

**Navigating the Road Ahead: The Padigm Shift from Internal Combustion Engines to
Electric Vehicles**

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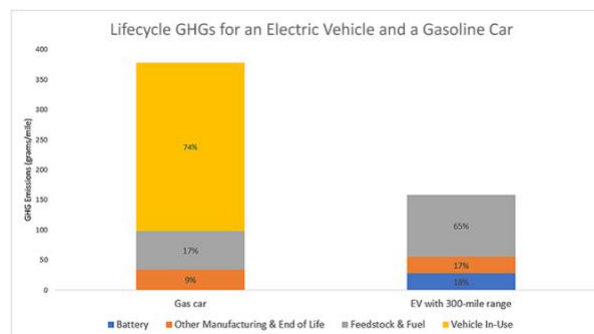
On my honor as a University Student, I have neither given nor received unauthorized aid on this
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Advisor

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Introduction

Our planet is slowly being poisoned by societies overuse of technologies with little consideration to the consequences, especially in transportation. Global warming has created a need in society to create alternate sources of energy, and more efficient forms of technology that limit pollution. One of the biggest forms of pollution on the planet is transportation, which is mainly composed of automobiles. Electric vehicles (EV) pose as a viable alternative to traditional cars, by emitting less greenhouse gases as seen in the figure below.



(*Lifecycle GHGs for an Electric Vehicle and a Gasoline Car 2023*)

Traditional cars, busses, trucks, etc. operate using an internal combustion engine to turn an air gas mixture into rotational energy, torque. With recent developments in modeling software's these engines have become highly optimize improving their gas mileage as well as power output. However, with these traditional engines still adding harmful toxins into our atmosphere we might ask: is it even worth iterating on them, or should we change directions all together?

This is the question I propose to you, if iterating on traditional engines and increasing the efficiencies is worth it if the world is shifting towards an all-electric future. To answer this, we will be using Kuhns cycle to help us determine where we are in this transition. Published in his book *The Structure of Scientific Revolutions*, Kuhns cycle is made up of a series of steps that

describe the paradigmatic shift from one technology to another. In our case we are transitioning from internal combustion engines to all electric motors, and by analyzing where we are in Kuhn's cycle we can determine if iterating and continuing to advance combustion engines is worth it or not.

Background

Looking at how Kuhn describes technological revolutions we must start by defining some things. Normal science is the normal state at which technology has reached from a previous paradigm shift. In our case this normal state is internal combustion engines, as these have been the standard of transportation since the previous normal science of horse drawn transport. In Kuhn's notion, a normal science will eventually reach a model crisis. A model crisis is where a situation arises which requires a reconstruction of the normal science from the foundation up. Using this framework to analyze the transition from ICE to EV, our situation that is creating a model crisis is the environmental effects ICE have on the global ecosystem. This situation has created a need for the rebuilding of our transportation sector into one that limits our carbon footprint. It is at this stage in Kuhn's paradigm shift that a field's energies are said to be best spent on constructing a new model that works. After a model crisis is reached, there is a model revolution. This step is characterized when one or more competing new models emerge from the crisis. Finally, once a model crisis occurs there is a short period of time, five to ten years, before there is a complete paradigmatic shift in technologies. This paradigmatic shift means that the previous normal science becomes obsolete and replaced. Looking at our system and following Kuhn's definitions, what stage are electric vehicles at? Well, the answer to that question is more complex than it may seem at first.

Methods

Implementing Kuhn's framework for technological transitions, we can approximate when a total shift from ICE to EV may occur. By looking into scholarly papers, journals, studies, and public polls to analyze the EV market and its growth. Once an understanding of the EV markets growth and predicted future is understood, we can state more definitively our place in the Kuhn cycle. Knowing when this shift will happen and our place on this cycle is the most accurate way we can answer the overarching question of whether iterating on ICE vehicles is justified.

When first applying these definitions to our system we may comfortably say that we have reached the model crisis and currently are in the beginning stages of model revolution. While companies like Tesla take an all-electric approach, many other car manufacturers see it as too big a risk and rely in the safety of hybrid cars. These hybrid cars use both electrical energy from a battery as well as an internal combustion system to generate power. Looking at these car manufactures beginning to change their entire transportation system from ICE to EV, you can see how this aligns with Kuhn's model crisis stage; the previous technology is being changed at its core. Kuhn describes the model revolution as beginning when one or more competing new models emerge. We are already seeing this today with new and existing automobile companies creating EV product lines. However, if we have already reached a model crisis then why is our transportation field not using all its energies on this new model of EV cars? And if we are in the beginning of a model revolution, what is limiting our paradigmatic shift into an all-electric car market?

To answer these questions, we need to look at the factors that play into the EV market and how they are affecting its growth. One of the strongest aspects of any technologies growth

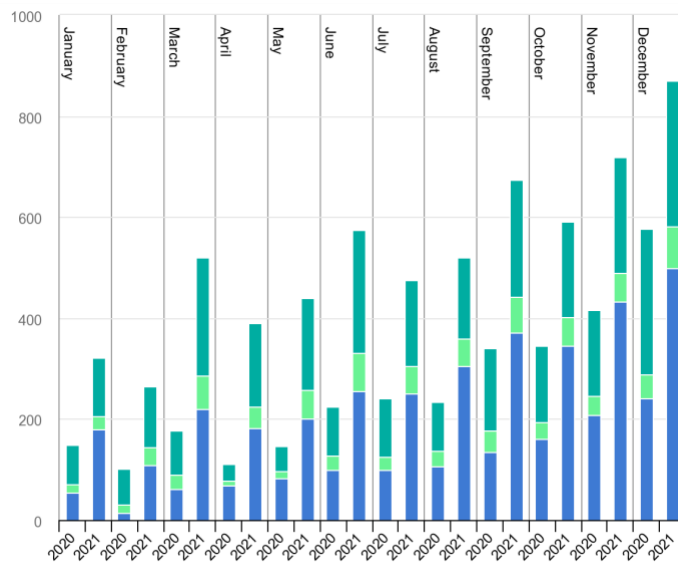
the perspective consumers have on it. There are many psychological effects that have protected humans by scaring them away from new or unknown things. However, in modern times this often is subconscious and not grounded in reality as we are no longer hunter and gatherers, but civilized humans. This subtle subconscious fear of new things can be seen everywhere whether it is anxiety from meeting new people or being scared of getting on an airplane for the first time. Sometimes there is no logical explanation to these fears or anxieties, it is simply built into our mind to be cautious and wary to new experiences. In the EV market aspects like range anxiety, auto driving, and engine reliability have a large impact of consumers perception and acceptance of EV's. By understanding the perceptions that society has on electric vehicle we can learn to see how quickly the societal perception of this emerging all electric technology is being accepted. This acceptance rate, and in turn the choice of consumers, directly correlates to the societal shift into an entirely electric transportation system.

The remaining factors influencing the EV market are the governmental policies directed towards electric vehicles and the availability of EV's to consumers. In the United States the government poses many benefits to consumers for purchasing EV's and has increased the infrastructure to support them over the last decade. However, the availability of EV's still remains out of reach for many consumers as the average cost for an EV is around \$66,000 (Lambert, 2022). As you can see these societal and governmental factors have a large impact on the EV market and in turn its growth. We will discuss these more in depth in later sections.

Results and Discussion

To analyze the EV market, we need to look at data sources from the past decade to see its growth and how societal perception towards EV has changed. For this analysis we will be using a combination of resources to understand the current state of electric vehicles. The EV market

has been growing at a rapid rate over the past decade with global EV sales in 2012 being 130,000 compared to the 10 million sold globally in 2022 (Paoli, 2022). Despite this internal combustion engines still have the majority of the transportation sector with EV's only making up 1% of vehicles in the United States in 2018. However, EV sales in 2018 were up 75% and now in 2023 EV's make up 7% of the automobiles in the United States (Hawley, 2023). Looking at a smaller sample of time we can see that with each passing year the sale of EV's is increasing drastically. The figure below shows the sales of EV's each month between 2020 and 2021. While this chart is questionable due to its data being collected during the covid pandemic, it is a large enough sample set over multiple different countries to still be a fair depiction of the EV market trend. The different colors on each bar of the graph represent the countries which they are sold; blue is China, green in the United States, and teal is Europe. Looking at this chart we can see that globally EV's are selling more each year despite the country. This large adoption and consumer use of EV's is not predicted to slow down any time soon which is largely due to and influenced by governments.



(Monthly sales of electric cars in major car markets 2022)

Many countries around the world, the United States included, have set out plans to reach zero carbon emission by 2050 as part of a global initiative to reduce pollution. A task like this requires momentous change and funding in order to create a new sustainable society. Due to the complexity of this change, there are many different plans governments are looking into to reach this goal. I do want to preface that these are not set into stone yet, but more so guidelines which they wish to reach, however they will still offer a good look into the future of EV's and ICE. One of these scenarios called the net zero emissions (NZE) scenario, proposed by the International Energy Agency (IEA), states that the production of ICE vehicles should cease by 2035, and in parallel have total EV sales encapsulate 60% of the market by 2030 (IEA 2022). With these conditions met it will push society onto the correct path and help to reach zero emissions by 2050. These conditions are largely dependent on the future growth of battery manufacturing and life, as well as the deployment of charging infrastructure. Government involvement like this is a huge factor when looking whether it is worth iterating on ICE vehicles. This scenario is worth discussion as it was proposed the United Nations after over 70 countries set a net zero emissions target. It provides a suggestive plan for countries to follow, and while many countries will choose their own paths it allows us to generalize the world and see what specific targets a large portion of the world is moving toward. Despite this not being officially planned, the fact that global governments are looking to phase out ICE engines in the near future tells us that we are beginning to transition from one normal science to the other and enter into the next paradigm of our technology as described by Kuhn. Traditional ICE vehicles are no longer being viewed as a viable form of technology but rather an outdated one with fundamental flaws that require a new solution.

If the government really does plan to create this change, what are they currently doing to begin reaching this goal of a zero-carbon society? The environmental defense fund is a nonprofit environmental advocacy group in the United States. This nonprofit published a report in 2022 that states how the United States government are starting to take action and move rapidly towards their goal. The United States environmental defense fund published a report in 2022 that shows how they are starting to move rapidly towards their goal. The report explains how electric vehicles investments will grow to more than \$620 billion by 2030 (Stein, 2022). This funding is being put into new infrastructure, EV passenger cars, as well as freight trucks, buses, and public transportation research. This funding for EV growth is only being propelled forward more by several federal and state actions like the Inflation Reduction Act passed by President Biden last August. Acts like this one essentially offer tax credit to consumers to trade in their old cars for EVs to incentives consumers to switch and keep growing EV production. In an attempt to reduce the charging anxiety many consumers have with EV's, the President Biden passed a Bipartisan Infrastructure Law that invests 7.5 billion dollars into creating more EV charging infrastructure. An additional 7 billion dollars was passed to be used in EV battery components and research (Biden, 2021).

Major automobile producers have also begun to change foreseeing the governments push towards an electric transportation sector in the future. This has led to an increase in diversity among EV's with 36 major car companies now producing an EV model (Morris, 2023). Not only are there more options now but cost is also decreasing as a result. The battery of EV's is one of the largest expenses and through government subsidies the cost of batteries has dropped 89% in the last decade (Peters, 2020). This battery price drop is then reflected onto EV prices which are dropping by 7.5% annually (Morris, 2023) making them more affordable for many consumers.

Many traditional ICE vehicle manufacturers are also turning towards electric vehicles. Creating entire product lines that are either fully electric versions of older car models or hybrids. This is the first-time automobile industry giants have changed in decades and this unprecedented behavior speaks to the severity of the EV markets rapid growth. These companies are realizing the future of their industry and changing to accommodate the new technology.

With all these aspects pushing consumers to EV's over their ICE counterparts, why are ICE vehicles still being manufactured and produced? Remember if we truly are in Kuhn's model crisis, then we should be using the majority of our automotive field's energy on the new technology. So, what is limiting our shift and keeping these ICE vehicles in production and on the market? Clearly the government is ready for a paradigmatic shift and even heavily pushing for one, but despite all their influences and advocating at the end of the day it comes down to the consumers and their choice.

EV's have many attractive attributes to consumers and economic benefits like less cost on fuel. But they still haven't taken majority of the transportation market from ICE vehicles. The perspective of the consumer on the technology is what creates a paradigm shift. If it becomes accepted by all, then the old technology becomes obsolete creating a new normal state. To analyze the EV market and its future we must look at the perspective the consumers have on it. This is where societal perception and human psychology begins to play a role. For one people have become very involved in being conscious of the environment and reducing their footprint. This mindset in society is what has spurred the EV market to where it is and given them a consumer base to begin with. However, people are often also afraid of the unknown and resistant to change. This can be seen in many historical advancements in technology, medicine, and mathematics. For example, when many physicists and astronomers made claims about how the

universe functioned society was very hesitant in accepting their new ideas as they changed what had always been known. While society isn't as strongly afraid of EV's as they were of astronomers, there is still a hesitation many consumers face when considering an EV. A study conducted in Germany collected data on the perceptions of almost 1,000 consumers before and after driving in an EV (Schneider et al., 2013). They found that users who experienced driving in an EV had a positive influence on their perceptions of them. This means that visibility and commonality of EV's have a large role in their acceptance from consumers. Looking at this study being conducted in 2013 we can infer that with the large rise in EV's around the globe that more consumers have been around or seen EV's on the road. With them becoming more widespread this only increases their view as a viable alternative in the public's eye, creating more demand in turn. This feedback will only help aid in the growth of the EV market. Combining the governmental incentives with the growing acceptance of consumers it can be confidently said that these are not limiting the EV market in any way and only aiding in their ability to shift into the new normal state. So, what is limiting the EV market and the paradigmatic shift away from ICE?

The largest aspect that is preventing EV's from overtaking their ICE predecessors is cost and social groups. EV's are a luxury and on average cost \$10,000 more than the average yearly salary in the United States. This greatly limits their accessibility, which is key to their growth. Over the past decade EV technology has gotten better, reducing their cost drastically. With new technology in the vehicles and larger scale manufacturers, companies have been able to reduce their cost. Despite this they still remain out of reach for many Americans, only being a viable option for the privileged. With that being said, social groups often lie within income ranges creating a target market for EV's. If EV's do replace ICE they need to reach all the different

social groups and not just the top ones. However, as we discussed previously the government has begun funding billions of dollars into technological research and infrastructure to support EV's. This is likely in an effort to reduce their price point and enlarge their possible consumer base. With this in mind, the largest aspect preventing EV's from shifting the paradigm may become obsolete in the next decade.

Conclusion

The EV market is growing and will continue to grow, that is undeniable. With perception from consumers beginning to change and becoming more acceptant of EV's as an alternate source of transportation, the desire for traditional ICE vehicles will continue to decrease. This is compounded by the fact that with government influences aiding consumers in their transition, and helping to bring down the price of EV's, they are only becoming more accessible. On top of this you also have governments actively trying to stop the manufacturing of ICE vehicles within the next 20 years and completely switch to an electric transportation system. Looking at these factors and how society has reacted to this new technology, we can confidently conclude that we are in a model crisis as defined by Kuhn in his Kuhnian cycle. It is at this stage in which the new technology is being accepted over the previous normal state. This model crisis is said to only last for a decade as the previous technology is phased out and the paradigmatic shift occurs.

Our dive into the EV market shows us that manufacturers and governments are actively seeking the shift to EV within the next decade. By being in a model crisis we know that it is futile to fight for ICE vehicles as they will soon become obsolete. This brings us back to our original questions, if iterating on traditional engines and increasing the efficiencies is worth it if the world is shifting towards an all-electric future. The answer is yes but in much smaller scope,

with the majority of resource allocation going towards EV. The shift to EV's is still at least a decade away, meaning that any progress to reduce climate change during then is a step in the right direction. However, a paradigmatic shift in a technology so widely used will not occur quickly but be a gradual change. So yes, traditional internal combustion engines should continue to be redesigned to reduce the carbon footprint as much as possible until the majority of vehicles on the road are EV's. However, I do believe that too much of our resources and focus is being put on iterating on these ICE engines. While they should still be improved upon, companies need to be putting much more of the research and money into creating cheaper and better electric vehicles. This shift isn't here yet, but it is coming. Traditional vehicles should not have the majority of resources and time spent on them when we are actively trying to switch the paradigm to EV's. Most of the money, resources, and time spent on refining ICE vehicles should be used to propel us the EV's quicker in an effort to reduce our pollution of the planet, while still having very efficient ICE vehicles as an option. This iteration and fine tuning of ICE vehicles from large car manufacturers is only prolonging the switch and actively going against the fight to reduce carbon emissions. They are only still being produced as the price range hasn't reached a value low enough to make EV's widely available. However, this could be obtained if less money and focus was being put into ICE vehicles each year. The fact is that while they are becoming more environmentally friendly, they will never be able to reach the emission rates that EV's offer. ICE vehicles will be gone within the next 50 years and continuing to pour the majority of research and production into them is only delaying their inevitable fate as an archaic technology.

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