Sluggish Electric Vehicle Adoption and The Related Impact of Inadequate EV Support Systems

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction -

Whilst Americans continue to battle the effects of global warming, such as forest fires and unseasonable weather patterns, the contemporary concern over Internal Combustion Engine (ICE) vehicle emissions is a common topic of conversation as the recent push for deployment of electric vehicles (EVs) to reduce carbon emissions has failed to reach the projections once thought it would achieve. With EVs finding a humble steady-state rate of adoption for all new vehicles being sold in the United States, we contend with the reality that they are contributing little to the decarbonization of the transportation industry. As new EV sales hover around 5-7 percent of new vehicles sold in 2022 (McKinsey&Co., 2022), we must accept that it does not constitute a substantial number of ICE vehicles being removed off American roads when taking into consideration the impressive "286 million vehicles operating on roads throughout the United States" in the first quarter of 2023 (Statista, 2023). The impact of EV and their attempt at ousting the ICE vehicle becomes more underwhelming when accounting for the fact that "Almost 38.4 million used [ICE] vehicles changed owners in the U.S. between the first quarter of 2022 and the first quarter of 2023, while new registrations of vehicles came to about 13.9 million units during that period" (Statista, 2023). Given the sizeable contribution to overall emissions stemming directly from ICE vehicles, the slow progression towards adoption of EVs can be cause for concern. As CO2 is produced in the energy production cycle and not only in the refining of fossil fuels but a second time in the process by the burning of the same fossil fuels by vehicles on the road, EVs replacing ICE vehicles altogether is seen as a major blow for the benefit of the environment in reducing emissions.

As United States legislation regulating carbon dioxide production continues to march towards decarbonization, it appears that now more than ever before it may be necessary for the U.S. to begin a radical transition towards vehicle electrification to reduce the significant impact that public transportation and privately owned vehicles have on the attainability of upcoming regulatory restrictions. This sentiment is reflected in a September 2022 Memorandum of Understanding supported by "leaders of the departments of Energy, Transportation, Housing and Urban Development, and the Environmental Protection Agency" (Energy.gov, 2023). These goals are necessary to address the greenhouse gas effects of the transportation industry and follow on the heels of President Biden's mandate of a 100% clean energy grid by 2035 and net zero carbon emissions for the 49% of light duty vehicles that are most eligible for this transition, as well as research and development opportunities for a National Battery Strategy, Charging Infrastructure, Grid Integration, and Battery Recycling initiatives in order to improve on EV adoption for nation-wide deployment (Energy.gov Factsheet, 2023).

Using the theory of Technological Momentum (Hughes, 1969), which explains that in order for "societies to accept a technological system, it must first align with social context and goals" (Wylie, 2024), this paper will clarify the ways in which EVs have failed to capture market majority via steady adoption of the technology and thus how the technology has failed to align with the contemporary American society's hopes for a zero-emissions future. Additionally, these stunted adoption patterns can be better understood thought the lens of Geoffrey Moore's modified Technology Adoption Life Cycle (1991). In this modified version, Moore posits that there exists a "chasm" between the "innovators", those that will always be on the frontline of all technology developments and early adopters of a technology, and the early majority which is described as those who prefer to wait for a technology to become more commonplace or proven, thus preventing successful and ubiquitous adoption of EVs. Moore's revised technology adoption life cycle can be seen below in figure 1 (Moore, 1991, pp.17). Superimposed over Moore's modified Technology Adoption Life Cycle, we can imagine EV adopters as Innovators being the group of people that was most likely to put a down payment on the first ever Tesla vehicle, the Tesla Roadster back in 2006, when the car and the technology were first popularized by mainstream appeal at a price of approximately $109,000 (Ramey, 2017) without needing to experience the technology and without being convinced of its effectiveness. The Early Adopters in this case would likely be the people who are most likely to adopt the technology quickly after an initial interaction with it, even if it isn't perfect or refined enough for large market expansion, or in the case of the Tesla Roadster – affordable. The Early Majority are the people that despite a widespread supercharging network spanning all 50 states totaling 2,216 stations ("Supercharger Map", 2024) they may still not be ready to fully adopt the technology.

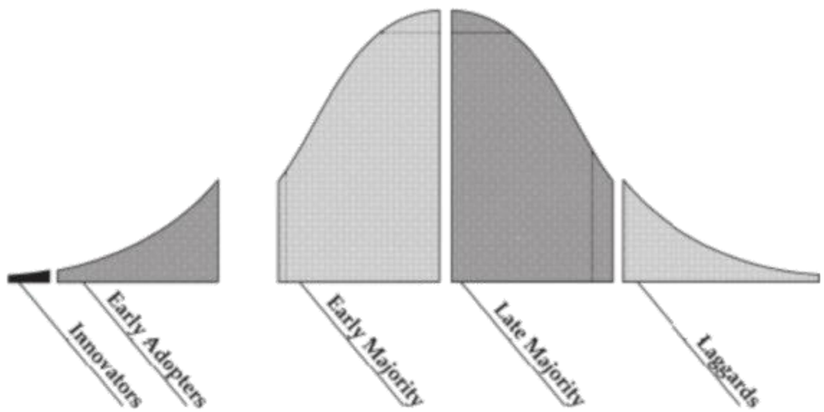

Figure 1: The Revised Technology Adoption Life Cycle, *Crossing the Chasm* (Moore, 1991)

This slow adoption rate may be attributed to a variety of cultural, technical, and organizational factors such as the inadequate infrastructure currently present to support a total roll-out of the technology, innate “range anxiety” of consumers when compared with the current norm of internal combustion vehicles, and the present ubiquity of ICE vehicles. Range anxiety is colloquially understood to mean a feeling of being uneasy regarding the remaining battery charge of an EV being insufficient to complete a “point A” to “point B” trip without potentially running “empty” and finding oneself outside of driving distance range of the next available electric charging station. This phenomenon has been around for just as long as EVs have, and it can be empathetically understood as after all, it’s not as if one could take a “gas can” to the nearest EV charging station to collect a few “watts” of power to make it home or the final destination. Slow EV adoption might also be attributed in part to a decrease in transition incentives for new or repeat EV buyers that may need to be financially incentivized via rebates or discounts due to the initial cost of entry and adoption woes, especially as the number of vehicles that are now eligible for any tax credits has dropped to just 19 models at the start of the year (Becker, 2024).

Finally, we’ll gain even deeper understanding by way of specific examples that show the interconnectivity of cultural, technical, and organizational factors as they can be related and explained through Arnold Pacey’s model of technology (Pacey, 1983) as explained by James Fleck (Fleck & Howells, 2001). Pacey explains, according to Fleck and Howells, that technological progress is affected by “cultural values” and that these values guide a human desire of attaining “fulfillment” through the technology with which they choose to interact (2001). In the lens of EV adoption, the research conducted for this document has been modeled as a modified graphical abstract representation of Pacey's triangle in Figure 2 below.

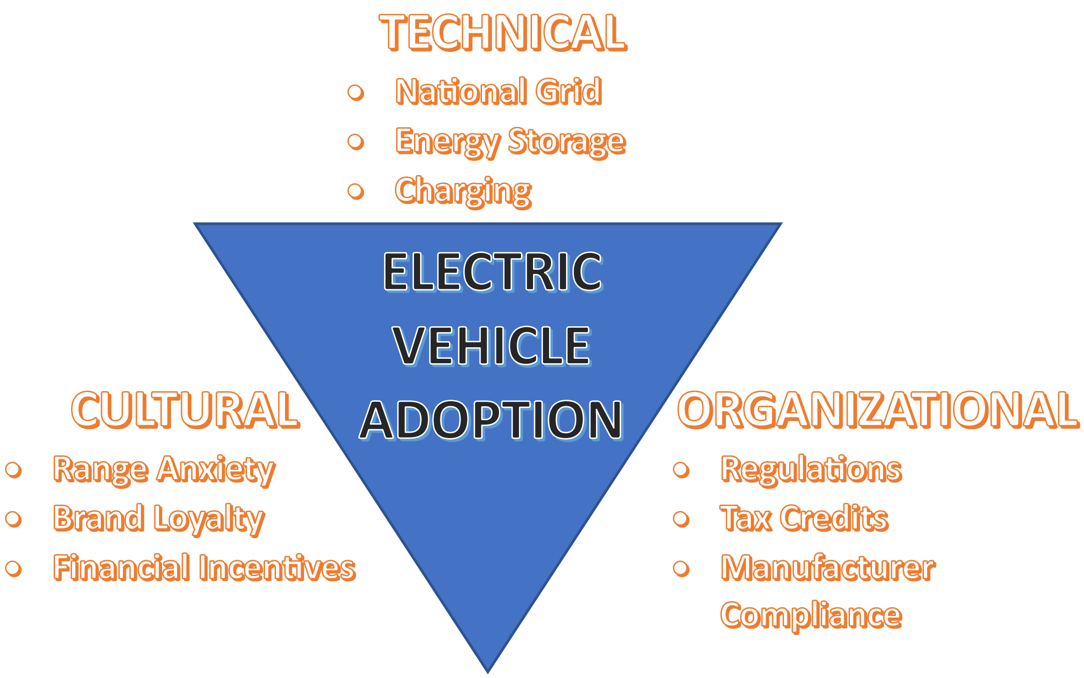

Figure 2: Electric Vehicle Adoption influences. A depiction of Pacey's model of technology practice (Created by De Oliveira, 2024).

Technical Factors -

The contemporary infrastructure of the electrical grid presents a formidable obstacle to the widespread acceptance and use of EVs in the transportation sector. As mentioned earlier, even though the current sales of EVs pales in comparison to ICE vehicles, global projections by the International Energy Agency for continued growth have been made and extrapolated to an estimated 60% of all new vehicle sales by 2030 (IEA, 2022). If the growth is projected to 2050, the potential strain on the power grid could be as high as 1.25 trillion kilo-Watt-hours (kWh), and this figure doesn't even account for national population growth (Vincent, 2022). For a more comprehensive understanding of the underlying issue, it should be noted that the current total energy produced and consumed through the U.S. grid is 4.12 trillion kWh (Vincent, 2022); thus presenting a serious concern for an aging grid which according to the U.S. Energy Information Administration, is heavily reliant on fossil fuels which account for 60% of current energy production (EIA, 2024). This presents a significant concern as a widespread adoption of EVs would only help to reduce emissions if the present and increased demand on the grid is met and substituted by a renewable energy supply not itself dependent on fossil fuels.

The absence of a comprehensive and efficient charging network akin to the well-established infrastructure supporting fossil fuel vehicles poses a substantial challenge in persuading consumers to embrace the transition to EVs, thus worsening the overarching issue of carbon emissions and environmental degradation as only 21.4% of energy produced in the U.S. comes from renewable energy sources (EIA, 2024). Several factors and empirical evidence underscore this assertion. Notably, consumers are largely reliant on manufacturer-provided charging stations, exemplified by the prominence of Tesla's supercharger network, historically catered exclusively to Tesla vehicles, which accounts for over 50,000 charging ports according to Tesla’s website, spread across 2,128 locations (ScrapeHero, 2024). Consequently, the absence of accessible and universally compatible charging options outside of manufacturer-specific networks, coupled with the scarcity of third-party charging stations throughout rural America, significantly hinders the seamless integration of EVs into the broader transportation landscape, which can be better understood as a comparison of EV charging stations and gasoline stations in figure 3 and figure 4 below from the Bureau of Transportation Statistics (2023).

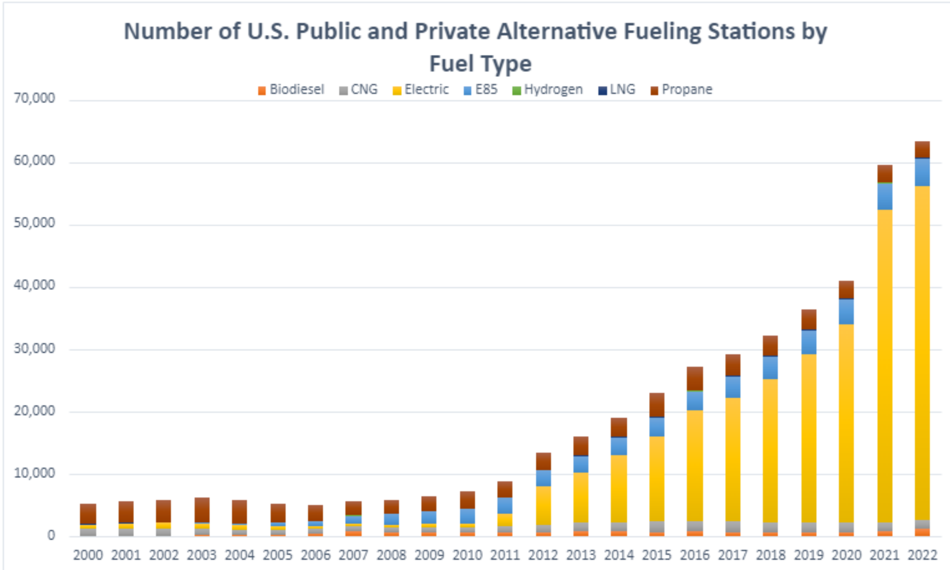

Figure 3: Bureau of Transportation Statistics, Alternative Fuel Stations by Fuel Type.

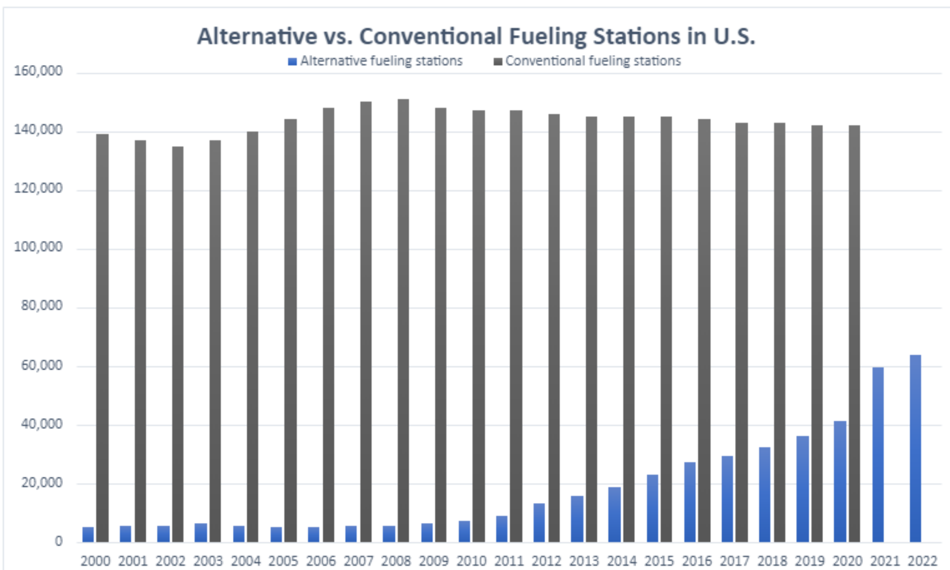

Figure 4: Bureau of Transportation Statistics, Alternative vs. Conventional Fuel Stations.

Furthermore, the impracticality and limited accessibility of charging EVs through conventional home power outlets, particularly for individuals living in multi-family dwellings or urban environments, further underscore the inadequacies of the existing charging infrastructure even for those not living in rural America, but instead limited by lack of access to a private driveway or garage.

The expected trajectory of EV adoption lends credence to the urgency of addressing these infrastructure deficiencies. As projections suggest, by 2030 approximately 60% of all new vehicles sold globally will be EVs (IEA, 2022), signifying a monumental shift in the automotive industry's landscape. These forecasts are corroborated by the IEA's report in which they explain the problematic issue of trying to increase the EV share of vehicles on the road, whilst simultaneously combatting an inadequately sourced energy grid that cannot meet the projected EV market share growth. Insights from Vincent (2022) and analyses featured in Car and Driver (2021), also underscore the burgeoning trend towards EV adoption and its profound ramifications for the existing power grid infrastructure, which currently supplies EVs which do not directly discharge any CO2, however due to the current share of energy produced being largely from fossil fuels, these EVs cannot rightly claim to be completely detached from the emissions tied to the energy produced to charge them.

Cultural Factors -

The phenomenon of range anxiety serves as a formidable barrier impeding the widespread adoption of electric vehicles (EVs) and merits comprehensive examination within the context of cultural factors influencing consumer behavior and acceptance of innovative technologies. According to research conducted regarding the ideal location of new EV charging stations, "To reduce range anxiety, it is suggested that the priorities of deploying new charging facilities should be given to the areas with higher daily traffic prediction, with more conservative EV users or that are further from residential areas," (Song & Hu, 2021). This research seems to support the claim of influence that a developing charging station network may have on adoption rates due to range anxiety in a sparsely supported region. Despite compelling research, findings in the academic textbook *Electric Vehicle Engineering, 1st Ed.* by Enge, Enge, & Zoepf, show that the fear of range limitations may be overstated, with an overwhelming majority of average drivers' daily commutes falling well within typical EV ranges: even an EV with around 75 mi of range could meet the needs of average U.S. drivers on 87 percent of their travel days, even without charging at all during the day (2021).

Moreover, this enduring apprehension is compounded by the notion that EVs may not be suited for longer journeys, such as vacation road trips, in single vehicle households for trips longer than 200 miles (Enge et al., 2021), thus worsening the reluctance of potential adopters to fully embrace this transformative technology. As pointed out by The Washington Post, this underlying concern persists despite notable advancements in battery technology that has alleviated some of the first anxiety experienced by early EV adopters (Mooney, 2016). However, the absence of a robust supporting infrastructure network and readily available charging alternatives slows the adoption process for users, particularly those within the early and late majority segments, who remain apprehensive about integrating EVs into their lifestyle and travel routines. As such, a holistic understanding of range anxiety within the broader cultural environment is imperative for devising effective strategies to ease the mainstream adoption of EVs and mitigate barriers to their widespread acceptance outside of metropolitan hubs already widely supported by Tesla and other third party private and public charging stations.

Cultural and Organizational Factors -

As the current tax advantages for new EVs have reduced eligibility from 40 to just 19 models in the U.S. (Becker, 2024), we see the offerings of EVs as limiting for those needing a financial incentive if not tied into a specific brand. An analysis of survey data by McKinsey&Co (2023) and a separate study by Marsh Finance (2024) it was found that the aspect of brand loyalty, coupled with the limited variety and availability of EV models, appears as a barrier that may significantly contribute to the sluggish adoption of EV technology within the United States automotive market. This intersection of cultural norms and industry dynamics as explained by Pacey's model of technology adoption, underscores a complex challenge that requires a comprehensive understanding and targeted interventions to facilitate the broader acceptance and integration of EVs into mainstream consumer behavior.

At its core, brand loyalty represents a deeply ingrained cultural phenomenon within American society, wherein individuals often develop strong emotional attachments to specific automotive brands that transcend mere functionality or utility. This phenomenon is particularly pronounced in North

America, where the ownership of a particular car brand is often perceived as a reflection of one's identity, lifestyle, and personal values. This cultural association between brand and identity shapes consumer preferences and buying decisions, exerting a considerable influence on the automotive market landscape. Moreover, the prevalence of brand loyalty in the United States automotive market is further worsened by the limited variety and availability of EV models compared to traditional ICE vehicles. While the EV market has seen steady growth in recent years, the diversity of EV models is still comparatively limited, with a smaller selection of options available to consumers across different vehicle segments. This lack of variety constrains consumer choice and hinders the ability of EV manufacturers to effectively cater to the diverse needs and preferences of the American consumer base.

To address this, governmental bodies have a unique opportunity to intervene and incentivize the automotive industry towards accelerated transitions of car, truck, and SUV lineups to EV technology. In the beginning of automotive history, Henry Ford greatly influenced the creation of automotive regulations and laws by way developing a ubiquitously adopted vehicle, the Model T. Given this large adoption rate by the public, the U.S. government was forced to develop regulations, and update laws for the roads that had been previously subject to laws made for horse drawn carriage. Ford effected automobile adoption by way of accessibility that was intrinsically tied to the advocacy for roads between cities just a year after his famous Model T was released (Schreiber, 2021). It may be similarly possible that by mandating stricter emissions standards and providing financial incentives for EV adoption, policymakers can influence a similar reverse of the Henry Ford effect. This reverse Henry Ford effect might create a more conducive regulatory environment that encourages automotive manufacturers to invest in the development and production of a broader range of EV models by way of stricter demands on total decarbonization of a manufacturer's vehicle lineup. This proactive approach would not only accelerate the transition towards a more sustainable transportation ecosystem but also foster a competitive market landscape that promotes innovation and diversity in EV offerings.

Furthermore, industry stakeholders and automotive manufacturers can play a pivotal role in addressing brand loyalty and diversifying EV models by implementing targeted marketing strategies and consumer education initiatives. By highlighting the unique features and benefits of EVs, addressing common misconceptions, and highlighting the performance and affordability of EV models, manufacturers can effectively challenge entrenched brand loyalties and expand the appeal of EVs to a broader audience.

Organizational Factors -

The claim put forth in this section underscores the formidable stronghold of ICE vehicles within the automotive landscape, emphasizing their entrenched infrastructure, reliability, and ubiquitous presence across generations and regions. This assertion lies at the heart of understanding the technological momentum faced by legacy manufacturers in pivoting towards EV production and the corresponding sluggishness in consumer adoption of EV technology. This, in turn, contributes to a lack of substantial pressure from government entities to drive significant investments in expanding EV lineups, perpetuating the status quo in the automotive industry. According to a 2023 report by Tyler Duffy of GearPatrol, manufacturers' total transition to completely electric model lineup may come from some brands as early as 2025, with the last manufacturer declaration coming from General Motors (GM) and its sub-brands GMC and Chevrolet announcing full transitions by 2035. Therein lies the contributing factor to sluggish adoption at the hand of the automotive industry, being that fully transitioning to EVs is largely up to them to decide rate of expansion and completion. Understandably though, no manufacturer wants to be last, and as such some have chosen to abstain from declaring a date or setting a goal altogether, thus kicking the proverbial can down the proverbial road as they patiently await more stringent regulations from whichever political administration is in office. As of this moment, they are subject to President Biden's goals for full electrification of light-duty vehicles by 2035, which may be indicative of many manufacturers making a move toward larger vehicles such as trucks and SUV's which would have a later transition date under the previously discussed multiagency Memorandum of Understanding (Office of Energy Efficiency & Renewable Energy, 2023).

Despite the burgeoning momentum towards EV adoption, as can be understood by Pacey's model, and the promising advancements in battery technology, legacy manufacturers have exhibited a cautious approach towards developing their EV lineups. This reluctance stems from a range of factors, including a lingering reliance on the extensive infrastructure supporting ICE vehicles, which has been meticulously developed over decades. This infrastructure includes an extensive network of fueling stations, maintenance facilities, and supply chains, all tailored to accommodate the needs of ICE vehicles. As a result, transitioning towards EV production would necessitate substantial investments in overhauling existing infrastructure and retooling manufacturing processes, presenting a daunting and expensive challenge for established automotive manufacturers. ICE vehicles have been the norm for world society, the transportation and service industry, and the privately owned vehicle for over a century, and as such, the organizational systems and infrastructure that support them cannot be changed easily, quickly, or cheaply.

Compounding this reluctance is the perceived lack of robust demand from the public for EVs, particularly in comparison to their ICE counterparts. Despite growing awareness of environmental concerns and a gradual shift towards sustainable transportation solutions, consumer adoption of EV technology has been slower than anticipated. This tepid response can be attributed to concerns about EV range, charging infrastructure, and upfront costs. Additionally, the absence of stringent regulatory measures or incentives that aim to accelerate the transition towards EV adoption further contributes to the laziness seen among legacy manufacturers.

Considering these challenges, major automotive manufacturers have opted to prioritize the augmentation of their existing ICE lineups rather than making significant investments in expanding their EV offerings. This strategic decision allows them to capitalize on their established market presence and brand loyalty while deferring the burden of innovation and expansion in the EV market to boutique manufacturers specializing in luxury EVs. Consequently, the mainstream adoption of EVs is still hindered by the prevailing dominance of ICE vehicles and the cautious approach of legacy manufacturers towards transitioning towards EV production.

Furthermore, while projections show the eventual achievement of EV price parity for models boasting a 150-mile range by the end of the decade, significant barriers persist for this milestone to be reached. Despite notable advancements in battery technology and economies of scale driving down the cost per kilowatt-hour of battery packs, EVs continue to lag behind conventional ICE vehicles in terms of affordability across various vehicle categories. This price disparity underscores the challenges faced by EV manufacturers in competing with ICE vehicles, particularly in segments where consumer preferences are heavily influenced by price considerations. As an example of this price parity for performance with price and range information Tesla and Car & Driver magazine ; the U.S.'s best-selling EV in 2023 according to Hagerty Media was the Tesla Model Y, with a battery range of 260 miles and a starting price of $42,990, and the number one selling midsize ICE vehicle for the same period according to Kelley Blue Book was the Toyota RAV4, with a fuel range of 430 miles and a starting price of $29,625 (Berg, 2024; Ireson, 2024). As a comparison of dollars per mile of the initial cost of entry for the vehicle, and ignoring for either fuel costs for ICE, or at home and public charging costs for the EV, the Toyota costs $68.89/range mile where the Tesla carries a price tag of $165.35/range mile (Tesla; Car&Driver, 2024).

Conclusion -

EV adoption is intertwined with many cultural, technical, and organizational factors, each influencing and shaping consumer attitudes and behaviors towards EVs. Cultural factors such as vehicle performance, aesthetics, range anxiety, and brand loyalty play a pivotal role in influencing consumer preferences and feelings around EVs. These cultural dynamics, in turn, are influenced by closely related technical and organizational factors, creating a complex interplay that affects the trajectory of EV adoption.

Technological advancements in battery technology have contributed to a decreasing cost trend per kilowatt-hour of modern battery packs, enhancing the affordability and viability of EVs. However, despite these improvements, late adopters of EV technology remain skeptical, particularly when comparing the current available options to conventional ICE offerings and their well-established supporting infrastructure. This reluctance is further compounded by the perceived convenience and familiarity of ICE vehicles, which continue to dominate the automotive market.

Policy interventions aimed at incentivizing car manufacturers to expand their EV offerings, such as tightening CO2 restrictions, have been implemented to accelerate the transition towards cleaner transportation solutions. However, manufacturers often find it more cost-effective to iterate on existing ICE technologies, focusing on improving fuel economies and emissions standards rather than committing to a complete overhaul of their vehicle lineups. This strategic approach allows manufacturers to navigate the evolving regulatory landscape while maximizing returns on investment in the short term, particularly given the extended transition window provided by current federal mandates stretching as far as 2050.

These technical and organizational factors intersect with the broader societal zeitgeist, shaping public beliefs and attitudes towards EV adoption. While there exists a largely idealistic motivation for transitioning to EVs among vehicle owners, particularly considering environmental concerns and the desire for cleaner transportation options, significant barriers remain for the early and late majority of consumers. These barriers include concerns related to convenience, infrastructure, and the reluctance to deviate from traditional car ownership norms. Overcoming these barriers will require concerted efforts from politicians, industry stakeholders, and consumers to address concerns related to performance, infrastructure, and convenience, ultimately fostering a more widespread acceptance and integration of EV technology into mainstream transportation practices.

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