**Literature Review - Green Vehicle Technologies**

# INTRODUCTION

Given the overwhelming popularity of internal combustion engine (gas-powered) vehicles on the road today, it should come as no surprise that they make up a substantial portion of greenhouse gas emissions. In fact, the US Energy Information Administration reports that transportation accounts for over a quarter of the energy used in the United States (Energy Use For Transportation, 2021).

Over the last ten years or so, one of the most prominent arguments has been to reduce the number of such polluting vehicles through legislation. While many have bought into the idea, likely due to Tesla’s dominance over the last few years, it is still important to audit these claims before implementing vastly disruptive laws.

Unfortunately, less invasive mitigation methods are seldom discussed in the mainstream, so the question is: are battery-electric vehicles (BEVs) better for the environment? If so, by how much? Is it worth the extra money to make the switch? And are there better options available?

# ELECTRIC VEHICLES & THE ENVIRONMENT

Before jumping into the details, there is nothing inherently wrong with buying an electric vehicle (EV). However, buying one simply out of environmental guilt may not be the best course of action.

Despite having no “tailpipe emissions,” battery-electric vehicles are far from carbon neutral and still cause widespread environmental harm. Primarily, all cars, including battery-electric vehicles, require some form of energy to run. When it comes to internal combustion engine vehicles (ICEVs), energy is released “on-site” from fuel. The difference with electric vehicles is that the energy that powers the car is put directly into it. The source of this energy can only be controlled to an extent. Electric vehicle users have only a few choices for primary energy sources. They can plug into their home and rely on a utility, or they can choose to make a further investment into at-home energy production.

When it comes to grid power, the end-user has little to no say in what According to the U.S. Energy Information Administration, roughly 60% of electricity in the United States comes from fossil fuels, and about 65% of that energy is lost (U.S. Energy Facts Explained, 2021).

Luckily, electric vehicles are quite energy-efficient – much more so than ICEVs. Almost all thorough life-cycle assessments agree on this. For example, *The Environmental Impact of Electric Vehicles: A Novel Life Cycle-Based Evaluation Framework and its Applications to Multi-Country Scenarios* concludes that “CO2 emissions associated to an EV over its life cycle are always lower than the ones associated to a comparable ICEV” (Franzo & Nasca, 2020).

Even if the green at-home energy problem is solved, building up the charging infrastructure required for mainstream adoption of EVs comes with its own set of environmental faults. In addition to the environmental damages associated with constructing the infrastructure, according to a 2018 study done in China, public chargers have a global warming potential of at least 11% more than at-home chargers (Zhang, Sun, Ding, & Yang, 2018).

Unfortunately, the environmental costs of electric vehicles do not end at energy production. Manufacturing and end-of-life impacts must also be taken into account.

When it comes to manufacturing, one of the most devastating components of an electric vehicle is the lithium-ion battery pack.

# ELECTRIC VEHICLES & SOCIETY

For several reasons, the widespread, enforced adoption of electric vehicles is a step in the wrong direction for society. First, the infrastructure for charging is sparse at best. Second, massive accessibility obstacles must be solved. Third, the current American electric grid is physically incapable of supporting the increase in power draw that would result from millions of people simultaneously charging. Finally, many electric vehicles are shipped with anti-consumer features.

Road trips can become quite burdensome for electric vehicle users. While gas stations are abundant and seldom more than a few minutes’ drive away, charging stations are too few and far between. When it comes to road trips, for ICEV owners, worrying about refueling is rarely an issue. Even in the worst of situations, where the gauge is pegged on empty, rescue fuel can be delivered in jerry cans. However, great care must be put into planning a battery-electric vehicle trip that will eat into the majority of the car’s range. The last thing you want is to be left stranded on the side of an Interstate without any way of charging up in less than a few hours.

In keeping with the theme of slow charging, electric vehicle users are faced with a dilemma when it comes to charging speeds. There exist two main charging speeds: fast charging and normal charging. Normal charging is slow, but it does not degrade the battery nearly as much as fast charging. Since lithium-ion batteries are components that wear out over time, each fast charge eats away at the lifetime of the car.

Compare this with ICEVs. It does not matter how fast gasoline or diesel is put into the tank. Even the slowest fill-ups are many times faster than the fastest chargers.

Beyond charging infrastructure, it is important to consider the implications of at-home charging, where the vehicle will likely be recharged the most. Since installing outdoor chargers is expensive and there are two competing charging port standards for electric cars, it is unlikely that landlords will willingly adopt electric vehicle charging. Therefore, for the time being, battery-electric vehicles are not a viable option for the third of Americans who are not homeowners.

This is not the end of the long list of social issues that come with electric vehicles. Since it would not be a true discussion about social impacts without bringing up corporate greed, it is about time that I confess something. Up to this point, each time I have referred to somebody who drives an ICEV, they were called “owners” while EV drivers were called “users.”

This was done for a very specific reason: modern vehicles, especially modern electric vehicles are prone to “locking down features.” For example, according to various news sources, German carmaker BMW has started a $12 per month subscription service to enable heated seats. What’s worrying about this is that the user is paying extra money to enable a feature that comes preinstalled in the car that they already paid for. Additionally, just while writing this review, another German carmaker, Mercedes-Benz, has announced a $1200 per year package to enable a full speed mode. Therefore, even if the car was paid for in full, it would not be able to accelerate to its maximum speed unless the user spends more.

Luckily, the future does not have to be like this. On September 22, 2022, a bill was proposed in The bill would, “[Prohibit] motor vehicle manufacturer or dealer from requiring subscription for certain motor vehicle features.” Clause 1a clarifies these features to be:

Any motor vehicle feature that:

     (1)   utilizes components and hardware already installed on the motor vehicle at the time of purchase or lease by the consumer; and

     (2)   would function after activation without ongoing expense to the dealer, manufacturer, or any third-party service provider (N.J. Legis. Assemb, 2022).

Although this bill is far from perfect, it is a start in the right direction. It is important that ownership be preserved, especially when it comes to something as individually focused as the personal automobile.

Further, while this bill protects all motor vehicles, it is much easier to manipulate the features of electric vehicles as they run on software rather than a chemical-mechanical process. Going forward, it is on the consumers to reject anti-ownership and do the proper research required to make smart economic decisions.

# THE HYDROGEN PROBLEM

If electric vehicles have such massive hurdles to overcome in both the environmental and social sectors, why not explore some alternatives?

One of the leading alternatives to battery-electric vehicles is hydrogen-powered electric vehicles. There are already some in production and even some hydrogen refueling stations exist. In a similar way to ICEVs, fuel is pumped into a tank to be used at a later time. For reason, this technology solves the slow-charging problem associated with battery-electric vehicles.

Hydrogen-powered vehicles typically fall into one of two camps: hydrogen internal combustion engines and hydrogen fuel cells. Due to hydrogen’s high combustibility, hydrogen has long been known as an alternative to gasoline and diesel. In fact, the first internal combustion engine, designed in 1806 by François Isaac de Rivaz, was powered by hydrogen. Unfortunately, hydrogen combustion engines are hardly 30% efficient, which has led to the development of the modern hydrogen fuel cell. The competing hydrogen fuel technology, fuel cells, gives hope, however. Hydrogen fuel cell electric vehicles can reach up to around 60% efficiency, but even this will not quite cut it for a consumer product.

Although hydrogen cell vehicles have been on the market for around eight years starting with the 2014 *Toyota Mirai*, they are yet to catch on at any scale as the range on a single tank of hydrogen is still quite low compared to traditional ICEVs.

The low range is due to hydrogen’s strength: its super high combustibility. As any *Led Zeppelin* fan could tell you, storing hydrogen is notoriously difficult. Notably, the *Hindenberg Disaster of* 1937 put a damper on hydrogen technology. Therefore, making a car that can both store enough hydrogen and ensures that the tank will not explode in the event of a collision is nearly impossible.

Beyond storage, another problem with mobile hydrogen power is fuel production. While hydrogen can be produced cleanly by splitting water into oxygen and hydrogen gas via electrolysis, it is quite inefficient and expensive. Currently, according to Renewable Synthetic Fuels and Chemicals from Carbon Dioxide, “Most [hydrogen] currently produced worldwide is generated via MSR” (Simakov, 2017). Methane steam reforming (MSR) is a chemical reaction that transforms methane and water into hydrogen and carbon monoxide. Due to its toxicity, the carbon monoxide is transformed into carbon dioxide in a secondary reaction. Therefore, even though hydrogen does not produce a carbon footprint when burned, it requires a substantial carbon footprint to produce. Additionally, hydrogen fuel cell vehicles are not nearly as efficient as BEVs. Overall, unless clean hydrogen production can be implemented at scale and the necessary infrastructure can be built, it does not seem like a viable alternative to ICEVs or even BEVs.

# THE “DO-NOTHING” SOLUTION

It should be apparent that literally doing nothing is not a solution to the problem, but if not hydrogen, then what steps can be taken to promote green transport? Possibly, looking into what *exactly* the problem is, to begin with, could point towards a profoundly effective solution.

If ICEVs are not the problem, then what is? To start, it is known that there are too many greenhouse gasses being released into the atmosphere. The catcher is that these gasses are being released without being recaptured. It just so happens that ICEVs are one of the primary culprits behind these emissions.

When it comes to ICEVs, the greenhouse gas in question is carbon dioxide, which comes from burning gasoline or diesel in the presence of oxygen. But gasoline and diesel are not magical unknown substances. Just like how water is just H2O, gasoline and diesel are made of long molecules of carbon and hydrogen. Called “long-chain hydrocarbons,” these substances contain large amounts of easy-to-access energy.

Analyzing the chemistry reveals that hydrocarbon fuels can be synthesized from two exceedingly abundant chemicals: water and carbon dioxide. In fact, the German automobile company Audi has been working on a synthetic diesel they call “e-diesel.” According to an article published by CNBC, Audi claims that this synthetic fuel would allow for ICEVs to run as normal without emitting any additional carbon dioxide (Ferris, 2017). If this technology is can be commercialized and scaled up, it has the potential to essentially bring net tailpipe emissions to zero.

Again, in his book, Renewable Synthetic Fuels and Chemicals from Carbon Dioxide, David Simakov goes into depth about how these reactions could work. He explains that although reactor design is challenging due to the chemical stability of the carbon dioxide molecule, producing fuels is possible.

Overall, perhaps the best solution is to do nothing about which vehicles are on the road and instead transition the source of the fuel. Not only would synthetic fuels bring net carbon emissions from ICEVs to near zero, but it would also help relieve some of the geopolitical tension caused by foreign petroleum operations. Additionally, it would likely provide a more competitive fuel market due to increased supply, helping to lower fuel prices. Finally, synthetic fuels would encourage the freedom of choice to opt out of the cons of being an EV user.

Even though it will be quite a challenge to implement a cost-effective solution, investing in synthetic long-chain hydrocarbon fuels might just be humanity’s one-way ticket to a clean and green future.