D.U.Quark

Volume 4
Issue 2 *Spring 2020*

Article 3

4-14-2020

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D.U.Quark 2020. Volume #4(Issue #2) pgs. 21-31
Published (April 14,2020) Peer Reviewed

ABSTRACT

Electric vehicles continue to increase in popularity as society encourages us to reduce the pollution in our environment. Since electric vehicles produce no tailpipe emissions, the production and decomposition of their components must be analyzed to compare the pollution of electric vehicles and internal combustion engines. The differences in the life cycle pollution of electric vehicles and internal combustion engine vehicles were quantified. Overall, internal combustion engines create from 1.2 - 1.6 times the CO_2 that electric battery vehicles create over the vehicles' entire life span. This is considering the vehicles' production, operation, and disposal. This data shows that electric cars are better for the environment, but they still contribute to the pollution and are not perfect. With continued research, we will see more eco-friendly electric vehicles in the future.

KEY WORDS: Electric vehicles, Internal combustion engine, pollution, carbon footprint, lifecycle comparison

INTRODUCTION

Automobiles have contributed to the destruction of our environment, in the form of carbon dioxide, since their creation. Emitting carbon dioxide into the environment increases the global-mean surface warming [1], and about 20 percent of all CO_2 emissions originate from road traffic [2]. However, internal combustion engine and electric vehicle technology is constantly advancing with changes to fuel economy and emissions year by year [3]. From just 2005 to 2017, the average fuel economy of all vehicles in the United Sates has increased by 5 mpg [3]. This increase in fuel economy is especially helped by the addition of many electric vehicle models [4]. Electric vehicles (EV) and plug-in hybrid vehicles (PHEV) have tripled in quantity from 2012 to 2017 [5]. Fully electric vehicles produce no tailpipe emissions; however, it must be noted that electric vehicles still contribute to the destruction of the environment through the carbon footprint generated by their production and disposal. It should be noted that a limitation of this field is the depth of research on electric vehicles. While many studies still exist, electric vehicles have not been sold in large quantities until recent years. Long-term studies are less prevalent. Following trends, electric vehicles will continue to be more common, so the analysis of their environmental effects is important.

This paper will compare the environmental impacts of internal combustion engine vehicles and electric vehicles. Specifically, this paper will focus on passenger vehicles as they make up over 80% of all light duty, personal vehicles on the road today [3]. To examine the differences, both types of vehicles' carbon foot prints will be examined over the vehicles' entire life span. This includes the vehicle's environmental impact of its production, operation, and disposal.

INTERNAL COMBUSTION POLLUTION

Internal combustion engines make up most of the vehicles on the road today because of their old, reliable technology. The technology has had countless hours of research to lower production costs and efficiency. It is important to note that among internal combustion engines, diesel fuel combustion engines produce less emissions than gasoline [5] and both are accounted for in all the studies used in this comparison. Biofuel combustion engines are also considered, but they make up very little of the automotive population, so they have a small effect on the data.

Vehicle Operation Pollution

The bulk of an internal combustion engine's air pollution comes from its day-to-day operation. Comparing many internal combustion engine mid-sized vehicles, they create, on average, 150.4 grams of carbon dioxide equivalent per kilometer (g CO_2 eq per kilometer) [6]. Comparing many SUV class internal combustion engine vehicles, they create, on average, 269.2 g CO_2 eq per kilometer [6]. This would mean that a mid-sized car with 100,000 miles would've produced approximately 24 million g CO_2 over its entire operation. A SUV class vehicle with 100,000 miles would've produced approximately 43 million g CO_2 over its entire operation.

Another study states that a combustion vehicle with 160,000 miles will produce approximately 45 metric tons of CO_2 over its entire operation which is 45 million g of CO_2 [7].

Vehicle Production and Decomposition Pollution

The production and decomposition of the combustion engine itself creates a smaller amount of pollution when compared to the carbon dioxide produced from the engine when

operating [6]. This is because, to create the engine itself, only the metal components must be formed and assembled. The metal components themselves are not particularly harmful to the environment. Internal combustion engine vehicles require approximately 10 million grams of CO_2 for their production and decomposition [7].

ELECTRIC BATTERY VEHICLE POLLUTION

Electric battery vehicles are a relatively new form of transportation. On the market as of 2017, there were only under twenty new electric vehicle models being produced [3]. This number can be compared to five years earlier where there was only one third the number of electric vehicles being produced [3].

Vehicle Operation Pollution

The environmental impact of the operation of electric battery vehicles can vary greatly because the electricity used to power these vehicles can be sourced from many different types of power plants. Nuclear, wind, and hydro plants generate the smallest environmental burden, but they only account for a small amount of energy when compared to the large amounts that coal and natural gas produce [6]. Considering all types of power plant energy, mid-sized electric vehicles can create from 73.9 g CO_2 eq per kilometer to 131.5 g CO_2 eq per kilometer [6]. An SUV class electric vehicle can produce 119.3 g CO_2 eq per kilometer to 196.45 g CO_2 eq per kilometer [6]. This would mean a mid-sized electric battery vehicle with 100,000 miles will have produced from 12 million to 21 million g CO_2 from its operation on the road and a SUV class will have produced from 19 million to 32 million g CO_2 from its operation on the road.

Another study has determined that electric battery vehicles produce approximately 25 metric tons of CO_2 over their entire operation [7] which is 25 million g of CO_2.

Vehicle Production and Decomposition Pollution

The production and decomposition of electric battery vehicles requires more energy and complicated labor [8]. In this area, electric vehicles are less eco-friendly than internal combustion engines. A lithium ion battery is the most popular battery type used in electric battery vehicles [9]. This is because the lithium ion battery is low-maintenance, safe, affordable and efficient, especially when compared to that of the older technology, ZEBRA batteries [9]. ZEBRA uses molten salt and nickel for their electrodes and has a complex production procedure when compared to lithium ion batteries [1].

Despite lithium ion batteries being the best battery technology for vehicles, the production of these still emits 1.43 times more CO_2 than the production of combustion engines [6]. Lithium ion batteries are not fully decomposed until 8 to 20 years after they are done being used [7]. With a lifetime of only around 10 years [11], the batteries often take longer to decompose than they last in the vehicle. An alternative to decomposing batteries is to recycle them. This will reduce the overall CO_2 footprint, as it removes the need to produce and decompose a whole new battery for each vehicle. Recycling is also a better choice because there is not enough lithium to meet the future demands of electric battery vehicles [11].

COMPARISON

To summarize, electric battery vehicles produce less CO_2 than internal combustion vehicles during the operation of the vehicle. However, the production and decomposition of electric battery vehicles produces much more CO_2 than that of internal combustion vehicles.

In some cases, a vehicle's environmental impact cannot be assessed alone by its CO_2 production. This section includes factors that should be considered when analyzing the difference between electric vehicles and internal combustion engine vehicles.

Energy Comparison

One study looks at the differences between two identical vehicles that differ only by their engine (one electric and one internal combustion vehicle) [12]. The internal combustion engine vehicle used approximately 3 times more energy than the electric vehicle [12]. The comparison of a vehicle's energy consumption does not directly correlate with CO_2 production because the energy is produced in different ways. However, this study does show how much more efficient electric battery vehicles are than internal combustion vehicles. A different study used a similar procedure and determined that internal combustion engine vehicles used 2.7 times more energy than electric vehicles [13].

Cost Comparison

It is also important to note that electric vehicles are much more expensive than internal combustion engines [7]. This includes production, decomposition and ownership costs. An electric battery vehicle is much cheaper to operate than a gas vehicle [7]. This is because the fuel prices are much more than the electricity costs that are needed to power the vehicle. However, an

owner may pay for this difference in power cost initially, as electric vehicles tend to be more expensive to purchase when comparing similar power and quality. Repairs to an electric vehicle are also more expensive when involved in an accident or collision [14]. A reason for this may be, as stated earlier, there will not be enough lithium to meet the future demands of these vehicles [11]. In order to push electric battery vehicle technology to more consumers, the initial cost must be lowered to create a greater incentive for purchasing. In the long term, battery research will put more electric vehicles on the road, improving the air quality and climate on earth.

Other Studies

Another study conducted shows that the lithium ion battery production, maintenance and end of life treatment, of an electric battery vehicle, make up approximately 10 to 15 percent of its total environmental burden [9]. This category is something that does not exist for an internal combustion vehicle. From the study we are able to see that the overall environmental burden of internal combustion engine is about 120 to 160 percent of a battery electric vehicle [9]. For a quantitative comparison between these two types of vehicles, reference (Table 1). As expected, electric hybrid vehicles produce approximately 200 g CO_2 per kilometer when operating [15]. This makes sense because it fits right in between the data of the two extremes.

CONCLUSION

Overall, electric battery vehicles and internal combustion engine vehicles contribute to the harming of the environment. However, they both contribute in different ways. In comparison to internal combustion vehicles, electric battery vehicles produce less CO_2 during the operation of the vehicle, but more CO_2 during the production and decomposition of the vehicle. Considering all factors together, electric battery vehicles contribute less to harming the

environment than internal combustion vehicles. The future of all vehicles is an increase energy sustainable technology that is less harmful to the earth. The best way to do so is to increase the number of electric vehicles on the road. Research must be done to improve the cost efficiency and lessen the environmental burden of the production of lithium ion batteries.

Table 1. Quantitative comparison of CO_2 produced from electric batter vehicles and internal combustion engine vehicles.

		Operation		Production / Decomposition	
		CO_2 Per kilometer driven (g)	CO_2 Produced from 100k miles (Mg)	CO_2 produced from the mechanical production / decomposition (Mg)	CO_2 Produced from Lithium Ion battery (Mg)
Electric Battery Vehicle	Mid-sized Electric Vehicle	73.9 - 131.5	12 – 21 AVG = 16.5	7.425	2.2
	SUV class Electric Vehicle	119.3 - 196.45	19 – 32 AVG = 25.5	11.475	3.4
Internal Combustion Vehicles	Mid-sized Combustion Vehicle	150.4	24	4.32	N/A
	SUV class Combustion Vehicle	269.2	43	7.74	

*Results were computed based on averages of relatively new vehicles (2010-present) using two sources (6,9) also assuming that each of these vehicles has traveled one hundred thousand miles [6,9].

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Nickischer, A. (2020). Environmental Impacts of Internal Combustion Engines and Electric Battery Vehicles. *D.U.Quark*, Volume #4 (Issue #2). Retrieved from https://dsc.duq.edu/duquark/vol4/iss2/article3