Electric Vehicles

Harvard College Consulting Group

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2. Executive Summary

The Covid-19 pandemic decreased global car sales from 2019 to 2021, but **sales of electric vehicles have continued on an upward trajectory**. With the expansion of charging networks, consumer demand for cleaner vehicles, and regulatory incentives, the transition from the internal combustion engine to the electric vehicle is well underway.

CONSUMER AND MARKET TRENDS

23%

Compound annual growth rate for EV sales from 2021 to 2030

The EV industry will experience a surge in car sales, driven primarily by rising environmental consciousness among consumers and regulatory measures. Analysts forecast Europe, China, and the US as the top three EV markets, with faster growth in Europe and China as compared to the US.

Europe

Carmakers should capitalize on positive word-of-mouth about EV drive quality and ease of maintenance in their marketing efforts, to leverage on rising EV penetration.

China

Affordable cars with lower horsepower appeals to the mass Chinese market, where efficient intercity rail transport reduces range anxiety.

USA

Premium sedans, SUVs, and pickup trucks will drive near-term profitability, but **long-term success requires the development of an affordable electric car** with 400 mi range.

INFRASTRUCTURE AND POLICY

Urban shopping centers and highway rest stops should brand themselves as "oases" of charging, by providing sufficient fast charging lots and offering food and entertainment options during charging.

Utility providers should upgrade power grids to handle significant intraday fluctuations in power consumption, and further expand renewable energy sources to reduce the share of electricity generated from coal and other fossil fuels.

10%

Current capacity of EV charging, as compared to the refueling capacity of gas stations

ADJACENT INDUSTRIES

"Only 28% of auto repair shops have invested in tools and equipment to specifically service EVs"

– Cars Direct

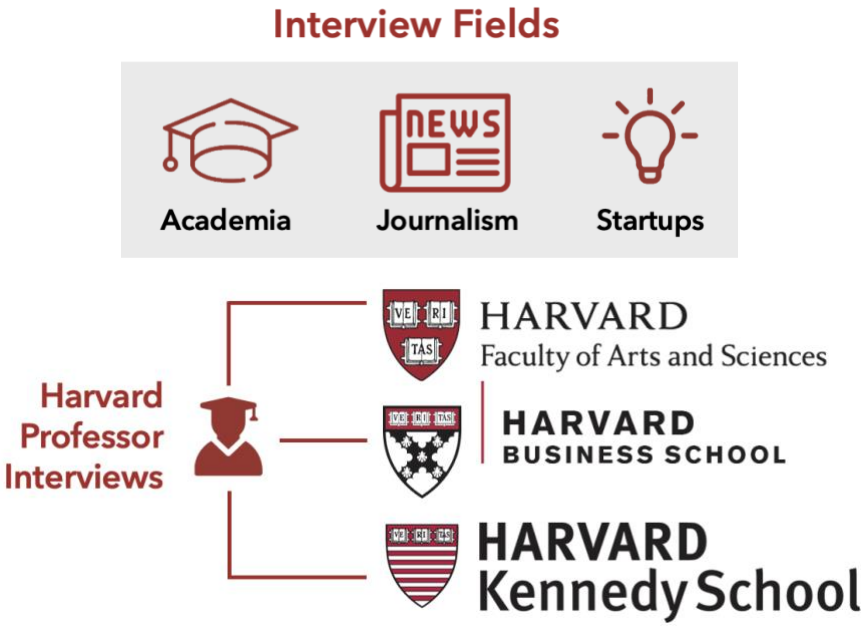
The auto parts, repair, and retail gas industries must prepare for the shift to EVs. Repair shops should train its staff and purchase equipment to service the EV architecture. Metal work companies should research into the fabrication of lower-weight metals. Gas stations should partner with auto companies, as retail shops and malls increasingly add their own charging infrastructure.

Mining companies must develop greener techniques to reduce environmental damage amidst rising concerns over the sustainability of metal extraction and refinement.

3. Methodology

To understand the characteristics of electric vehicles and examine their implications on the automotive industry, the HCCG team conducted extensive secondary research, drawing from industry reports, news coverage, and academic literature. In total, the team assembled, reviewed, and synthesized takeaways from over 60 sources. The information drawn from this secondary research helped to shape the team's overall trajectory of work and formed the basis for a rich set of case studies included throughout this report.

Building off this secondary research, team members conducted interviews with 8 academic and industry experts, including professors from the Harvard Kennedy School and Harvard Business School, journalists, and former automotive startup founders. These interviews bolstered the team's analysis of current and proposed policies revolving around electric vehicles and informed the team of business risks and ideas for companies and individuals in the automotive industry.



By drawing from both primary and secondary research, the team was able to form a comprehensive portrait of both the challenges posed by the arrival of electric vehicles to the current automotive industry and the opportunities presented by the future of electric vehicles in the United States and abroad.

4. Introduction to Electric Vehicles

4.1 Description of Electric Vehicles

An electric vehicle (EV) is structurally similar to a traditional internal combustion engine (ICE) vehicle, but instead uses **electric motors in place of a gasoline engine** for propulsion and a **battery in place of a gas tank** for fueling.[1] These distinctions require EVs to have a large and **powerful rechargeable battery**. Electric motors also provide instantaneous acceleration compared to ICE vehicles. Furthermore, EVs boast fundamentally mechanically **more streamlined designs**, including the lack of a complex-geared transmission, lowered needs of oil supplements, or lowered usage of the brakes.[2]

This design also allows EVs to unlock new practical use cases. An EV battery can act as a power source; for example, in case of a power outage, the recently announced **Ford F-150 Lightning** can use its battery as a generator to power a house for up to 3 days. The lack of an internal combustion engine also allows the vehicle to have substantially larger cargo space.[3] Joseph White, the global automotive editor of Reuters, shared that these differences will inevitably allow EVs to have **unique, unprecedented advantages** over ICE vehicles.[4] In 2020, the EV market size was estimated at $246.7 billion, and was projected to grow at an annual growth rate of 24.3% through 2028.[5]

In conjunction with EVs, there exist various configurations of drivetrains on the market, which create variation in vehicle dependence on electricity. An **EV**'s only power sources are its battery and motor(s). A **PHEV** (plug-in electric vehicle) vehicle uses both electric and gasoline power sources, and a **HEV** (hybrid electric vehicle) means the vehicle's main power source is gasoline that is assisted by an electric motor.[6] With such a wide variety of power modes, each of the vehicles has drastically different usage. Exhibit 1 puts this these differences into context; the remainder of this paper will focus specifically on EVs.

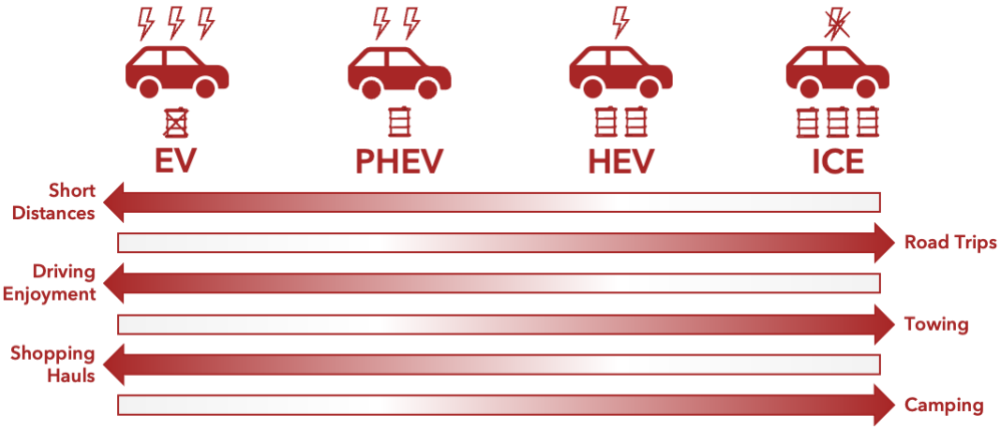


Exhibit 1: *Differences between EVs, ICEs, and related vehicle types*

[1] Forbes
[2] Ibid
[3] Ford
[4] Interview with Joseph White
[5] Fortune Business Insights
[6] Edmunds

The production of EVs poses unique manufacturing considerations, such as with the development of **specialized factories** for battery production.[7] Furthermore, both the battery and motor(s) require **rare earth metals**, a major factor that keeps EVs from being truly sustainable.[8] In fact, the sustainability of rare earth mining in its present state is both economically and politically infeasible, due to the quantities of material needed and the difficulty of gaining access to rare earth metals.[9] The cost of continuing research and development as well as costly manufacturing means that **EVs are still mostly inaccessible** from a financial standpoint. In fact, Robert I. Goldman Professor of Economics David Laibson of Harvard University argues that EV subsidies only benefit those who are financially successful, exacerbating income inequalities.[10]

Despite higher upfront costs, an electric vehicle is cheaper to maintain and operate. An EV owner will enjoy **less maintenance trips**. The innovations in electric vehicles also allow them to operate much more efficiently than ICE vehicles. An ICE is notoriously inefficient in burning fuel, such that even if only fossil fuel sources were used to generate electricity, electric vehicles would still be more **efficient and environmentally sustainable**.[11] Todd Alexander, a former ICE startup finance and strategy associate, shared that despite his company having spent well over half a billion dollars on research and development, he believes that it might be physically impossible for an ICE vehicle to achieve EV-level efficiency.[12]

4.2 Prominent Examples

An emergent leader in the EV industry over the past several years is Tesla. Tesla makes up 54% of EV sales in the United States, with Chevrolet (10%), Toyota (8%), and BMW (6%) also producing high numbers.[13] **Tesla is by far the largest EV company,** with its market capitalization standing at $869 billion as of February 2022, a staggering ten times larger than its closest competitor, **Rivian**.[14] The most popular EVs are Tesla's Model Y and Model 3, selling about one million units combined; the **Chevrolet Bolt, Ford Mustang Mach-E, and Volkswagen ID** rounding out the top five.[15] More Model Ys were bought in the first half of 2021 than all other non-Tesla EVs, indicating that the EV market is still highly concentrated.[16]

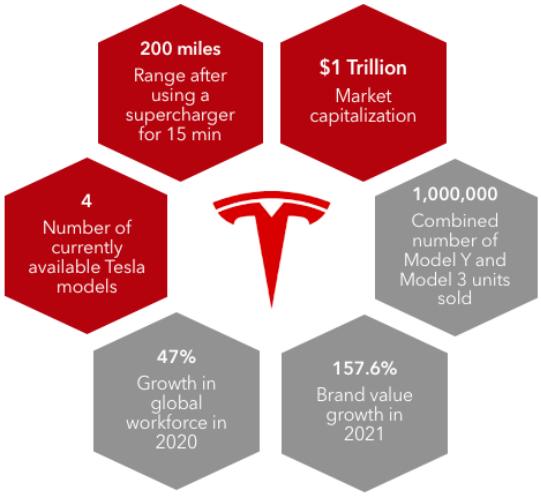


Exhibit 2: *Key statistics about Tesla.*

Tesla's astronomical growth over the last decade has made the company's image synonymous with electric vehicles. Their dominance in marketing is also a point of interest, as their brand value grew the fastest of any company in 2021, at a 157.6% rate. **Tesla's growth is also driven by their concerted effort to pursue international expansion**, with their global workforce experiencing a 47% growth from 2019 to

[7] Oil Price
[8] IDTechEx
[9] Forbes
[10] Interview with Professor David Laibson
[11] U.S. Department of Energy
[12] Interview with Todd Alexander
[13] EV Adoption
[14] The Street
[15] Car and Driver
[16] Ibid

2020.[17] Tesla's creation of new **gigafactories** and **superchargers**, particularly in Germany and China, has the company poised to greatly expand its global reach. Gigafactories allow Tesla to manufacture all parts for their cars in one place, eliminating transportation costs.[18]

Other automotive firms are producing new EVs of their own. The **Ford F-150** appears to be the most prominent competitor to Tesla. The F-150 is America's most popular car, and Ford has announced that a fully electric version will be available by spring 2022.[19] As GreenBiz states, this announcement is truly a "turning point in the evolution of electric vehicles".[20] Experts, however, are **not ready to assert that this necessarily poses a threat to Tesla**. Senior Lecturer Lou Shipley of Harvard Business School and Professor Joao Peças Lopes of the Faculty of Engineering of Porto University both believe that it will be almost impossible for legacy automakers to catch up to Tesla's level of innovation.[21] This is because the EV industry revolves around software, and Tesla simply has far and away the most innovative software design. From regulating the brakes and critical systems to providing entertainment and heated seating, computer systems control all the operations in EVs: "electric vehicles are more about software than hardware."[22] **Software-wise, the most apparent threat to Tesla is Rivian**. Backed by Amazon, Rivian is now worth $116 billion–its market capitalization now exceeding that of established automakers like Ford–but whether they have the necessary software capabilities remains to be seen.[23] [24] [25]

4.3 Regulatory Environment

An increased focus on climate change, renewable energy, and urban air quality has contributed to a series of government incentives to promote the adoption of electric vehicles. These measures range from investment in battery technology and charging infrastructure to subsidies and carpool lane access for EV buyers.[26] [27] [28]

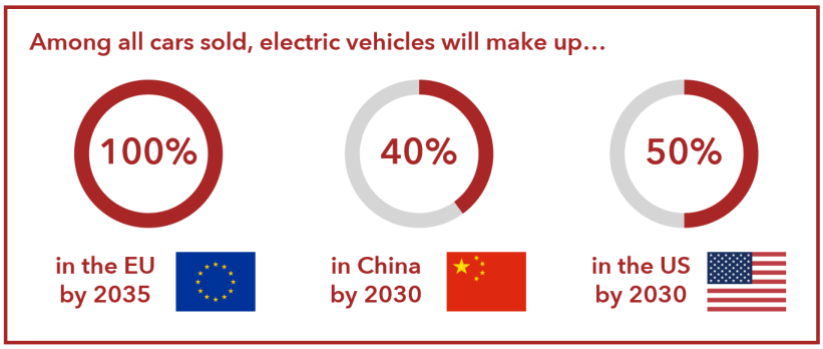


Exhibit 3: *EV sales projections in different geographical areas.*

The EU boasts the highest EV penetration in the automobile market, with EV sales having grown at 60% annually from 2016 to 2020. The "Fit for 55" climate action package pledges to **cut EU emissions by at least 55% by 2030**, with the goal of attaining climate neutrality by 2050. EV adoption is central to achieving these targets, and the EU has proposed a ban on sales of ICE cars, starting 2035.[29]

China has the world's largest number of EVs. Significant government investment was provided to EV makers in a bid to combat air pollution and gain technological leadership. In the early and mid-2010s, the

[17] Bloomberg
[18] Electrek
[19] Newsweek
[20] GreenBiz
[21] Interview with Lou Shipley
[22] eFaraday
[23] The Motley Fool
[24] The Street
[25] Go Banking Rates
[26] European Union
[27] MIT
[28] The White House
[29] Pew Research

Chinese government sought to leapfrog the EV race and produce larger and more expensive electric cars for the global market. By the late 2010s, state support shifted towards the production of lower-horsepower EVs for the domestic market. EV production has now matured to the extent that the Chinese government plans to end subsidies for EV purchases before 2023.

In the United States, the federal government provides an **income tax credit** of up to $7,500 for purchases of new EVs.[30] State-level incentives play a key role in explaining regional variations in EV adoption, with California as the nationwide leader. At least twelve states have adopted California's low-emission and zero-emission vehicle standards, which mandate that a minimum percentage of an automaker's new car lineup must comprise EVs.[31] **Geopolitical tension between** the US and China has accelerated the US government's investment into the EV sector. Warning that "China is increasingly cornering the global supply chain for electric vehicles and batteries", President Joe Biden included $**7.5 billion of funding to build a national charging network** in the 2021 Bipartisan Infrastructure Law, in addition to a proposed expansion of federal subsidies for EV purchases.

[30] Interview with Professor Henry Lee

[31] National Conference of State Legislatures

5. Consumer and Market Trends

Regulatory trends and technological advancements have accelerated the development of new EV models and consumer adoption of electric cars. This section analyzes EV growth in three key markets and evaluates current consumer perceptions of the EV market.

5.1 Trends in China, Europe, and the US

Following a decade of rapid growth, 10 million electric cars were sold in 2020. While the Covid-19 pandemic contributed to a 16% drop in global car sales, **EV sales have remained buoyant**, increasing by 41% in 2020. The world's top three EV markets are China, Europe, and the US, which account for 94% of global EV sales. While China leads in the absolute number of EVs sold, Europe has the highest EV penetration, i.e. sales of EVs as a fraction of all car sales.[32]

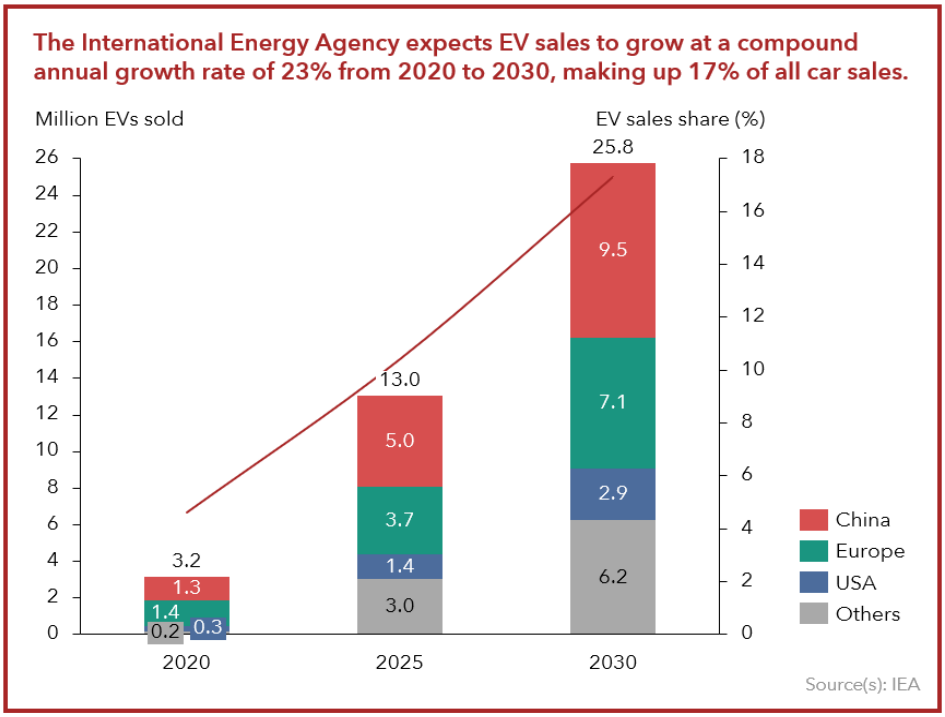


Exhibit 4: *Projected growth in EV sales for China, Europe, and the US.*

In the next 5-10 years, **growth in EV sales in Europe and China is expected to be significantly faster than in the US**. By 2030, Deloitte estimates that China will comprise 49% of the global EV market, followed by Europe at 27%, and the US at 14%.[33] EV sales in the US slowed down pre-pandemic, as annual growth dropped from 80% in 2018 to 12% in 2019.[34] Higher growth in Europe is fueled by an extensive EV charging network with competition between local energy providers and private companies. In China, relatively short intra-city trips make EV range a lesser concern. EV adoption in the US is likely to

[32] IEA Global EV Outlook 2021
[33] Deloitte
[34] McKinsey & Company

accelerate from 2025 onwards, especially after utility providers rework infrastructure to make home charging more feasible.[35]

5.2 Consumer Preferences and Takeaways

Globally, more than 40% of those intending to purchase a new car are considering an EV. With the Covid-19 pandemic increasing environmental awareness, Ernst & Young argues that "a tipping point has been reached in green consciousness—for many years a peripheral concern that lagged behind more practical matters such as cost and range". **Desires for sustainability are gaining traction** and translating into changes in consumption patterns, driving EV growth post-pandemic.[36]

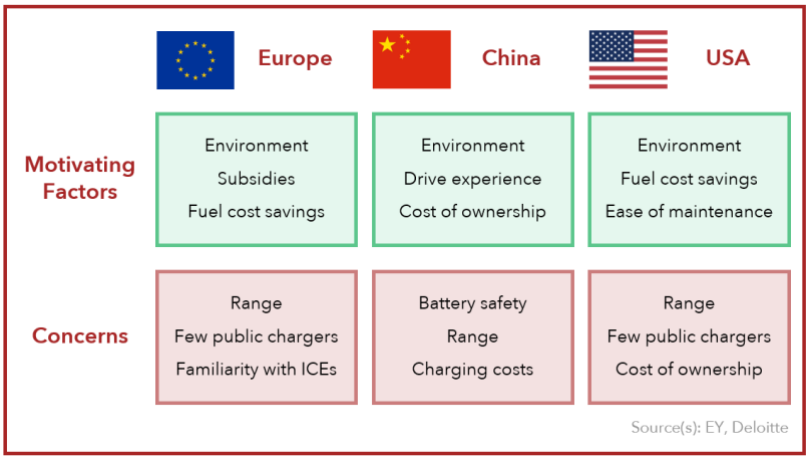


Exhibit 5: *Consumer sentiments surrounding EVs in Europe, China, and the US.*

5.2.1 Europe

The popularity of EVs in Europe is **motivated in large part by generous government incentives**. With the maturation of EV technology, many key concerns about purchasing an EV are gradually alleviated. For instance, despite higher upfront costs, subsidies and the lower maintenance and fuel costs of EVs mean that the total cost of ownership of an electric car is similar to that of a gasoline-powered car. Newer EV models have ranges comparable to ICE vehicles, and some governments in Europe have committed to additional investment in charging infrastructure, in part as a form of Covid-19 stimulus. In fact, the **rising adoption of EVs creates a virtuous cycle**, as consumers become more reassured about driving a new type of car when they hear positive stories from their family and friends, which drives further adoption. Government deployment of electric buses, such as in Denmark and the Netherlands, has further normalized the use of EVs in day-to-day life.[37]

[35] Interview with Professor Henry Lee
[36] Ernst & Young
[37] Deloitte

Case Study: Consumer Profiles in the UK

Following a survey of UK residents about their car preferences, Deloitte segmented consumers into nine segments based on car travel habits and demographics. Young and middle-aged adults who commute to work—with a combined size of 4 million people—are the most willing to consider an EV for their next purchase. In targeting this segment, EV makers can market models with higher range, and package car sales with home chargers for slower overnight charging.

Those who do not currently own a car – about 3 million people – view a better driving experience as the key reason for considering an EV, above environmental consciousness. EV makers producing entry-level models should market improved acceleration and drive quality and increase customizability of the vehicle interior to better target this group.[38]

The pandemic has disrupted global supply chains, impacting the EV industry. The chip shortage has slowed EV production around the world and is expected to last into 2022.[39] As the pandemic continues in 2022, **personal travel is expected to recover faster than work-related travel**, and work trips are likely to increase in distance; this could be because the shift to hybrid or fully remote work has encouraged some to move away from city centers.[40] The reduction in frequency of car usage may make consumers more content with slower home charging instead of fast charging, though having sufficient range will likely remain a key priority.

5.2.2 China

In China, domestically produced EVs with **lower horsepower and lower range** have found the greatest success. Intercity rail transport is relatively advanced in China, meaning that cars are typically used for local commuting: the average daily distance driven in Beijing is a mere 28 miles.[41] Hence, **"range anxiety" is much less prevalent among Chinese consumers** as compared to European and American buyers.[42] Coupled with policies exempting EVs from expensive car registration lotteries, EVs are a compelling choice for lower-income urban residents. Hence, in late 2021, EVs made up close to 100% of new sales of A00-type microcars, the smallest size of passenger cars.[43] For foreign carmakers seeking to capture a slice of the booming Chinese market, a pivot towards smaller-horsepower and lower-range EVs may be helpful.

[38] Ibid
[39] JPMorgan Research
[40] Ernst & Young
[41] Hou, Wang, and Ouyang
[42] Interview with Professor Henry Lee
[43] Interview with Xin Sun

Deep dive: The four best-selling electric cars in China in 2021

	1. Wuling Hongguang Mini	2. BYD Qin	3. Tesla Model Y	4. Tesla Model 3
				
Type	Microcar	Sedan	Compact SUV	Premium sedan
Price (aft. subsidies)	USD 4,500	USD 20,400	USD 47,500	USD 41,800
Sales	395,000	187,000	170,000	151,000
YoY Growth	250%	260%	-	10%
Range	75 mi	250 mi	340 mi	350 mi
Torque	85 Nm	180 Nm	400 Nm	400 Nm

All specifications are for the base BEV model
Source(s): China Passenger Car Association, manufacturer data

Exhibit 6: *Differences between best-selling EVs in China.*

Tesla is the only foreign carmaker to produce a car model which ranks among China's top 15 best-selling EV models. The Chinese government provided fast-track regulatory approval and subsidized land to Tesla in a bid to stimulate competition and raise the quality of domestic carmakers, giving Tesla an early lead over other foreign carmakers.[44] With the lifting of restrictions surrounding foreign investment in car manufacturing, **a window of opportunity has opened** for foreign carmakers to enter the Chinese market.[45]

One concern that is especially pronounced among Chinese consumers is the **safety of lithium batteries**. A spate of battery fires forced EV manufacturer NIO to recall 5,000 vehicles in 2019, while Shanghai-based WM Motor recalled 1,000 vehicles after four cars caught fire in a month. Domestic carmakers, especially unproven startups, must improve their safety credentials, while established carmakers can leverage their track record of reliability when marketing in China.

After a decade of growth in its electric car industry, **some consolidation of EV manufacturers may be expected in China**. With a multitude of state-owned and private carmakers, the Chinese Ministry of Industry and Information Technology has encouraged mergers to combat a situation which it described as "too many companies, each too small and scattered".[46] Proposed regulations include a minimum production capacity utilization rate, where provinces which fall below the quota will not be allowed to approve new plants.[47] If these restructuring efforts produce stronger EV makers capable of producing higher-quality cars, then Chinese consumers may grow even more favorable to EVs.

[44] Interview with Xin Sun
[45] CNBC
[46] China News
[47] Bloomberg

5.2.3 US

Range anxiety is the chief concern expressed by American buyers but is on a declining trend. Low driving range and a lack of charging infrastructure (discussed later in this report) are consistently among the top three concerns expressed by American consumers in surveys. This belief is especially strong in rural areas and is "as much psychological as it is practical," according to White.[48] However, with improved batteries, newer EV models have comparable ranges to ICE vehicles. Consequently, **HEVs and PHEVs are falling out of favor**, in part because their range advantage is being eroded.[49]

Although the average American driver travels just 27 miles a day, **peak transport needs over holiday seasons are much higher** in the US.[50] While EVs are popular for day-to-day trips, many EV owners also have ICE cars that they use for longer-distance trips, especially during winter periods when lower temperatures reduce driving range.[51] Hence, EV adoption will be **concentrated among higher-income households with more than one car**. Indeed, according to Professor John Graham of Indiana University, EVs have penetrated the premium sedan market because "consumers of such vehicles tend to value performance".[52]

Within urban population centers, **regulation plays a critical role in boosting EV uptake**. California, which leads in emissions standards and monetary incentives, accounted for 42% of all EV registrations in the US in 2020, more than seven times the rate for Florida, which had the second-highest number of registrations.[53]

US carmakers have invested billions of dollars into developing and building EVs, and many new models are expected to arrive in the mid to late-2020s, including larger SUVs and pick-up trucks. General Motors announced an end to the production of gasoline and diesel-powered cars, trucks, and SUVs by 2035, while Ford has committed $10.5 billion in EV investment through 2025. The **influx of new models across a diverse range of vehicle types** is likely to boost EV adoption in the latter half of the decade. The desire for sufficient range for long-distance travel has resulted in carmakers concentrating their efforts in building premium cars and pick-up trucks. However, owing to the high cost of battery production, **an affordable sedan with a driving range comparable to an ICE vehicle offers little profitability**. According to Professor Graham, unless the cost of lithium batteries decreases significantly, or expanded charging networks reduce the minimum range consumers would accept, it is **unlikely that the US will reach President Biden's stated goal of 50% EV penetration by 2030.**[54]

[48] Interview with Joseph White
[49] Schroders
[50] Graham and Brungard
[51] CNBC
[52] Graham and Brungard
[53] McKinsey & Company
[54] Interview with Professor John Graham

Case Study: ICE Companies are Shifting to EVs

Different ICE vehicle makers are responding to the EV boom in different ways. While some are choosing to innovate and introduce EV models in-house, others are focusing their efforts on strategic areas.

Ford is collaborating with Volkswagen and leveraging its partner's Modular Electric Drive toolkit to produce smaller-sized cars for the European market. Meanwhile, its in-house research efforts are focused primarily on larger-sized SUVs and pick-up trucks, enabling Ford to strategically capture the light commercial segment. This includes the introduction of the Mustang Mach-E SUV, the E-Transit (the electric version of America's top-selling van), and the F-150 Lightning (the electric version of America's top-selling truck).

In response to consumer concerns over performance, Ford's marketing emphasizes the power of its electric models, including a demonstration in which a prototype F-150 Lightning towed ten double-decker freight cars, weighing over a million pounds.[55]

The findings above demonstrate that for American carmakers, premium sedan and pick-up truck submarkets offer higher profitability, and EV variants appeal to consumers because of superior acceleration, drive quality, and towing capability. However, **competition in this slice of the car market will intensify**, with EV versions of popular ICE trucks (such as the all-electric GMC Hummer, Ram 1500, and Chevrolet Silverado) and new models (such as Tesla's Cybertruck and Rivian's R1T). Investment into the lower-end sedan and hatchback range may not be immediately profitable but entering at the right time to exploit decreasing battery costs could offer a substantial first mover's advantage.

6. Infrastructure and Policy

Robust improvements in infrastructure are required to support the widespread adoption of EVs. This section, focusing specifically on the US, characterizes current infrastructure deficits and opportunities for expansions.

6.1 Charging Infrastructure

The number of charge points for EV infrastructure is currently only **10% of the number of fueling points in current gas networks**. Furthermore, a gas station has an average of 10 pumps, whereas an EV station has only 3 charging points, which means charging points are located sparsely from one another and individually have less capacity.[56] [57] This poses a concern, as the current long charging times for many EVs means drivers may have difficulty finding and using charging stations, as manifested in consumer sentiments as discussed above.

Tesla's **Supercharger network** currently dominates the landscape. Historically, the network has been exclusive to Tesla models and played an integral role in attracting customers. It not only has the greatest

[55] Ford Media Releases

[56] Reuters

[57] PricewaterhouseCoopers

number of stations, but it also maintains most upkeep and offers the quickest charging.[58] However, as of November 2021, Tesla has allowed non-Tesla models to charge at 10 of its Netherlands stations. It is unclear when Tesla will expand the program to the public.[59] Drivers of other EV models often have critical problems with charging. The YouTube content creator MKBHD did a case study in which he compared taking a road trip with a Tesla Model S, a Ford Mustang Mach E, and a gasoline Audi Q5. The results were not surprising: the Audi took the lead, but the Tesla closely trailed behind. The Ford, however, struggled to catch up, as charging points along the path had issues with quality assurance.[60]

Non-Tesla networks also need to match the quality control and assurance that is seen in Tesla Supercharging stations. ICE drivers typically do not have to worry about range as gas stations are ubiquitous, intuitive, and reliable: gas pumps are universally compatible and maintainable. Bridging the **infrastructure gap between EV and gas pumps and ensuring these characteristics hold with charging stations** will be key to the mass adoption of EVs.

The current EV infrastructure mostly fulfills niche driver behaviors, as most charging stations are located near malls or shopping centers, leading EV drivers to stop to charge and spend the wait time in nearby establishments. Given this behavior, **malls and shopping centers may position themselves as spaces to accommodate EV drivers** for food and entertainment. As pointed out by White, this "convenience charging" behavior also allows—infrastructure permitting—the opportunity for "oases" of charging and establishments along remote locations to spawn, especially in areas where drivers drive long distances.[61] This may **change road trip culture** at large, opening new economic opportunities.

Currently, however, the dominant criteria which drivers consider when fueling are price, convenience, loyalty, and quality.[62] Charging networks also must match this existing driver behavior, which **prioritizes convenience**—meaning spontaneous demand for recharging, as quickly as possible—as a primary concern, upwards of 55% of the time.[63] Better range management assisted by software might help, but inner-city usage might benefit from a **sharper fast charge curve**.[64] The other criteria might not be as applicable when translated into the EV context. Prices for charging are already lower than fueling, as many EV manufacturers provide free charging as a sales perk. The number of charge points is also presently too low for drivers to develop loyalties to certain networks based on brands or features.

Improving charging infrastructure will inevitably bring large changes and opportunities to the economy at large. It is obvious that building and servicing charging stations will employ more high-talent workers. Furthermore, the increased foot traffic from customers waiting for their car to charge also means that **establishments surrounding this new charging infrastructure will thrive**. Finally, as pointed out by White, the **required technology to improve fast charging to fit current driver needs provides innovation opportunities**, as discussed later.[65] Current shortcomings in the charging landscape provide new and potentially lucrative economic opportunities.

[58] CNBC
[59] Forbes
[60] MKBHD
[61] Interview with Joseph White
[62] Reuters
[63] PricewaterhouseCoopers
[64] Inside EVs
[65] Interview with Joseph White

To promote the organic and fast growth of charging infrastructure, Professor Laibson argues that the government should not intervene. He argues that current shortcomings, such as the exclusivity of specific charging networks, will sort themselves out in the future, as already demonstrated with Tesla opening their network in the Netherlands. With that said, the political implications of EV charging are unavoidable. Scattered throughout a city and taking up valuable spaces, charging stations **might affect zoning laws** as residents will have to adapt to living around them. Furthermore, assuming advancements in technology allow the removal of rare earth material in EV production, the mass adoption of EVs and advancements of EV charging infrastructure will allow countries to **lessen their direct reliance on fossil fuels**, helping achieve green energy goals.[66]

6.2 Power Grids

If all vehicles in the United States were EVs, the country would need to produce **roughly 25% more electricity than it uses today** to satisfy charging demands.[67] This number in and of itself is not a concern, as the gasoline costs saved will offset the increased utility price hikes.[68] However, there is a major difference between generating electricity and delivering it through the grid.

Energy consumption fluctuates like a wave, peaking in the afternoon when work hours end and dropping during the days when houses are left unoccupied. The amount of energy required during peak hours hovers near the maximum capacity that the grid can deliver. This means that if EVs, post-mass popularization, are charged when consumers get back home, the increased electricity demands will cripple the existing gridlines, despite utility companies being able to, in theory, provide the needed electricity. The below figure illustrates the problem, visualizing daily fluctuations.

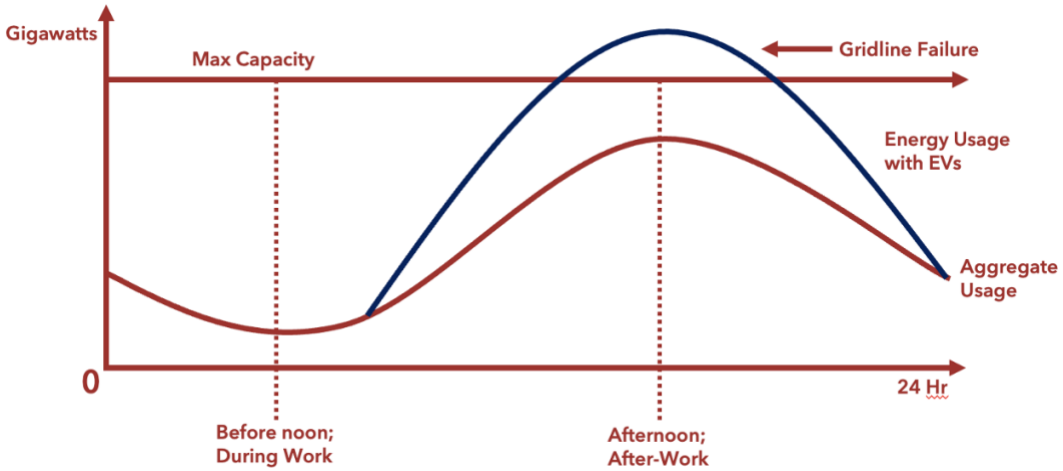


Exhibit 7: *Fluctuations in energy demand may cause issues with handling surges and high loads.*

Grid lines require increased attention and robust upgrades to match future increased electricity demand. Grids must be equipped to handle daily variations in energy consumption, which can be offset using different incentives, such as smart monitoring and different rates throughout the day. Another upgrade is

[66] Interview with Professor David Laibson
[67] The New York Times
[68] The Conversation

the number and diversity of power generation methods. Furthermore, further local infrastructure upgrades are needed in a commercial context. Shipping depots will need to re-equip their facilities to accommodate large numbers of electric cargo trucks. Apartment complexes will also have to implement grid engineering and designs for tenants.[69]

As of 2021, the Department of Energy is currently working on plans to revitalize power grids. Current considerations include **microgrids** to provide green energy for centralized areas, **advanced metering** to have more transparency, **energy storage** to combat peak usages, and overall improved grid hardware.[70] Each plan addresses a unique concern, but it is still unclear on the logistics surrounding the plans. The **state-regulated nature of the power grids** hints at the possibility of power struggles between states as they grapple with federal funding. Furthermore, it is unclear how the public will perceive certain lifestyle changes such as smarter energy consumption budgeting. With that said, improving the power grids should **allow more highly technical jobs to form** such as technicians and engineers, opening fields for which the government can invest subsidies. Components of the revitalization plan that require complex algorithms will also benefit from computer scientists. In short, the expansion and adoption of better grid infrastructure will create high-skill jobs that benefit local and even rural communities.

6.3 Energy Generation

Most of the US's energy generation comes from **non-renewable sources**: gasoline, hydrocarbon gas liquids, natural gases, and coal. Biomass, hydropower, wind, solar, and geothermal, respectively, comprise trailing renewable energy sources.[71] Coal's involvement in electricity generation is a strong talking point by those who oppose electric vehicles. Aside from that, however, there is almost **unanimous bipartisan support towards green energy** sources: both conservative and liberal citizens have supported the expansion of wind and solar energy both prior to and after the Trump presidency, which suggests that political tensions surrounding future green energy policies may diminish.[72] [73]

To generate electricity more cleanly and move away from fossil fuels, there have been numerous efforts to make **renewable energy production more accessible** to the public. An example of such efforts was shown at CES 2022: solar panels with an innovative, highly efficient installation process at substantially lower costs.[74] The plan will allow more residents to equip their house with solar panels at more affordable prices. Other commercial advancements include floating wind turbines to harness more gusts of wind with minimal change to the landscape.[75] There is no shortage of innovation in bringing electricity generation to full sustainability.

Current predictions expect renewable energy sources to make great strides in the future.[76] As argued by Professor Laibson, if the government wants to intervene and trickle the green economy, it needs to do so more efficiently. Many subsidies are given to households and utility companies within regions where there

[69] The New York Times
[70] U.S. Department of Energy
[71] U.S. Energy Information Administration
[72] Pew Research
[73] Business Insider
[74] CNET
[75] The Guardian
[76] U.S. Energy Information Administration

are not enough natural resources for proper and efficient energy generation. This is **ill spending**; money can be allocated not only more efficiently, but also in a socially just manner.[77]

[77] Interview with Professor Laibson

7. Adjacent Industries

The forecasted growth of the EV industry has posed many potential threats and opportunities for automotive-adjacent and EV-adjacent industries. The Motor & Equipment Manufacturers Association estimates that up to 300,000 jobs could be lost in the auto parts industry when the transition to EVs is complete. While all automotive-adjacent industries will be starkly affected by the rise of EVs, other business opportunities in EV-adjacent sectors are also apparent.

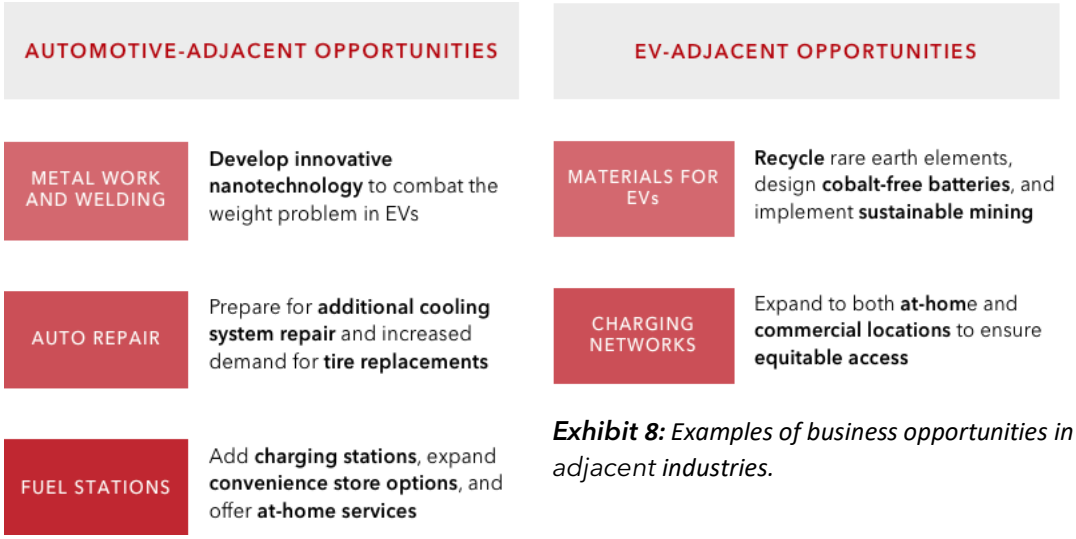


Exhibit 8: *Examples of business opportunities in adjacent industries.*

7.1 Automotive-Adjacent Industries

7.1.1 Metal Work and Welding

A fundamental challenge for automotive-adjacent industries posed by the shift to EVs is that **new EV-tailored jobs will fail to resemble the ones lost**. This phenomenon is most clearly seen in metal workers: mechanics who have spent decades training specifically in engine manufacturing may struggle when making the transition to battery production.[78] ICEs have over 2,000 parts, but EVs do not contain structures such as the cylinder, the piston, and the crankshaft.[79] Intriguingly, EVs do offer **new lucrative opportunities for sheet metal fabricators**. One of the major concerns with electric vehicle models is that the components required for the battery (discussed later) add significant weight. These "lightweight components are key to reducing vehicle curb weight", which is needed to maximize vehicle efficiency.[80] Many EVs use aluminum to account for this weight problem, and while there are mechanical differences between welding aluminum and traditional steel, this switch is a potential opportunity for aluminum welders to gain more prominence.[81]

[78] Ibid
[79] JRank Science Encyclopedia
[80] Bloomberg
[81] Industr

To tackle the weight problem, companies such as AK Steel and GM are also in the process of using new **nanotechnology to make vehicles lighter**.[82] These nanotechnologies will not only help with vehicle weight, but will also help to increase battery capacity, improving the vehicle's range.[83] This new technology has yet to popularize in the market and can provide promising opportunities for firms that can make strides in this area. **The global nanotechnology market size is expected to more than triple by 2028**, and the demand for increased vehicle efficiency will "create new opportunities for players in the market".[84] Any firms that can make strides in this area have a promising future.

7.1.2 Automotive Repair

The auto repair industry is perhaps the sector that will be most affected by the rise of EVs. EVs simply contain fewer parts than internal combustion engines and require servicing less frequently.[85] Oil changes, emission checks, and fuel filtration are examples of automotive services rendered obsolete when dealing with EVs. Of the current auto repair shops that service EVs, although only 3% of all cars that are serviced are EVs, 89% of shops have seen an increase in the numbers of these vehicles coming in for servicing.[86] While auto repair shops see a spike in the increase in the number of EV customers, this **radically different design of the electric vehicle and dominance of EV companies leads the future for independent auto repair shops to look somewhat bleak**. Companies like Tesla have already begun establishing widespread repair shops of their own, totaling over 170 by the end of 2021, and currently, only 28% of [independently owned auto repair] shops have invested in tools and equipment to specifically service EVs.[87] With Tesla also making house repair visits that can be arranged in seconds through their app, it will be difficult for these independent shops to gain the capital to restructure their business models. Senior Lecturer Lou Shipley at Harvard Business School sees little hope for these small auto repair shops. Moreover, as Tesla also builds their own EV software, they can repair their vehicles most efficiently. Shipley even claims that owners of these shops should sell their businesses now when gas prices are high, as their businesses will slowly depreciate.[88]

Despite the seemingly discouraging future, there are several opportunities for these auto repair shops to remain profitable. First, they have **ample time to prepare**. Most experts think it will take 10 to 15 years for EVs to truly dominate the market, giving these small businesses time to adapt through learning and education, which is discussed below.[89] Second, due to the added weight, EVs also consume tires at much higher rates than ICEs. Some analysts claim that EV customers will seek tire replacements up to 30% more frequently than ICE owners, meaning that these repair shops will still offer necessary services. EVs also have **more demanding cooling needs**: this leads to a need for more efficient materials to maintain the vehicles, leading to new opportunities for these shops, as these parts will inevitably wear down over time.[90]

[82] Bloomberg
[83] Azonano
[84] BioSpace
[85] Bloomberg
[86] Charged Fleet
[87] Cars Direct
[88] Interview with Lou Shipley
[89] The Washington Post
[90] TechCrunch

Finally, the **prevalence of software within electric vehicles provides an opportunity for auto repair shops to reposition their services to become more IT-focused.** In our increasingly digitized world, learning these skills is easier than ever and can even be taught from home via online programs. Learning mechanical skills can take years of close apprenticeship, but the increased ability to learn computer science skills online makes the shift to repairing EVs more accessible for mechanics.[91] 31% of shops have already begun the process of training mechanics in EV servicing, and this figure stands to increase over the next decade.[92] By proactively teaching mechanics computer science skills and focusing on providing services to EV-specific mechanical issues, auto repair businesses may be able to adapt to supporting EVs.

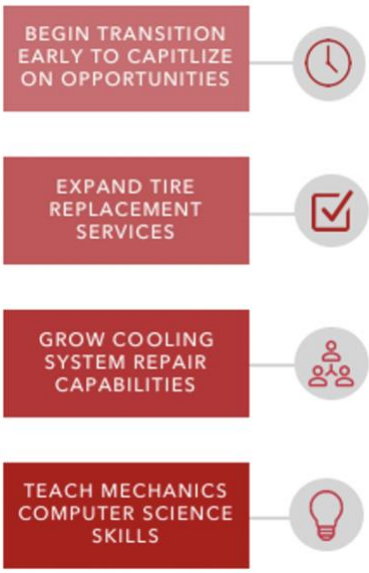


Exhibit 9: *Recommended steps for repair shops.*

7.1.3 Fuel Stations

Like with independently owned auto repair shops, it seems likely that fuel stations will face setbacks with the rise of EVs. Drivers of EVs may simply rely on charging stations, and some individuals can even charge their vehicles from home. The effects on this industry are stark: BCG predicts that **up to 80% of gas stations could be unprofitable by 2035.**[93] Compared to electric charging stations, fuel stations also face higher operational and inspection costs due to government environmental regulations.

White emphasizes that given the slow transition to EVs, gas stations also have time to adapt. The **main challenge with converting to charging stations is the cost,** as installing the necessary electrical systems is likely more than independent stations can afford. Fuel stations owned by large corporations will likely be the ones to first make the switch, as they have greater capital.

Lou Shipley provides a slightly different perspective, as he claims that **as restaurants, bookstores, and liquor stores begin building charging stations in their parking lots, people will no longer have an incentive to go to a gas station**, predicting that these stations will likely be forced to cut deals with the government to keep their gas stations afloat. The clear path forward for fuel stations is to **add charging stations alongside fuel pumps, financed by partnering with larger corporations or the government**.[94] Other experts claim that additional actionable items such as delivering gasoline and services to houses, expanding healthy options in convenience stores, delivering food orders to drivers at the pump, and adding Amazon self-delivery lockers are all potential opportunities for these stations to attract customers and stay afloat.[95]

[91] Green Car Future
[92] Charged Fleet
[93] CNET
[94] Interview with Lou Shipley
[95] Jerry

7.2 EV-Adjacent Industries

7.2.1 Raw Materials

The materials used to make electric vehicles versus internal combustion engine vehicles are quite different. The rise of EVs has led analysts to predict that by 2035, the demand for copper, an essential element for EVs, will double compared to current levels.[96] As a result, the mining and metal industries will be significantly altered. The simple fact is that **low-carbon energy systems are more metal-intensive than traditional energy systems**.[97] EVs also rely on rare earth elements, including materials like lithium, cobalt, nickel, and graphite. The demand for these materials is expected to rise dramatically, with expected compound annual growth rates of 2-3%.[98]

To meet the increased demand for EVs and their batteries, some analysts claim there must be a $30-45 billion investment into mining capacity.[99] Demand for copper, a metal essential in EVs, is expected to double by 2035, spurring the emergence of opportunities surrounding the extraction, exploration, and refinement of copper.[100] Currently proposed mining projects will produce enough copper to build over 6 million new electric vehicles, but there are questions about their feasibility. Due to environmental concerns, the construction of certain mines is being denied by governments.[101] **Companies that can utilize green, low-impact mining techniques, such as in-situ leaching, institute land rehabilitation practices, and purchase electric equipment will be the future of the mining industry**.[102] One company that is leading the way for sustainable mining is Anglo American. By instituting programs to hold board members "accountable for responsible business conduct" and designing systems to "ensure its operations support local entrepreneurship and local procurement", Anglo American has been a model for sustainable mining, and its practices have been praised by the Responsible Mining Foundation.[103]

Another area of concern is the recycling of these materials. While extracting these rare earth metals requires an immense amount of energy and takes a toll on the environment, these toxic chemicals are often left to waste once the cars are out of use. **Researchers are currently searching for ways to make recycled lithium economically attractive**, creating multitudes of business opportunities for firms that can efficiently solve this problem, as it is currently much easier to mine the material than to recycle it.[104]

Changes to the use of cobalt in EV batteries also present a potential opportunity. Cobalt is the **costliest ingredient in EV batteries**, sometimes costing more than the other materials combined. Consequently, companies are currently trying to create cobalt-free cathodes to lower battery costs.[105] The current cobalt-free batteries, called lithium iron phosphate ("LFP") batteries, struggle from low energy density, leading to shorter driving ranges for vehicles. China currently dominates the LFP supply chains, and the US Department of Energy is highly encouraging domestic LFP manufacturing. With Tesla set to expand its use of LFP batteries to all its Model 3 and Model Y vehicles, coupled with strong support from the government, the LFP market presents many profitable business opportunities for firms to innovate in.[106]

[96] General Kinematics
[97] Science Direct
[98] Ibid
[99] Linklaters
[100] General Kinematics
[101] Reuters
[102] Empowering Pumps and Equipment
[103] Responsible Mining Index
[104] Nature
[105] Ibid
[106] CNBC

7.2.2 Charging Network Opportunities

As mentioned previously, the potential for growth in charging networks presents many profitable channels. **The global charging stations market is expected to increase astronomically from 2021 to 2028, increasing from $17.59 billion to $111.90 billion**, with a CAGR of 30.26%.[107] Currently, the number of charging stations cannot accommodate the surge in EVs, and experts claim that the two highest-growth areas for charging stations are at work and in the home. Dr. Scott Hardman of the University of California Davis Institute of Transportation Studies claims that **home charging is the most important because it is "the cheapest and the most convenient"**.[108]

Companies considering building charging stations must consider two main factors: location and charging speed. While home charging provides a convenient solution to many individuals, there are clear equity concerns. Lower-income individuals often do not have access to a garage or consistent parking spot; to accommodate a variety of demographics, chargers would need to be placed in strategic locations such as restaurants, shopping malls, and grocery stores.[109] These places have a clear business opportunity, as individuals can complete other necessary tasks while waiting for their vehicles to charge.

The issue of charging speed is one that scientists have not yet solved, but the new DC Fast charger presents an interesting case study. While most chargers take between 6 and 12 hours to fill the battery of an EV, the DC Fast charger takes only 15 to 45 minutes to charge most EVs up to 80% capacity. One potential obstacle for DC Fast charging is that it will likely cost more with the added speed.[110] **This point reflects a central theme: firms with the appropriate capital will be the ones which can drive the shift to full electrification.** Currently, there are only 5,000 DC Fast chargers in the US, "with big gaps in parts of the Midwest and Mountain West," creating opportunities for expansion in this section of the country. With increased funding from the government, expanding the electric charging network will be a highly profitable opportunity for businesses.
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[107] GlobeNewswire
[108] Vox
[109] Ibid
[110] EVBox

8. Conclusion

EVs bring a myriad of business threats and opportunities owing to their significant design differences from traditional ICE vehicles. From a technological perspective, they offer unique advantages, using streamlined and more straightforward designs, offering larger cargo spaces, and often better performance. However, they require the use of specialized batteries, charging systems, and often offer less range as compared to ICE vehicles.

While the industry is currently dominated by the recent disruptor Tesla, traditional automotive companies and startups alike are currently aiming to break into this ever-expanding market. While the rate of market growth will differ across geographic areas, the industry is poised for continuous double-digit growth through the next decade. Consumer sentiments also reflect a growing interest in EVs. These sentiments differ across geographical areas, and broadly concern issues of affordability, range, performance, and environmental impact. Automotive manufacturers seeking to harness the growing interest in these markets should therefore make sure to tailor their products and brand to the specific characteristics of each market.

The change brought by EVs extends far beyond just automotive companies, however, with far-reaching implications surrounding infrastructure and neighboring industries. Current fields which rely heavily on ICE designs, such as metal work, automotive services, and fuel stations, must develop ways to accommodate an EV-oriented future; possible avenues include employee training and investment in relevant R&D. The energy demand brought about by charging EVs requires significant upgrades and investment in charging networks, power grids, and energy generation methods. Various business opportunities also surround EVs based on projected needs, such as with supplying raw materials and creating new charging technologies. These are just a few of the ways in which EVs are poised to revolutionize the automotive industry, and the world at large.

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