zero-emission, effectively setting a transition deadline for automakers and charging providers alike (European Commission, 2023). These mandates are complemented by vehicle taxation based on CO2 emissions, city-level low-emission zones, and green procurement requirements.

Europe's success also lies in its standardization. Unlike the commonly fragmented charging standards, EU member states have adopted universal charging protocols such as CCS2. This allows EV drivers to charge across borders without compatibility issues, an essential factor in achieving seamless electric mobility.

The "Global Timeline of ICE Phase-Out Targets and EV Adoption Commitments" chart, adapted from BloombergNEF (2024) (Figure 9), provides a consolidated view of international pledges to eliminate internal combustion engine (ICE) vehicles across different vehicle classes. The chart delineates phase-out timelines for Light-Duty Vehicles (LDVs), including passenger cars and SUVs, as well as Heavy-Duty Vehicles (HDVs) such as trucks and buses. It also highlights commitments for Medium Commercial Vehicles (MCVs) and Light Commercial Vehicles (LCVs), underscoring the multi-tiered strategy many countries are pursuing to electrify both personal and commercial transportation sectors. This global roadmap illustrates not only the 2035 zero-emission targets for new passenger cars set by regions like the European Union but also broader ambitions to decarbonize freight and logistics fleets by mid-century. The inclusion of vehicle-specific targets reflects growing recognition of the need to address emissions across the entire transportation ecosystem.

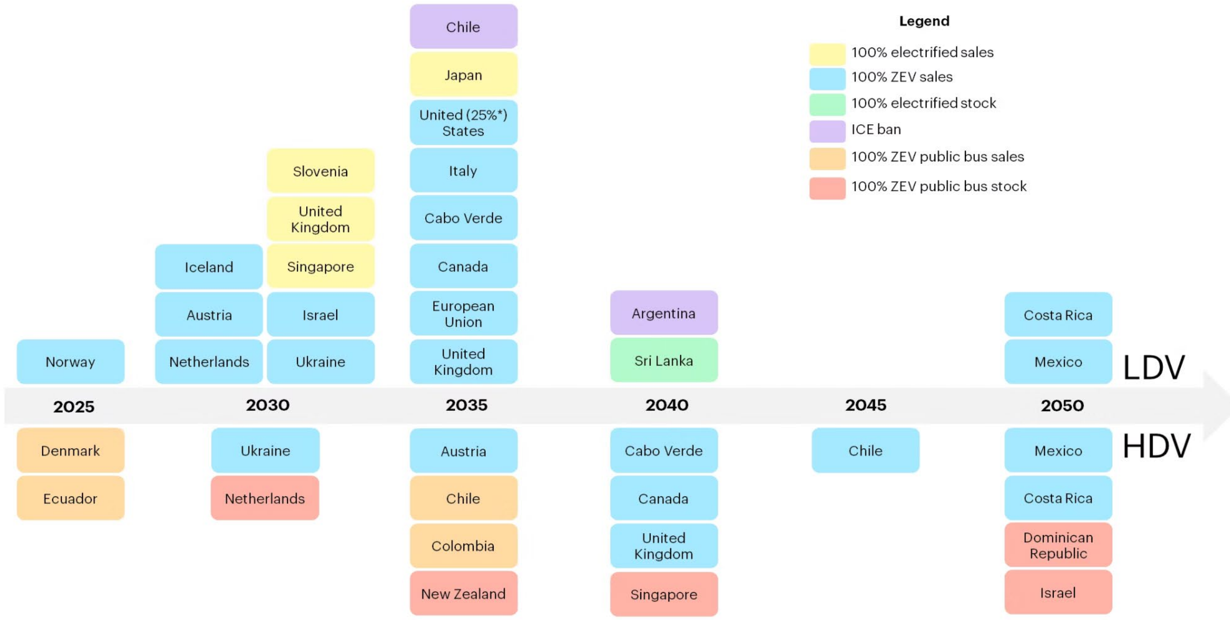

Figure 9 Global Timeline of ICE Phase-Out Targets and EV Adoption Commitments for Heavy Duty and Light Duty Vehicles

Source. Adapted from BloombergNEF. (2024). Zero-Emission Vehicle Transition Council Dashboard. Retrieved from https://about.bnef.com/

CONCLUSIONS AND CALL TO ACTION

The transition to electric vehicles (EVs) represents both a critical environmental imperative and a transformative economic opportunity for the United States. This report has identified several persistent barriers to widespread EV adoption nationwide, including inadequate and uneven charging infrastructure, high upfront costs, evolving battery technology challenges, consumer hesitancy driven by misinformation, and increasing strain on the electric grid. However, global best practices, alongside domestic success stories, particularly in states like California and New York, demonstrate that these challenges can be overcome through coordinated investment, forward-thinking policy, and robust public-private collaboration.

For the United States to meet its climate targets and maintain competitiveness in the global clean transportation market, immediate and strategic action is essential. The National Electric Vehicle Infrastructure program's $7.5 billion investment in national EV infrastructure provides a critical foundation for building an extensive, reliable, and equitable charging network that serves both urban centers and rural communities. Furthermore, nationwide policy innovations, such as expanding purchase rebates, piloting battery-swapping stations, standardizing EV-ready building codes, and advancing solid-state battery research, will be pivotal in addressing affordability and performance gaps.

This report recommends the following national priorities.

- Establish a National Zero-Emission Mobility Strategy that aligns federal, state, and local policies with 2030 and 2035 climate and transportation targets, ensuring cohesive progress across all regions.

- Expand public-private partnerships involving the U.S. Department of Transportation (USDOT), state transportation agencies, utility companies, automakers, and clean-tech innovators to co-develop scalable EV infrastructure and smart grid integration projects.

- Launch nationwide public awareness and education campaigns to combat misinformation, increase EV literacy, and promote hands-on experiences with EV technology across diverse demographic and geographic populations.

- Invest in next-generation battery technologies, domestic battery manufacturing, and comprehensive recycling programs to create a resilient and sustainable EV supply chain within U.S. borders.

- Enhance standardization efforts to unify charging connectors, payment systems, and grid interoperability nationwide, ensuring seamless EV operation and consumer convenience.

By implementing these actions, USDOT and national policymakers can ensure the United States not only keeps pace with global EV leaders but also establishes itself as a pioneer in sustainable, electrified mobility. The window for transformative change is open, but swift, decisive action is required to capitalize on this historic opportunity.

REFERENCES

AAA. (2024, June). EV charging prices. AAA Gas Prices. Retrieved from https://gasprices.aaa.com/ev-charging-prices/

Android Authority. (n.d.). Lithium-ion battery alternatives: What could replace them? Retrieved from https://www.androidauthority.com/lithium-ion-battery-alternatives-3356834/

Axios. (2024, March 14). EV charging costs are rising in the United States. Retrieved from https://www.axios.com/local/houston/2024/03/14/ev-charging-cost-texas-electric-vehicle

Batteries News. (2023, March 30). Lithium-sulfur battery is soaring as the next-gen battery. Retrieved from https://batteriesnews.com/lithium-sulfur-battery-soaring-next-gen-battery/

BloombergNEF. (2024). Zero-Emission Vehicle Transition Council Dashboard. Retrieved from https://about.bnef.com/

Bluetti Power. (n.d.). Electric car charging infrastructure: Challenges and solutions. Retrieved from https://www.bluettipower.com/blogs/news/electric-car-charging-infrastructure-challenges-and-solutions

California Energy Commission. (2024, September 11). California awards $32 million in federal funding to deploy over 450 fast chargers along interstates and highways. Retrieved from https://www.energy.ca.gov/news/2024-09/california-awards-32-million-federal-funding-deploy-over-450-fast-chargers-along

Car and Driver. (2023, October 26). How much does it cost to charge an electric car? Retrieved from https://www.caranddriver.com/news/a45036169/electric-vehicle-ev-cost-to-charge/

CBT News. (2023, June 20). Electric vehicle charging infrastructure challenges and solutions. Retrieved from https://www.cbtnews.com/electric-vehicle-charging-infrastructure-challenges-and-solutions/

ChargeHub. (n.d.). Electric car charging guide. Retrieved from https://chargehub.com/en/electric-car-charging-guide.html

CNBC. (2024, April 5). Poor resale values of EVs are a problem for the industry, warn experts. Retrieved from https://www.cnbc.com/2024/04/05/poor-resale-values-of-evs-are-a-problem-for-the-industry-warn-experts.html

Electrek. (2024, December 16). New semi-solid-state battery EV launching 2025. Retrieved from https://electrek.co/2024/12/16/new-semi-solid-state-battery-ev-launching-2025/

Environmental Defense Fund. (n.d.). Electric vehicle sales and satisfaction continue to rise. Retrieved from https://vitalsigns.edf.org/story/electric-vehicle-sales-and-satisfaction-continue-rise

European Commission. (2023). EU 2035 zero-emission vehicle mandate. Retrieved from https://ec.europa.eu/clima/policies/transport/vehicles_en

EV Adoption. (2024). US charging network rankings. Retrieved from https://evadoption.com/ev-charging-stations-statistics/us-charging-network-rankings/

EV Magazine. (2023). Top 10 EV charging companies. Retrieved from https://evmagazine.com/charging-and-infrastructure/top-10-ev-charging-companies

Gairola, A. (2024, March 20). EV battery swapping vs charging station: Comparative guide. Bacancy Systems. Retrieved from https://bacancysystems.com/blog/ev-battery-swapping-vs-charging-station

GEP. (2023, December 7). Lithium-ion vs. sodium-ion battery: A comparison. Retrieved from https://www.gep.com/blog/strategy/lithium-ion-vs-sodium-ion-battery

Gibson, K. (2023, October 12). Electric vehicles show reliability issues despite rising popularity. CBS News. Retrieved from https://www.cbsnews.com/news/electric-vehicles-consumer-reports-reliability-report/

GreenCars. (n.d.). Environmental impact of EV batteries. Retrieved from https://www.greencars.com/greencars-101/environmental-impact-of-ev-batteries

Greenly. (2023, August 28). Sodium batteries: A better alternative to lithium? Retrieved from https://greenly.earth/en-us/blog/ecology-news/sodium-batteries-a-better-alternative-to-lithium

Habib, A. K. M. R., & Butler, K. S. (2022). Alternatives to lithium-ion batteries in electric vehicles. Future Technology, 1(1), 28-29. Retrieved from https://doi.org/10.55670/fpll.futech.1.1.5

International Energy Agency (IEA). (2023). Global EV Outlook. Retrieved from https://www.iea.org/reports/global-ev-outlook-2023

Kanellakis, M., & Kanakas, N. (2023). Advanced lithium-sulfur batteries for next-generation electric vehicles: A review of recent progress and challenges. Journal of Energy Storage, 65, 107009. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10636766/

Lindsay, G. (2023, September 14). Infrastructure challenges facing widespread EV adoption. WardsAuto. Retrieved from https://www.wardsauto.com/electric/infrastructure-challenges-facing-widespread-ev-adoption

Macioszek, E. (2020). Electric vehicles—Problems and issues. In Sierpiński, G. (Ed.), Smart and Green Solutions for Transport Systems. Advances in Intelligent Systems and Computing, 1091. Springer. Retrieved from https://doi.org/10.1007/978-3-030-35543-2_14

Metz, R. (2023, May 17). How 5-minute battery swaps could get more EVs on the road. MIT Technology Review. Retrieved from https://www.technologyreview.com/2023/05/17/1073265/how-5-minute-battery-swaps-could-get-more-evs-on-the-road/

Popien, J. L., Thies, C., Barke, A., et al. (2023). Comparative sustainability assessment of lithium-ion, lithium-sulfur, and all-solid-state traction batteries. International Journal of Life Cycle Assessment, 28, 462–477. Retrieved from https://doi.org/10.1007/s11367-023-02134-4

Power-Sonic. (n.d.). Fast charging and battery life: How do charge rates affect battery performance? Retrieved from https://www.power-sonic.com/blog/fast-charging-battery-life/

Qu, J. G., Jiang, Z. Y., & Zhang, J. F. (2022). Investigation on lithium-ion battery degradation induced by current rate and operating temperature during fast charging. Journal of Energy Storage, 52, 104811. Retrieved from https://doi.org/10.1016/j.est.2022.104811

Santini, D. J. (2011). Electric vehicle waves of history: Lessons learned about market deployment of electric vehicles. In S. Soylu (Ed.), Electric Vehicles—The Benefits and Barriers. InTech. Retrieved from https://www.intechopen.com/chapters/16300

SparkCharge. (n.d.). EV charging station infrastructure costs. Retrieved from https://www.sparkcharge.io/blogs/leadthecharge/ev-charging-station-infrastructure-costs

Statista. (2024). Electric vehicle purchase likelihood in the U.S. by consumer age group. Retrieved from https://www.statista.com/statistics/1277794/electric-vehicle-purchase-likelihood-in-the-us-by-consumer-age-group/

U.S. Department of Energy. (2021). National Electric Vehicle Infrastructure (NEVI) Formula Program. Retrieved from https://afdc.energy.gov/laws/12744

U.S. Department of Transportation. (n.d.). EV benefits and challenges: Rural toolkit. Retrieved from https://www.transportation.gov/rural/ev/toolkit/ev-benefits-and-challenges

Ufine Battery. (2024, January 15). Comparing lithium-sulfur and lithium-ion batteries. Retrieved from https://www.ufinebattery.com/blog/comparing-lithium-sulfur-and-lithium-ion-batteries

Anton, A. (2024). Strategies for Overcoming Barriers to Electric Vehicle Adoption in the U.S. Unpublished student report, Center for Transportation Research, The University of Texas at Austin.