MSc Program
Environmental Technology & International Affairs

Fuel Efficiency in the Automotive Industry: Design, Development, Manufacturing and Marketing around the Abundance of Oil

A Master's Thesis submitted for the degree of
"Master of Science"

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03.10.2016

Affidavit

I, **Dominique Richard Seramy**, hereby declare

1. that I am the sole author of the present Master's Thesis, "FUEL EFFICIENCY IN THE AUTOMOTIVE INDUSTRY: DESIGN, DEVELOPMENT, MANUFACTURING AND MARKETING AROUND THE ABUNDANCE OF OIL", 62 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The purpose of the research is to examine types of passenger vehicles being produced in the USA automotive market considering the increasing attention to the environmental impact of the production process. Existing supplies of oil and demands for cleaner alternative fuels are considered in light of the total production cost of a vehicle, including costs of components used in the production process. The role of consumer preferences is also considered in projecting what USA passenger vehicles may resemble in the future. Limited comparisons of passenger vehicle preference in the EU, China and Japan are also sited.

The methodology followed in this thesis is mainly qualitative in nature. Qualitative methods include the examination of documents in the public domain, analysis of data and literature contained in EPA documents, automotive and other published literature and personal observations gained through limited work experience in the automotive industry.

The look and efficiency of future USA passenger vehicles is difficult to predict given the diverse and complex factors influencing the automotive market. Availability of oil in the USA, governmental and consumer demand for cleaner automotive alternatives together with consumer demands for traditional automotive vehicle designs complicates the vision. It is likely that the high cost and availability of Hybrids and electric vehicles may become more competitive with traditional combustion driven vehicles. In turn combustion driven vehicles may become more efficient and environmentally friendly in the future thus leveling the competition between Hybrid, electric and combustion driven vehicles. It is possible that demand for Hybrid vehicles using a combination of plug-in technology and gas combustion power will dominate USA automotive markets in the not so far off future. Lessons learned from the analysis of the issues affecting the future of the USA automotive market may be useful in projecting automotive market trends in other countries taking into consideration the diverse factors affecting individual market trends including infrastructure capacity and major brand market dominance.

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Abbreviations

A	**Area**
a	**Acceleration**
CFRP	**Carbon Fiber Reinforced Plastic**
CO	**Carbon Monoxide**
CO2	**Carbon Dioxide**
Cd	**Drag Coefficient**
D	**Drag**
EPA	**Environmental Protection Agency**
EU	**European Union**
EV	**Electric Vehicle**
GHG	**Green House Gas**
HEV	**Hybrid Electric Vehicle**
Hwy	**Highway**
i	**Innovation**
km	**Kilometer**
LCI	**Life Cycle Impulse**
m	**Mass**
MPG	**Miles Per Gallon**
MPGe	**Miles Per Gallon equivalent**
NO	**Nitrogen Oxide**
NO2	**Nitrogen Dioxide**
NOx	**Nitrogen Oxides**
O2	**Oxygen**
OEM	**Original Equipment Manufacturer**
PHEV	**Plug-in Hybrid**
PM 2.5	**Particulate Matter 2.5**
PM 10	**Particulate Matter 10**
r	**Density**
SUV	**Sports Utility Vehicle**
USA	**United States of America**
v	**Velocity**
W	**Weight**

Chapter 1: Introduction

Chapter 1.1. Motivation

The automotive industry in the United States of America (USA) should focus more of its attention and resources towards the research and development of super-efficient plug-in Hybrid technologies rather than on all electric technologies.

From a global perspective the USA consumes more fossil fuels compared with any other country on the planet (Enerdata 2016). Additionally, it is also known that the USA drives more vehicles in comparison with all other countries. The easy availability of fossil fuels and their relatively low cost during the last several decades have contributed to this situation even during periods when fuel prices have risen slightly, the USA still continues to consume more fossil fuels.

Automotive manufacturers in Europe, Asia and domestically in the USA continuously engineer and produce vehicles that meet the needs of the USA mainly because of the USA market's favorable profitability. Some of the factors that make the USA automotive market such an interesting market to observe are related to the factors that contribute to the evolution of the automotive industry. Factors such as growing norms and trends in the USA have continuously helped steer automotive engineers in new directions. One of the most current trends that have emerged is undoubtedly the need to be more environmentally conscientious. Trends such as this one have not only led to policy reforms in the USA that regulate emissions and vehicle standards, but have also forced automotive companies to adapt their products to these new standards in order to maintain sales in their economies.

The race to produce the most efficient vehicle of vehicles seems to have taken center stage in the automotive industry. As a consequence, vehicles powered by alternative fuels are starting to attract market attention. Nevertheless, new automotive technologies are not perfected overnight, nor are they accepted overnight. New emission and vehicle standards

are being implemented within the USA, however, in order to support a market transition and to maximize profitability, time factors regarding implementation play a critical role in planning such changes. The likelihood of the USA automotive market being populated mainly with vehicles powered by alternative fuels seems unreasonable at this time for a number of reasons.

Given the dominance of oil consumption in the USA and the fact that the USA economy relies heavily on fossil fuels, the automotive industry has found itself tip-toeing around the idea of creating an emission-free vehicle on a large scale. As of now, given the current automotive infrastructure and consumer demands in the USA, automotive companies have only flirted with the idea of making fully electric or Hybrid vehicles since charging stations for those vehicles are limited.

The automotive companies that have been somewhat successful have produced limited quantities of alternative vehicles for the niche market that exists today. It seems apparent that automotive companies interested in maintaining their presence in USA markets have taken notice of this emerging trend and have been adjusting their technologies accordingly. While the success of Hybrid vehicles has proven to be a good solution for the niche market, the USA market is still dominated by fuel-powered vehicles.

Given the current automotive infrastructure, environmental policy developments and vehicle standards, as well as availability and affordability of fossil fuels in the USA, the ideal vehicle of the future may likely be a "super" efficient plug-in Hybrid. Given that this assumption is viable, the fuel companies should be able to adjust to new demands. The demand for vehicles will not likely fall, and if the automotive companies maintain their authenticities the American people may likely buy into this new vehicle type.

Chapter 1.2: Theme

This thesis paper covers topics currently impacting the USA automotive market including the demand and availability of fossil fuels as well as alternative fuels, the environmental

impact of government regulations and standards, consumer preferences, technical innovations including changes to and materials used to manufacture automotive component parts, automotive processes, aerodynamics of a vehicle, reducing the carbon footprint of the production process and battery range.

Chapter 1.3: State of The Art

The main goal of any business is to maximize profits. The automotive industry is no exception and the need to maximize profits is always on the forefront of agendas. The development and production of vehicles must always adapt in ways that allow the company to grow while maintaining their sense of authenticity. Traditionally, automotive manufacturers have divided their developmental costs into creating a luxury, performance, safe, and/or economically centered vehicle. It is apparent that if a company utilizes most of its budget towards making a performance-based vehicle, its standards when it comes to luxury, safety, and/or affordability may be less than that of a manufacturer who puts most of their effort into producing a luxury vehicle. The opposite would also be possible. These four classes of vehicles have traditionally dominated the way consumers in USA markets choose their vehicles. With the demand for efficiency on the rise, the automotive industry has inherited a fifth class along the lines of efficiency.

While many automotive brands evolve to meet emission standards in the USA, ultimately driving them to produce more efficient vehicles, their long-term success will always lie in the way they maintain their authenticity in their most dominant class. For example, if a performance-based brand decides to develop more efficient vehicles, it must do so in a way that doesn't compromise its authenticity of being a performance-based brand. This idea is not new and has been successfully implemented by developing new engine technologies that require smaller engine sizes to perform with less fuel while at the same time being able to compete with larger sized engines.

A review of related literature suggests that in order for consumers to be interested in driving a fully electric vehicle, total vehicle range is of key importance to its success. An

article posted in the *Engineer Job Magazine* issued in 2014, states that if automotive industries plan to succeed in the all-electric vehicle market, they must be able to produce a vehicle that has a substantial amount of range that is equivalent to a tank of gas in standard gasoline vehicles. The availability of charging stations must be made available on a larger scale as well (EngineerJobs 2014). While this article dates back almost two years, the problems have yet to be fully resolved. In addition, even though there are some long-range electric vehicles available on the market, they are for the most part too expensive for the average car user to consider.

This paper will analyze literary resources and examine whether or not time has proven sufficient to resolve many of the issues involved in producing all electric or alternative fuel sourced vehicles in order to be competitive in the mainstream USA market. The paper will also take into consideration automotive incentives and energy credits available to manufacturers and consumers aimed to change the direction of the automotive market. It will review engineering patterns that may help influence the future direction of the automotive industry. If the premise that profit drives businesses is universally agreed upon and undisputed, the answer as to what the automotive industry may look like in the future may already be under the noses of consumers. This paper will attempt to unveil the factors underlying the direction the automotive industry is headed and ultimately provide a prediction of what the ideal vehicle may look like for the USA consumer in the future.

Chapter 1.4: Hypothesis

Given the increasing attention to the environmental impact of the automotive production process and in light of the USA tradition and consumer preference for driving combustion fueled vehicles, what is the likelihood that the demand for alternatively-fueled vehicles in the USA automotive market will increase to become a market leader?

The reality of having 100% electric vehicles in the USA is not likely in the foreseeable future since consumers tend to be nervous about automotive change, reliability, vehicle

range, and an infrastructure lacking charging stations. For example, the average daily miles driven/fuel consumed creates less of a demand for low range EVs.

The reality of fuel-efficient gas/diesel powered engines is more likely to dominate markets. Gas/diesel engines are becoming more efficient and are able to maintain and improve performance. For example, four cylinder vehicles are already becoming more efficient and performance is increasing as well.

The reality of Hybrid technologies sharing the market together with gas/diesel powered engines looks achievable. For example, if the cost of ownership were reduced for plug-in Hybrid technology, the demand would increase significantly over time.

Chapter 2: Consumption of Fuels

Chapter 2 reviews the most common types of fuels used to power vehicles in the USA, namely gas, diesel, Hybrid, and Electric. Information is presented on emissions, types of vehicles available in the market, technical innovations, and fuel type preferences in other countries and the environmental impact of government standards on the automotive industry. Fuel cell vehicles are also discussed as a developing technology for future markets.

Chapter 2.1: Differentiating the Fuels

There are several types of fuels available in the global market used to power passenger vehicles. The two most available fuels used for everyday driving include regular gasoline fuels with varying octane levels and diesel fuels. As a general rule, diesel powered engines consume less fuel than regular gasoline powered engines. Diesel fuels contain more energy compared with gasoline fuels. Diesel powered vehicles therefore benefit from an extra boost of miles per gallon consumed implying an increase of efficiency. Diesel engines are not as popular as their gas driven counterparts in the USA. However, there has been a shift in perception in the USA in recent years. Previously, diesel engines were perceived to be noisy and high in terms of pollution. This perception has changed slowly and the popularity of diesel-powered vehicles in the USA is starting to increase within the context of everyday driving. This is in part occurring because current diesel engines produce less carbon emissions than their gasoline engine competitors. Nonetheless, diesel engines produce NOx emissions and these emission levels remain one of the main focuses for improvement in diesel engines.

The traditional regular gasoline engine is notorious for its role in global pollution, yet these engines continue to dominate the USA market. Both gasoline and diesel fueled engines have benefited from technological advances over time. Through technological innovation and adequate funding, automotive manufacturers have been able to meet state and federal environmental standards and work together with regulators to continue to produce more

efficient combustion engines for the market. This is a notable achievement and it has led to a significant increase in fuel efficiency and the improved capacity of manufacturers to consistently meet or beat existing or anticipated emission standards.

Electricity is another form of fuel used to propel vehicles currently available in the USA market. Electric vehicles have been making somewhat of a comeback due in part to manufacturers such as Tesla. Electric vehicles have continued to gain momentum in popularity in recent years due to their increased attractiveness emanating from the fact that they produce no tailpipe emissions although PM from non-exhaust sources remain when driven and have the ability to be recharged in places other than standard fueling stations.

A combustion free engine vehicle is no longer a fantasy, but more of a reality for the evolving automotive market. While an increase in market share for combustion free engine vehicles may not pose a significant shift in everyday driving habits, it is unreasonable to say that combustion free engine vehicles don't come without drawbacks. One of the biggest concerns to consumers is the currently limited range of miles per charge electric vehicles have to offer. The issue of range is directly related to the battery storage capacity. Today's automotive batteries offer limited range. This limited battery range hampers consumer confidence when it comes to the decision to consider the purchase of an electric powered vehicle. On top of limited range, consumers fear the scarce number of charging stations currently available. There are a number of diverse variables that go into the development, manufacturing, and design of electric vehicles and the need to increase the range for electric vehicles is an important one.

Gasoline and diesel fueled combustion engines have always driven the global automotive market. Recently, however, the Hybrid automobile has entered the automotive market and has become a household name. If one were to ask a consumer what is the first word that comes to mind when hearing the word Hybrid, it seems reasonable to assume that the Toyota Prius would be the response. The Prius movement deserves much praise and should not be neglected in any forum when discussing automotive innovation. A Hybrid vehicle utilizes more than a single form of energy. The most common form of a Hybrid on the

market propels a vehicle using the traditional combustion engine working along side or separate from an electric motor. This combination of fuel sources not only increases fuel efficiency, it also sets a new standard as to what is possible and what the future of automotive engineering may look like. The Hybrid vehicle has been mainstream for almost two decades now thanks to Toyota and has proven its worth in the automotive industry, even influencing other brands in the industry to develop and produce their own version of a Hybrid vehicle. This market shift has been a phenomenal one in and of itself. Even though the Hybrid may not dominate the automotive market at present, it conceivably has the potential to be a market leader and hypothetically could be a frontrunner and take the lead in the not to distant future.

There are three different types of electric vehicles in today's market, namely, the Hybrid Electric, the Plug-in Hybrid Electric and the all-electric vehicle. For the purposes of this thesis an all-electric vehicle is not classified along side Hybrid vehicles. Technology utilizing one or more alternative fuels in order to propel a vehicle defines a Hybrid and will be discussed in this chapter. All-electric vehicles - or EVs - store electric energy in a battery that is used to power the motor. Although EVs are considered an emission free vehicle due to the lack of exhaust, batteries are charged via an electric power source (DOE 2016b). As sustainable as this may sound the production of electric energy contributes a significant amount of air pollution to the atmosphere and if there is an increased demand for electric vehicles in the future, renewable sources of energy should be seriously considered in order to offset any additional pollution.

EVs, on average, have a driving range of 50 to 120 miles (80-190 km) per charge and vary somewhat depending on individual driving habits and road conditions. Additionally, factors such as the design, materials and technology used to manufacture the EV play a significant role in the overall performance of EVs. There are a few models of EVs that have a range of 200 to 300 miles (320-480 km) in today's market. Major drawbacks EVs face stem from charging times, which could take up to 24 hours depending on the power source. The cost, size and weight of batteries have also proven to be a challenge for automotive engineers (DOE 2013a). Although EVs are efficient and environmentally

friendlier compared with their counterparts to a certain degree, it seems apparent that the automotive industry will have to invest heavily in the future to resolve or mitigate these challenges.

Two mainstream Hybrid vehicles coexist in today's market competitively. These include the Hybrid Electric Vehicle (HEV) and the Plug in Hybrid Electric Vehicle (PHEV). An HEV has an internal combustion engine and an electric motor that has energy stored by electric power. The battery used to power the motor charges itself internally and cannot be charged by an external power source. The battery gains energy through technologies such as regenerative breaking systems and the internal combustion engine. The main battery of an HEV can use its extra stored energy to power certain features otherwise powered by the internal combustion engine (DOE 2013b). The extra boost of energy reduces the internal combustion load on the vehicle in order to increase fuel efficiency. Not all HEVs share the same technology and automotive manufacturers often engineer their vehicles based on the best available technology that provides the most efficient results.

Mild and full are two classifications of existing Hybrids. The difference between the two is that mild Hybrids do not have the capacity to power the vehicle using only electricity whereas full Hybrids possess the ability to propel the vehicle solely on electricity for a limited amount of time.

PHEVs are Hybrids that require charging from an electrical power source. The storage capacity allows for an increase in fuel economy. The two versions of this Hybrid are range extender Hybrids also known as series plug-in Hybrids and parallel Hybrids. The difference between the two is that range extenders are charged via an external power source but also include a small gasoline engine that's main purpose is generating electricity for the electric motor. In essence, the gasoline engine works much like a generator and will only turn on when the main battery is almost drained. A parallel plug-in Hybrid uses both the electric motor and engine to propel the vehicle at all times. Many parallel plug-in Hybrids will allow the electric motor to power the wheels alone at slow speeds. PHEVs can use up to 60% less fuel than internal combustion engines but these vehicles come with

a higher price tag (DOE 2013c). Although these vehicles cost more than average the amount saved at fueling stations can offset the price. Like EVs, PHEVs biggest challenge may be range and charging times but the technology of range extenders has proven to be an innovative solution to this challenge.

Hybrid vehicles in general result in more range than traditional internal combustion engines alone by a few miles per gallon and have better fuel economy and a lower carbon footprint at the tail pipe. Measuring the actual miles per gallon equivalent is difficult considering that every consumer will have different driving habits and charging habits. By utilizing multiple technologies on a vehicle, Hybrids have proven to be a step forward in automotive ingenuity and have great potential to reduce the need for fossil fuels in the long run. Although Hybrids reduce fuel consumption to a limited degree, it is a step forward leading to the development of other new technologies and ideas.

Fuel cells offer passenger vehicles a cleaner, smoother and overall more efficient alternative to internal combustion engines. They also offer advantages over Hybrid technology and electric technology passenger vehicles. Fuel cell vehicles are not a new technology and have been in development for quite some time. Hydrogen from fuel combined with oxygen from the atmosphere is an electrochemical process that converts chemical energy into electrical energy. Pure hydrogen gas is one of two supplies for fuel cells. The alternative is hydrogen rich gas, which is created through a fuel reformer that converts hydrocarbon fuels. Fuel cells contain one positively charged electrode (anode) and one negatively charged electrode (cathode). A substance is placed in-between these electrodes to conduct electricity. Figure 1 illustrates a fuel cell (CEC 2016).

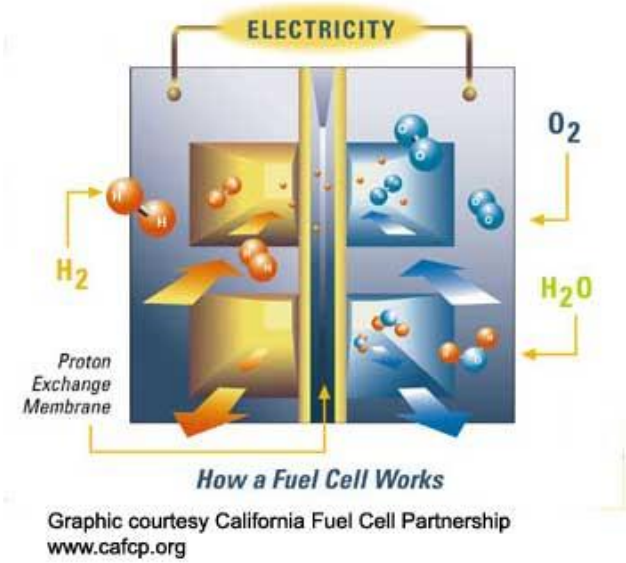

Figure 1: Fuel Cell Technology (CEC 2016)

The advantages of fuel cells could solve many of the issues mainstream passenger vehicles are challenged by. First, Pure hydrogen supplies would provide a pollution free alternative. Secondly, since fuel cells are combustion free, electricity converted from fuel is much more efficient than modern technology utilized in alternative passenger vehicles. Hydrogen is not only the most abundant element in the world but it also has a higher energy content than any other fuel on the market, is clean for the environment and is a renewable fuel source. While the advantages sound overwhelming the biggest drawback to hydrogen as a fuel source is the fact that it is simply expensive. While it is the most abundant element in the world it is however difficult to develop, store and maintain. The equipment weight and costs offset the advantages in today's market. Consumers would be reluctant to pay the extra costs due to the available alternatives. An infrastructure lacking hydrogen stations would also prove to be a timely, costly and challenging issue to both the consumer and producer as well.

Chapter 2.2: Global Preferences

While the basis of this chapter is to describe and examine the consumption of automotive fuels in the USA and automotive efficiency, it is important to indicate why some other countries around the world prefer one fuel source compared with another. At first glance, it seems apparent that most countries will naturally utilize resources that are most available and affordable. Given this premise, it seems reasonable to state that the USA makes regular gasoline fuel readily available and affordable to its consumers while EU countries prefer diesel fuels due to their supply and demand. The question arises as to what would drive demand for diesel or other fuels in other countries compared with demand for regular gasoline demand in the USA. A closer look at government issued vehicle standards across the globe may explain consumer preferences.

The USA issues federal and state level emission standards aimed at increasing fuel efficiency and decreasing green house gas emissions. In comparison, the EU issues standards aimed at reducing carbon dioxide emissions. Japanese standards on the other hand focus on fuel economy while Chinese standards focus on decreasing fuel consumption. What's interesting about these variations is that many of them go hand in hand. For example, an increase in fuel efficiency would decrease carbon dioxide emissions, yet the focus of the EU is the reduction of CO2 emissions. This would explain why the EU currently has a serious problem with NOx emissions. If the EU consumed more standard gasoline the NOx problem would decrease significantly but the CO2 emissions would increase significantly as a result. This helps to explain why EU consumers may prefer diesel fuel since diesel fuels don't produce as much CO2 emissions as the fuel counterparts (EIA 2015).

How governments structure vehicle standards is also important to consider. In the USA, the structure is footprint based corporate average while in the EU it is weight based corporate average. The difference between the two is that a footprint based corporate average sets Green House Gas (GHG) emission and fuel economy targets while a weight based corporate average is based on vehicle weight. Since automotive manufacturers are

based all over the world, each vehicle sold in a country must comply with that country's standards and not the standards of the origin of production (EIA 2015). This sets the stage for a new task for automotive manufacturers if they intend to produce and/or distribute globally. This is a complicated, yet doable task that involves yet again a combination of variables such as production, design, and manufacturing in order to compete in the global market.

Chapter 2.3: Environmental and Health Effects

The negative effects of the use of fuels on the environmental and human health are evident. CO2, H2O, NOx, Volatile Organic Compounds, Ozone, CO, Particle Matter (PM10 and PM 2.5) and toxins are the main vehicle emissions produced when driving. While these post-production emissions are generally evident to the consumer and the public, the pollution effects of the automotive production process are seldom considered when a consumer purchases a vehicle. This is because the everyday consumer fails to take into account the amount of pollution produced during the production phase of a vehicle. Some of the effects and hazards on the environment post-production that occur during everyday operations of a vehicle are described below.

Diesel fuels, as opposed to regular gasoline fuels, do not require a spark to ignite the engine vehicle. In its place, the compression of air and fuel mixture combined combusts in order to create a force strong enough to drive the components in the engine. Diesel as compared to gasoline engines never reach a stoichiometric combustion of fuel and air and reaches around 1.1 for a full load and up to 5 for idling. Diesel fuels have an overall greater thermodynamically efficiency than gasoline resulting in increased fuel economy. Refining practices greatly determine the compositional properties of the fuel. Efficiency is directly affected by the quality of the diesel fuels used in engines and the overall impact on the environment. Emissions produced by diesel fuels that pose more of an impact on health and the environment as compared with diesel fuel counterparts are NOx and PM. Technology aimed at reducing PM has been an ongoing priority for automotive engineers considering the adverse effects it has on human health. Emission control technology in

vehicles has led to increased efficiency but challenges remain since fuel characteristics are complex such as sulfur that influences the exhaust gas aftertreatment systems (DOE 2014).

Gasoline engines work by sparking a mixture of fuel and air in the combustion chamber of the engine resulting in a reaction that forces components in the engine to operate. A stoichiometric ratio of fuel and air is desired in order to make a more efficient combustion. At a stoichiometric ratio the three way catalyst as an exhaust gas aftertreatment system in gasoline engines reduce harmful emissions including carbon monoxide, hydrocarbons and nitrogen oxides (ENERGY 2013).

Among a diverse list of vehicle components that aid in reducing harmful emissions to the environment, the catalytic converter found in both diesel and gasoline engines is an example that plays an integral part with regards to automotive engine efficiency. The catalytic converter is engineered in such a way that it causes as well as speeds up a reaction without any adverse effects on the catalytic converter itself. A three-way catalytic converter can be found on most gasoline vehicles today. The "three-way" refers to the three main vehicle emissions regulated according to current vehicle standards. A reduction catalyst and an oxidation catalyst are the two catalysts at work in modern catalytic converters. The reduction catalyst consists of platinum and rhodium used in order to reduce NOx emissions. The NO or NO2 molecules contained in the exhaust reacts to the catalyst by separation of the nitrogen and oxygen. Nitrogen atoms then bond with other nitrogen atoms to form N2 in the catalyst. Oxygen is freed and formed into O2. The second stage of the catalytic converter, the oxidation catalyst, reduces unburned hydrocarbons and CO by oxidizing them over platinum and palladium. The leftover oxygen in the exhaust gas assists the reaction of the CO and hydrocarbons within the catalytic converter. As a result of the development of technology the third stage of the catalytic converter, the control system, monitors and uses sensors in order to send information to the vehicle. The sensors adjust air-to-fuel ratios by sending more or less oxygen to the exhaust when needed to meet stoichiometric rates as close as possible. The sensors also help sensor whether the oxidation catalyst has sufficient oxygen needed to burn unburned

hydrocarbons and CO (Berger 2009). Since diesel engines never operate at a stoichiometric ratio there is no three-way catalytic converter, only an oxidation catalyst.

Both diesel and gasoline engines need catalytic converters in order to reduce emissions and increase efficiency. A major development and an important difference between gasoline and diesel catalytic converters is the use of urea solution. Diesel engines require urea solution since they do not operate at a stoichiometric ratio, which explains why gasoline vehicles do not require urea technology. Since catalytic converters work most effectively under high temperatures and, urea solution is injected in the catalytic converter in order to evaporate and mix the exhaust and force a chemical reaction to reduce NOx. Urea, a carbon, nitrogen, oxygen, and hydrogen based organic compounds react with NOx. The reaction produces nitrogen and water vapor to eliminate a significant amount of NO in exhaust gasses (BP 2016).

Preheating of catalytic converters is a solution to maximize efficiency. While placing the catalytic converter near engine components in the vehicle that exert high amounts of heat is a solution, the life expectancy of the catalytic converter would be greatly reduced due to its resistance capabilities. In the past the batteries contained in Hybrid vehicles, since they provide a much greater amount of energy than standard 12-volt batteries, had the ability to preheat the catalytic converter with the use of electrical resistance heaters (Persaran 2003). In today's market one of the two catalysts is placed near the engine for optimum start up as a solution. Catalytic converters are just one of many examples of automotive efficiency innovations but they are by no means perfect in reducing emissions. The limitations of catalytic converters are constantly being tested and pushed to new heights in order to sufficiently meet or exceed the amount of pollutants acceptable in the atmosphere.

Electric vehicles on the other hand produce zero exhaust when in operation but are still not 100% clean post-production. While electric vehicles do not require liquid fuels such as gas or diesel, in most cases, electric vehicles pollute the atmosphere while charging the battery. Plug-in Hybrid vehicles share this similar challenge when charging the battery from an external power source. The only instance when an electric vehicle could be considered

completely clean of pollution post-production is in the case when the battery is charged from a source that generates electricity entirely through the use of renewable energy.

Most charging stations are connected to local power often generated by fossil fuels in the USA as well as Europe and the increase in demand for electricity to charge vehicle batteries increases the need for the supply of electric power. Figure 2 represents the sources of USA energy production. Consequently, an increased demand for energy results in additional pollution affecting the environment. An additional investment into renewable energy sources at home would provide an individual with a sustainable source of energy resulting in an overall carbon footprint reduction. While most automotive manufacturers team up with renewable experts to make options of sustainable practices available to consumers, many regions of the USA or the globe in general may or may not be practical for the installment of at home energy alternatives and the consumer is therefore forced to consume the best available alternative energy source.

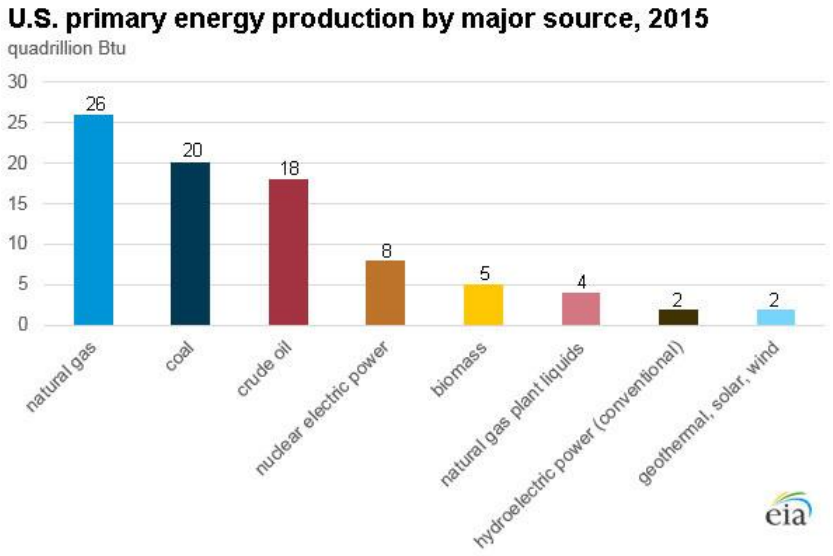

Figure 2: United States Primary Energy Production by Major Source 2015 (EIA 2016c)

Chapter 2.4: Ranking

Determining whether or not one fuel type or multiple fuel types are better than another in terms of efficiency and pollution reduction does not eliminate the fact that all vehicles, be they powered by electric, Hybrid, or liquid fuels pose health and environmental threats. These threats are evident during both the production process and the consumption process.

Government regulators and automotive manufacturers play an important role in the overall effort to reduce automotive pollution and damage to the environment and health. Consumers can further support this effort by making good choices when purchasing a new automobile. Consumers should consider which vehicle works best for their individual needs and circumstances both financially as well as in general. In that light, a consumer should consider which vehicle best reduces the overall carbon footprint during the vehicle's expected lifetime compared with its counterparts while staying competitive. The current automotive market is packed with diverse options that target a wide range of consumers. An individual that is environmentally conscience is likely to pick a vehicle that is environmentally friendly as long as that vehicle meets their current needs. On the other hand, if an environmentally conscience person was given an option to pick a Hybrid, electric, or fuel combustion engine vehicle that were all comparable in efficiency and cost the decision making process would become a little bit more complex. Such a situation presents an interesting lead for discussion as to what the future of the USA automotive market may resemble. Assuming that the chances of having only one automotive fuel choice in the near future are slim due to the nature of supply and demand, it seems apparent consumers will always haves multiple vehicle fuel options as choices. Nonetheless, the nature of competition and technological innovations together with automotive standards and consumer demand will continue to influence the automotive markets. The future will reveal which form of automotive propulsion drives the markets.

Chapter 3: Price vs. Abundance of Oil

Chapter 3 analyzes oil price trends during the period 1946 to 2016 in the USA market as seen in figure 3 and the consequent influence the price of oil has on vehicle sales demand, the introduction of alternative vehicles, and the effects of changes in environmental awareness on automotive efficiency and automotive production and infrastructure.

Chapter 3.1: Complimentary Goods vs. Substitute Goods

Economic theory states that complimentary goods - goods used in conjunction with each other – can help to explain and identify certain market trends. With regards to the automotive industry, petroleum oil products and vehicles are considered complimentary goods. In comparison, substitute goods refer to alternative goods with similar or better results available for use (Living Economics 2016). An example of a substitute good is a Hybrid or electric vehicle as an alternative to a more traditional fuel combustion vehicle.

Nearly all of the crude oil that is produced or imported into the USA is refined into petroleum products (EIA 2016a). When global crude oil prices decrease, the final refined petroleum oil price almost always decreases as well. As a consequence, when crude oil prices decrease, disposable income for consumers inherently increases assuming that consumer oil consumption habits remain the same. In theory it seems logical to assume that consumers would prefer more disposable income in their pockets due to savings at fueling stations. The question remains whether or not the average consumer takes this increase in disposable income when oil prices are low into consideration when purchasing a new vehicle. The dilemma that arises is that while consumers may have more disposable income, purchasing vehicles solely based on crude oil price reductions is a risky investment.

The purchase of a new vehicle is a considerable financial investment for the average consumer and factors such as oil price trends are not always considered adequately. The potential loss or gain on investment consumers would face would be too unpredictable if

they considered buying and/or selling their personal vehicles based on oil price fluctuations alone. This may be one reason why fuel consumption tends to remain steady even during peak price periods. Therefore when the price of fuel increases, miles driven do not necessarily decrease proportionately even though vehicles and oil prices are complimentary. This trend could however be affected if for instance a suitable alternative to the traditional combustion engine vehicle was taken into consideration.

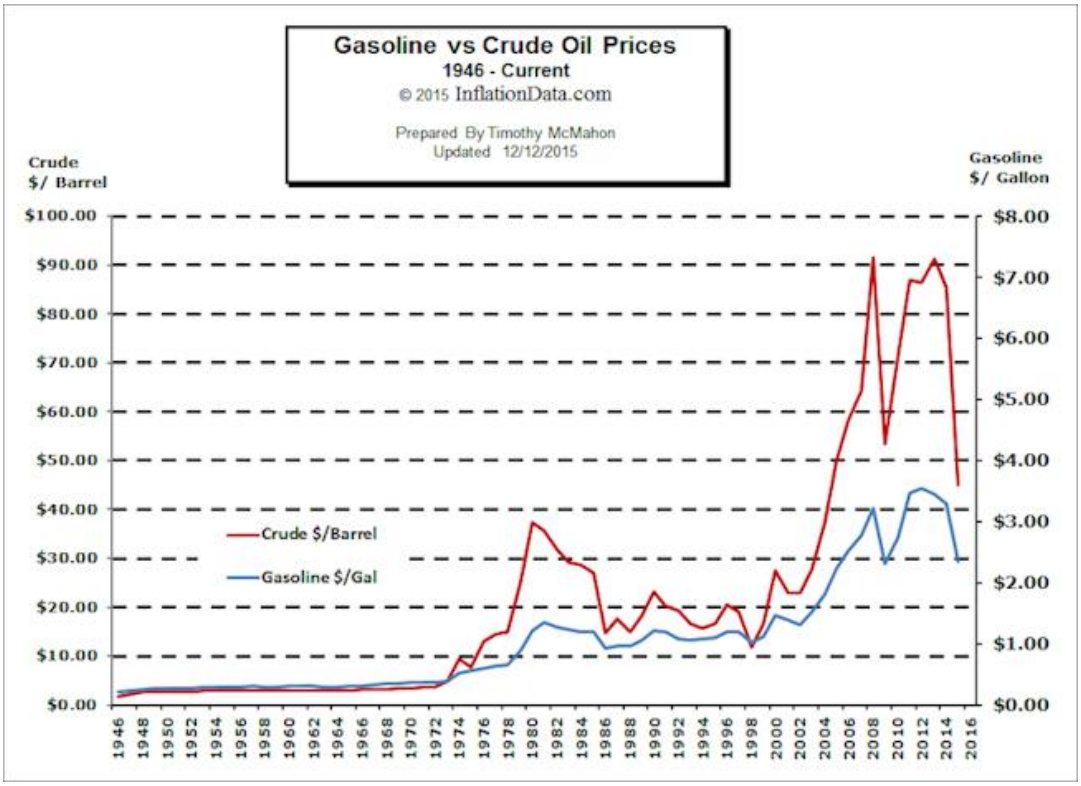

Figure 3: Gasoline vs. Crude Oil Prices (McMahon 2015)

The question arises as to whether or not there are acceptable and marketable substitute goods for the standard vehicle currently available to consumers so that they can avoid any loss of investments or unintended additional investments should the consumer decide to make a new purchase.

As demonstrated in Figure 3 USA fuel prices fluctuate over time. These price fluctuations can directly or indirectly affect the automotive industry. The average life cycle of a vehicle

provides key information related to underlying factors driving consumption trends. A consumer is free to own their vehicle for however long they want, but knowing the costs of ownership over the years provides some insight as to how ownership costs are determined and how fuel price increases may influence ownership rates. Figure 4 compares owner cost percentages across different points in time.

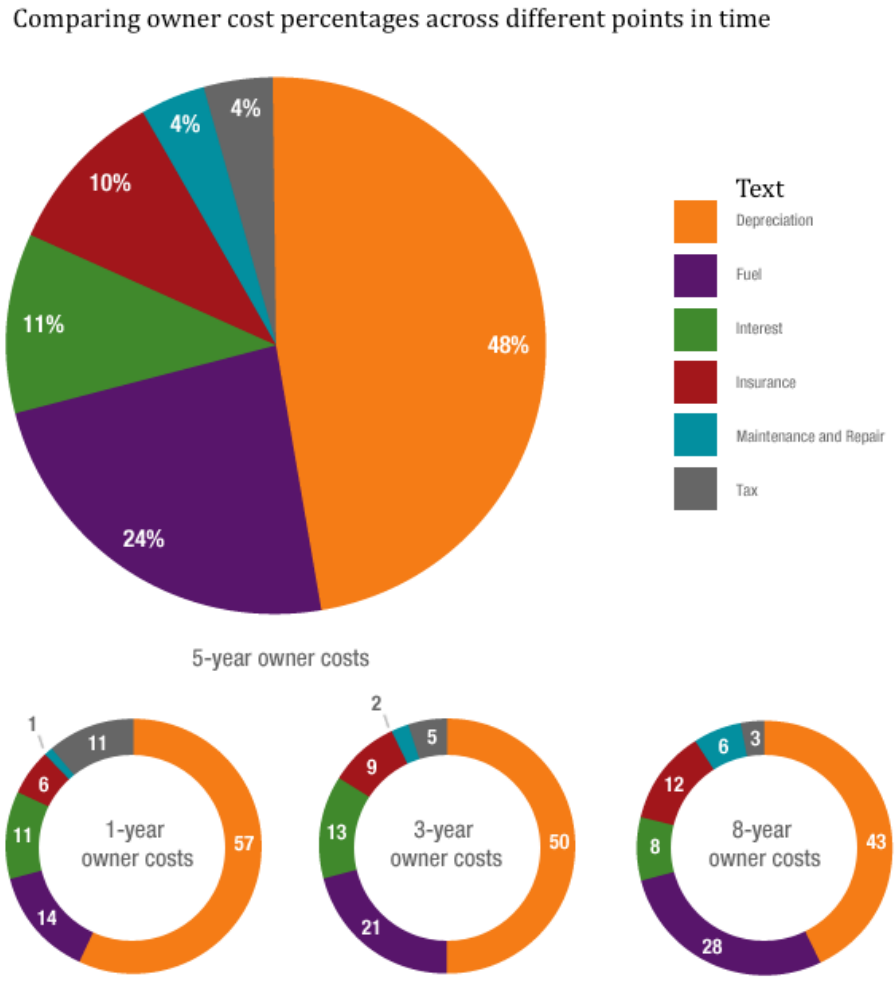

Figure 4: Comparing Owner Costs (CR 2013)

Figure 4 illustrates that the largest loss of investment during vehicle ownership is the depreciation of a vehicle, but the most important variable to consider in conjunction with average fuel prices is the overall investment of fuel during vehicle ownership. The figure

shows a clear decline in every variable except for fuel costs, which may give some insight as to how consumers' purchasing behaviors are formed. Several outcomes may arise as a result of these findings. First, consumers may find that owning a vehicle for a longer period of time is beneficial, thus reducing overall sales of vehicles. Secondly, consumers may consider purchasing used cars vs. new cars to avoid depreciation value losses. Thirdly, consumers may consider avoiding internal combustion engines or consider purchasing Hybrids as an alternative to offset the cost of fuels. The scenarios are endless, but what presents itself is that even with information made available about owner costs the automotive industry continues to break record sales. These factors are likely a result of automotive manufacturers' mastering consumer purchasing behaviors and figure 4 is likely accurate but fails to take into consideration the dynamics of the sales process. Leasing, financing, renting, and maintenance cost coverage options are all examples of how the automotive industry creates flexibility across the board and continues to appeal to consumers.

Chapter 3.2: Consumer Purchasing Behavior

While fuel prices somewhat affect a consumer's decision process to purchase a vehicle, there are other variables that also affect a consumer's vehicle purchase decision. A question worth considering is to what degree fuel price levels actually affect consumer-purchasing behavior.

The end goal for automotive manufacturers is to generate a profit and in order to accomplish this their specific vehicles must successfully appeal to the relevant mainstream market. When a consumer makes a decision to purchase a vehicle and the consequent sale of a certain product results, it can be assumed that an individual's decision-making process played an important role in the sale of the product. The consumer's final decision regarding the purchase of a certain vehicle is very likely the result of the consideration of a series of complex technical factors as well as consideration of numerous personal preferences. Some of these factors are likely pre-considered outside of the sales office and other factors were probably considered spontaneously. As an example, an individual

entering a dealership looking to purchase a vehicle that is eco-friendly may drive out of the lot in a new sports utility vehicle that is far from what they had intended to purchase before entering the dealership.

Most consumers already have a certain brand in mind when considering the purchase of a new vehicle. This mindset can be based on the result of personal experience, the influence of word of mouth, exposure to advertising, marketing, or just simple research. Whatever the reasons may be behind the mindset, consumers have multiple options to consider and these are some of the reasons why automotive choices are so diverse and consequently the automotive industry so lucrative.

Manufacturers tend to have a wide selection of vehicle line-ups with the same predominant goal in mind - to sell as many of their vehicles as possible to as many consumers as possible. This is a fundamental strategic goal all businesses must strive to achieve in order to stay competitive in the marketplace.

Certain automotive brands have become synonymous with certain vehicle criteria. For example, if an individual is looking for a very safe vehicle, Volvo may come to mind. On the other hand, if an individual is looking for a luxury vehicle, Mercedes may be the best choice. The point in case is that all brands have a certain authenticity or identity and it is important that manufacturers maintain this authenticity and identity over time assuming that these characteristics are positive. Manufacturers in turn can manage their budgets to enhance desired outcomes whether their target is to produce a performance, luxury, safe, or economically geared product. As a result, the consumer is often drawn towards the brand that appeals to their preferences the most. Based on consumer demand, manufacturers strive to meet those demands by ensuring that the supplies are available.

Chapter 3.3: Oil Abundance Over Alternatives

Nearly all of the crude oil that is produced or imported into the USA is refined into petroleum products. On average, in 2016, USA consumers have been paying around $2.20 per gallon of regular gasoline and $2.40 for diesel fuel (EIA 2016b).

The current abundance of oil and the influence oil has on the automotive industry in the USA raises intriguing questions with respect to the emergence of alternative fuel in the automotive market. It is noted that even during periods when there are spikes in the price of oil, consumption of oil products in the USA dips slightly but usually bounces back rather fast. It appears that during these periods of price volatility, USA consumers continue to purchase SUVs or other less gas efficient vehicles and continue to adapt to oil price fluctuations. Consumer habits tend to reflect familiar patterns in the short-term. Nonetheless, the introduction of alternative fuel vehicles has steadily made its way into the mainstream USA automotive market due in large part to the overall global increase in environmental awareness.

Environmental issues related to the automotive industry have attracted consumer attention and this focus has been steadily increasing during the past few decades. This increase in consumer awareness and subsequent increase in responsibility for the state of the environment are reflected in the growing movement for increased environmental responsibility and the automotive industry can be found right in its crosshairs. As such, the automotive industry and the environmental movement are clearly linked.

Many vehicles on the market today are already fitted with various eco-friendly technologies regardless of whether the vehicle is a Hybrid, electric, or traditional fuel combustion engine. The implementation of new technologies plays a key role in understanding where the automotive industry is headed. Automotive innovation is critical in that without it, it makes it very difficult for automotive engineers to meet new vehicle standards suitable for production. Although alternative fuel vehicles are already more than efficient to meet federal and state automotive standards, it is important to note that the automotive industry has been able to effectively engineer the traditional fuel combustion engine in such a way that it provides consumers with improved efficiency results. This is in part due to the introduction of new technology such as break regeneration systems, automatic start/stop technology, computer software upgrades, and an overall improvement

in most components. In many ways, the traditional combustion engine driven vehicle has become more competitive with alternative vehicles in terms of automotive efficiency.
The question of how abundant is the supply of oil and how much oil is left on earth continues to be an important global issue for discussion. This is a broad topic and as such almost impossible to answer with a simple explanation since oil is such an important resource used on a global scale. What is known is that oil is a natural resource, but it is not an unlimited natural resource such as wind or solar power. Unless the earth stops spinning and the sun stops shining it seems unreasonable to imagine that oil stands a chance as a valuable long-term resource compared with renewable energy sources. With such a philosophy in mind, what could be keeping the use of renewable sources of energy from rapidly succeeding in the automotive markets? The idea that renewable energy sources could potentially and likely dominate the energy sector in the future is clearly viable. The future of oil markets may depend on how well currently known supplies are managed or sustained and the availability and management of resources not yet identified. The growth of renewable energies and alternative fuels will subsequently help manage the supplies of oil on a global scale as well as continue to make it a viable option for fuel consumption. The development of the automotive industry relies heavily on such variables and its continuing relationship with the energy sector will clearly play a significant role in the development of automotive technical innovations and the future of vehicle production.

It is apparent that transportation, energy and its consumption are essential elements for modern human life and a world without this combination is unlikely. Sustainable environmental practices will consistently evolve the direction of the automotive industries. In order to sustain such practices, businesses need to continue to set strategic goals focused on profit generation while at the same time meet or exceed related governmental and environmental standards. The risk that changing consumer demands may influence the success or failure of some manufacturers will remain a possibility.

The need to continue to introduce alternative fuel vehicles on a global scale is here. From a business perspective it is unclear as to when it is absolutely necessary to speed up this introduction and to what degree. If alternative fuel vehicles were already in high demand

in today's markets there would have already been a huge shift in the automotive industry towards vehicles driven with alternative fuels. Currently, and as previously stated, most manufacturers have alternative fuel vehicles in their line up but none of the manufacturers have actually been able to propel their businesses in such a way that would eliminate the demand for traditional combustion engines.

Tesla on the other hand is a prime example of a company that has continued to demonstrate that it can withstand a competitive automobile industry. Tesla is currently the only USA manufacturer that markets primarily electric vehicles in their line up. The visionary behind the company, Elon Musk, entered the automotive industry guns drawn. A bold yet necessary move needed in the industry that has proven to give a glimpse into what the future automotive market may look like. Tesla's automotive innovations entered the global market with a boom in 2008 and Tesla has been able to shake up the industry in ways that are intended to "promote to accelerate the advent of sustainable transport by bringing compelling mass market electric cars to market as soon as possible" (Tesla 2016). The subsequent urge to enter today's market is what makes Tesla so intriguing. Is there something Tesla knows that the rest of the automobile industry isn't paying attention too, or does Tesla just have what it takes to withstand the market punches it has just inherited within its larger business plan?

Chapter 4: Automotive Development

This Chapter reviews levels of actions aimed at reducing air pollution, emission variables, the increase in Hybrid sales, changes in policies and their impact over time and the blending of automotive and technology sectors.

Chapter 4.1: Levels of Actions Aimed at Reducing Air Pollution

At the USA national level, air pollution reduction is dealt with by legislation such as the Clean Air Act. In order to pass a law elected Congressional representatives must agree to the law by majority vote prior to the signature of the President. The Clean Air Act gives the Environmental Protection Agency (EPA) the legal authority to control how much pollution is allowed into the air. For example, it allows the EPA to set emission standards automakers must abide by, and it issues permits to factories and power plants setting limits on how much air pollution they can emit. In practice, however, the EPA often lets state/regional authorities handle permitting and/or the setting of tighter auto emission standards (California is especially known for this) (EPA 2015a)

The role of the EPA can be simplified in order to better understand how the agency adheres to its mission of protecting human health and the environment. In short, air pollution related laws written by Congress provide the EPA with "the authority to write regulations. Regulations explain the technical, operational, and legal details necessary to implement laws" (EPA 2015a). In turn, the EPA helps to "regulate how entities meet federal requirements and it holds entities legally accountable for environmental violations. The EPA also issues policy and guidance documents to assist the public and regulated entities" (EPA 2015a).

At the state and regional level, air pollution is dealt with mostly by regulation, that is, rules and permits issued by state environmental agencies. For example, any business with air emissions in the USA requires an air permit. This means that any business, whether it is a restaurant or a production plant must hold appropriate permits.

At the city level, air pollution is dealt with mostly by urban planning, also known as zoning. Transportation planning including the moving of vehicular traffic additionally attempts to consider the need to assure that people are moved safely and efficiently. Urban planning is not limited to the planning of moving vehicle traffic efficiently but also considers other long-term goals such as sustainability and the development of public spaces. The amount of car traffic, and consequently, the amount of air pollution from cars, is determined primarily by how the city is laid out. If people live very far from where they work, there will be more air pollution generated. If people live walking distance from where they work, there will be hardly any air pollution generated. City planners have to carefully balance the needs of developers together with the needs of the public.

Individuals, in their own capacities, also possess the ability to reduce air pollution. If individuals are properly educated on the impact of their daily activities, they can adopt healthy practices that help reduce air pollution. Their actions whether it be participating in forms of activism or just choosing to ride a bike rather than drive a motor vehicle can contribute to an air pollution reduction.

Chapter 4.2: Emission Trends

Annual emissions estimates are used as one indicator of the effectiveness of air pollution programs. Figure 5, provided by the EPA, presents the growth of various indicators in relation to growth areas and emissions from 1980 to 2015. The total miles traveled by vehicles increased by about 106% and the USA experienced a 25% growth in energy consumption. All indicators were accompanied by a 41% increase in population growth. During the same time period, total emissions of the six principal air pollutants dropped by 63%. The most interesting observation gathered from this figure is the steady decline of CO2 emissions from 2008 onward (EPA 2015b). Although the drop occurred around the beginning of the recession, it could also be suggested that the desire for fuel-efficient vehicles emerged as well causing the steady decline. The section that follows provides a look at the cumulative U.S. Hybrid-Electric Vehicles sales by year.

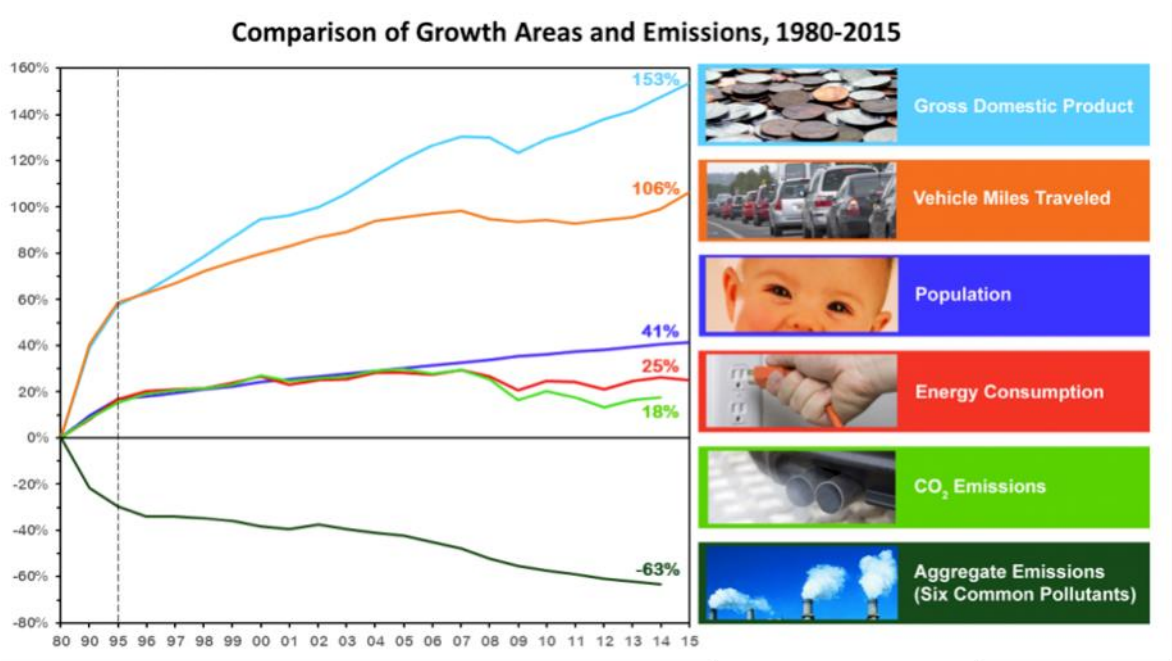

Figure 5: Comparison of Growth Areas and Emissions (EPA 2015b)

Chapter 4.3: Cumulative USA Alternative Vehicle Sales

Figure 6 is an indicator that the rise of EVs, PHEVs and HEVs is on a steady upward trend (Gordon 2011). Figure 7 shows that vehicle sales as a whole in the USA have been on the rise following the 2008 depression. At around 18 million in sales in 2016 Figure 6 and Figure 7 indicate that in 2016 alterative fueled vehicles represented roughly 15% of vehicles purchased that year (Trading Economics 2016). The rapid growth of alternative vehicle sales has also pushed automotive makers to compete, by forcing newer models to be more fuel-efficient since the demand is supported. While these growth trends are estimates on average, only time will demonstrate the actual success of alternative fuel vehicles.

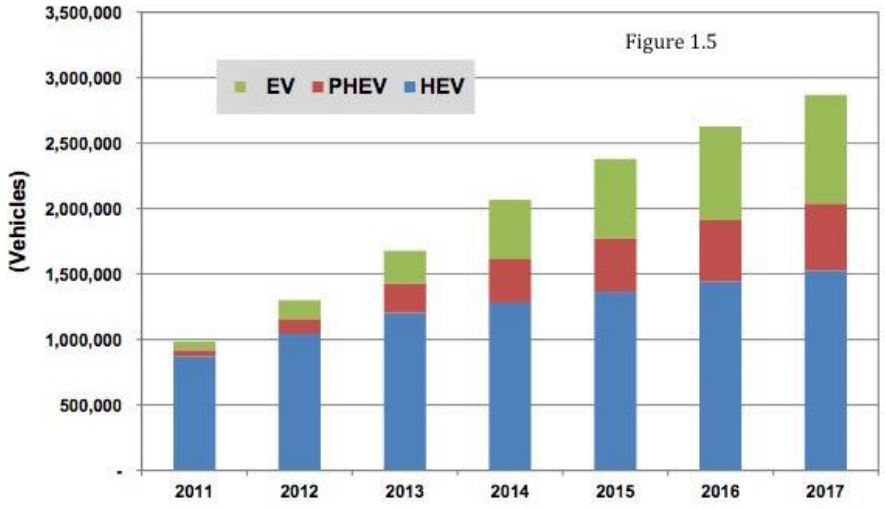

Figure 6: United States EV, PHEV and HEV Sales (Gordon 2011)

Figure 7: United States Total Vehicle Sales 2006-2016 (Trading Economics 2016)

The EPA states that the USA transportation industry contributes to 31% of CO2 emissions. The transportation sector is not limited to passenger vehicles but also includes air, marine and rail transportation (EPA 2016) .Figure 8 provided by the EPA shows the CO2 emission trends from 1990-2014. CO2 emissions have increased by almost 10% between 1990-2014 due in large parts to the combustion of fossil fuels. These increases are however influenced by population growth, energy consumption, and economy as seen in Figure 5. The growth of miles traveled is also evidence that CO2 emissions rise as a result.

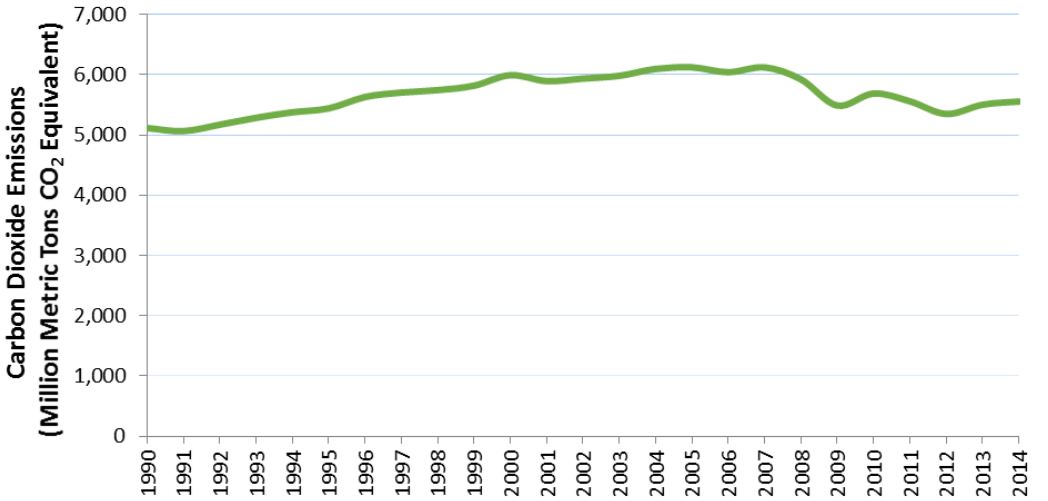

Figure 8: Carbon Dioxide Emissions (EPA 2016)

Chapter 4.4: Emissions, Adherence and Incentives

Automotive manufacturers are mandated to adhere to federal and state emission and automotive standards. The implementation of related laws and regulations help pave the production processes of automobiles in that many manufacturers aim to exceed standards for all brands entering the market. The introduction of safety standards is an example that led to the mandating of front bumpers and passenger safety belts on all automobiles produced from 1973 onward in the USA. Similarly, lead was phased out of fuel and

emission standards leading to a subsequent increase in fuel economy. Such standards are designed to reduce the impact of everyday driving on the environment and phase out poor practices and replace them with more sustainable ones.

Policies are driven by norms and trends in the USA much like they are across the globe. Laws are used as tools to meet objectives laid out by policies. As a by-product of implementing certain automotive laws, the automotive industry effectively alters its automotive development stages. Vehicles pre- and post-production must adhere to federal and state standards accordingly. Inherently, government incentives and grants often provide financial opportunities for automotive manufacturers to produce products that are more environmentally friendly. Incentives and grants encourage consumers to purchase more efficient vehicles including electric and Hybrid powered vehicles. Such incentives generally benefit both automotive manufacturers and consumers.

Tax credits are also often available to encourage manufacturers to produce automotive alternatives and to encourage consumers to purchase automotive alternatives. Tax credits and incentives can drive change and support new trends in the market. These trends often become norms, which then drive demand and eventually shift policy and law in one direction or another. The direction policy is driven directly affects the automotive industry as manufacturers are pressured to meet new standards and shifts in consumer preferences. The manipulation and interpretation of new trends and standards are left up to the automotive industry to implement bearing in mind that manufacturers must at a minimum meet federal and state standards. A positive outcome of these pressures can be observed by the innovative ways the automotive industry continues to re-craft vehicle efficiency through multiple forms of propulsion.

Chapter 4.5: Options and Directions

The automotive industry continues in new directions as a result of the combination of adapting to policies, regulations, standards and consumer behavioral trends. Governmental standards are not the only set of standards that drive the automotive industry in one

direction or another but are shared with consumer standards and expectations. The automotive industry is thus on a regular basis presented with new challenges and advantages for development. As mentioned previously, trends and norms in many cases lead to policy change. These changes are critical and in a way help to map out the direction of the automotive industry so that the industry remains competitive and consumer friendly. Retrospectively, it can be noted that the automotive industry has the ability to influence the outcomes of these variables through consumer outreach vectors that once were limited in reach. These extensions support the goals of the automotive industry since new ideas and a better understanding of consumer behavior and purchasing patterns can emerge through the study, analysis and collection of relevant data. Automotive manufacturers are in a position to utilize these vectors to the extent they believe is appropriate. In the future, the importance of developing new customer acquisition techniques and stronger brand loyalty may likely intensify and be a key game changer in a competitive and diverse automobile market.

Today's consumers are technologically savvy and increasingly more aware of sustainable practices in part due to rapidly growing social media outlets. Consumer preferences are constantly influencing the direction of all industries, including the automotive industry. The rapid rise of car sharing practices has proven that individuals in today's society are seeking alternative modes of transportation at staggering rates. The success of companies such as Uber and ZipCar has shown the automotive industry that media connectivity and convenience play a huge factor in consumer transportation preferences. The link between technology and mobility is proving to be a pivotal trend in today's society as consumers are becoming accustomed to being a click away from almost anything.

According to global surveys conducted by Pew Global Research Center, three quarters of Internet users across the globe use the Internet at least once a day. Of those users, 76% use social networking sites such as Facebook and Twitter. More specifically, 89% of people in the USA and EU countries use the Internet daily and about 52-72% of people have a smart phone (Pew 2013). These percentages will likely continue to increase. The question that arises is whether or not patterns such as these have an impact on the automotive industry

from a developmental standpoint. Initially, the patterns reflect the potential need for automotive manufacturers to veer from traditional business models and incorporate flexibility as well as develop integrated technologies into vehicles. The increased use of the Internet also provides the automotive industry with more insight as to consumer preferences and marketing capabilities.

The automotive industry will likely be interacting with other industries as new partnership opportunities present themselves. For example, many vehicles utilize their own software and programs for connectivity and the desirability for Original Equipment Manufacturer (OEM) parts has fallen in favor of brands such as Apple regarding vehicle connectivity. Such consumer demands have forced automakers into partnerships with companies whose loyalties are not limited to one automotive brand. These transitions and breaks with tradition will likely drive automotive manufacturers to further develop innovative technology, business models, and solutions to help differentiate themselves from their competition while maintaining authenticity.

While these observations are limited in scope, the assumption that brands will merge with technology may heavily influence car buyers preferences in the future is apparent. With that said, it is likely that the Life Cycle Impulse (LCI) of vehicles will also need some attention. The LCI, which is commonly referred to as an "automotive facelift" refers to updates a vehicle receives during its production run. The LCI of a vehicle receives upgrades not limited to software. Minor vehicle tweaks and component changes will occur throughout the production cycle that could potentially increase efficiency on many levels. The typical production run of a vehicle can range from four to seven years depending on the manufacturer. The reason the LCI is an important factor to consider is that the LCI of a smart phone and/or technology in general has much smaller ranges. The iPhone for example usually has a production run of about two years, but is able to update its software throughout its production run effectively (BMW Group 2016). The reason for these fast life cycles of technology is because the rate that software and hardware evolves is staggering. These changes cause consumer expectations to rise as the need to be updated has become a necessity in today's society. Automotive manufacturers must be able to track

these trends and work alongside partners or develop integrated technology in their vehicles that follows a similar schematic. Vehicle hardware must be able to support software updates throughout the full production run if manufacturers want to stay competitive in the future. The alternative, and a costly one at that, would be reducing production runs that may prove inefficient on many levels in the long run.

Chapter 5: Automotive Design

Chapter 5 takes a look at activities involved in creating the style, look and feel of the product. The mechanical architecture, materials, process and the engineering of components needed are discussed as well.

Chapter 5.1: Understanding Aerodynamics

In simple terms, aerodynamics is the motion of air around an object. More specifically, depending on the shape of an object moving through the atmosphere, the object is subject to gravity and drag, and as such the object disperses the air around it. Drag is defined as the resistance an object faces as it moves through a medium like air. Basically, drag responds to velocity and the slower an object travels the less drag it experiences. The opposite is true when the speed of an object is increased (Dunbar 2011) In the case of an automobile, several variables are considered to measure its motion. For instance, the automobile's weight, acceleration, velocity, mass, and force could be considered. When an automobile produces drag, its acceleration is affected. This in turn has an impact on the automobile's fuel efficiency, overall performance and safety.

Acceleration is calculated as follows:

a= Acceleration | W= Weight | D=Drag | m=Mass

$$a = (W - D) / m$$

When a vehicle increases acceleration through the atmosphere its velocity and drag will also increase. Increased acceleration will continue and only be limited in the event that the drag of the vehicle equals the weight of the vehicle (Dunbar 2011). Automotive designers use Newton's Laws to determine the drag coefficient of a vehicle. This is an important coefficient that helps to determine and measure how efficient vehicles can move through the atmosphere.

The Drag Coefficient is calculated as follows:

Cd= Drag Coefficient | D=Drag | r=Density | v=Velocity | A= Area

$Cd = D \div (A \times .5 \times r \times v^2)$

Automotive designers can use the summation of the coefficient drag to measure the force of air resistance of a vehicle. Since the force of air increases with speed as previously noted and when the coefficient drag number is lower, aerodynamic efficiency increases.

Most passenger vehicles in today's market achieve a coefficient drag number of 0.30 (Sherman 2014). This number does increase in range with larger passenger vehicles though the increase is not significant. When simply looking at vehicles such as the BMW i8, Toyota Prius and other sedans such as the Audi A6 compared with other competitors it is not possible to discern the Cd numbers of the automobiles, however, it is safe to assume that they all fall within the range of 0.30. The following table details some of the most efficient vehicles in today's market with their drag coefficient numbers. These numbers help put aerodynamics into perspective. The vehicles represented in Table 1 is categorized by model/year, Cd, Miles Per Gallon (MPG), Miles Per Gallon equivalent (MPGe), range and fuel type. What is clear is that Cd numbers are relatively close to .30 but a lower Cd does not entail better fuel economy (Bugbear 2014). While the Cd does contribute to efficiency of passenger vehicles it is clear that it is not the sole contributor. The fuel type contributes to efficiency significantly as well as tank capacity or battery capacity. Although these are just a few examples of passenger vehicles available, the combination of fuel, MPG, MPGe, Cd, and range provide some perspective as to the direction automakers are headed. The United States Department of Transportation and EPA set a threshold for automakers to produce vehicles that average 54.5 MPG or MPGe by 2025. What is clear is that these targets are already being met and based on the table. Gasoline vehicles may require the most improvement. Although there are already passenger vehicles averaging 40

MPG not listed in the table below, the challenge is not impossible based on the trajectory of improvements over time

Table 1: Vehicle Side by Side Comparison (DOE 2016a)

Model/Year	Audi A6 2016	BMW i8 2016	Toyota Prius 2016	Tesla S 2016	Smart Fortwo 2016
Cd	*0.26*	*0.26*	*0.25*	*0.24*	*0.34*
MPG (City+Hwy)	*28*	*28*	*52*	*X*	*71*
MPGe	*X*	*76*	*X*	*89*	*X*
Range (Miles)	*538*	*310-370*	*565-610*	*219-294*	*547*
Fuel	*Gasoline*	*PHEV*	*HEV*	*EV*	*Diesel*

A force that is entirely invisible affects everyday drivers. Air is an obstacle automotive designers must face when determining the aerodynamics of a particular vehicle model. Air resistance plays a role in the overall performance of a vehicle and much like an airplane soaring through the skies an automobile must be able to challenge this force in order to maximize its performance under all conditions. As a result, automotive designers strive to reduce the amount of work an engine, or any type of propulsion system, must perform in order to push through air as effectively as possible.

Over the last few decades the design of many vehicles has evolved into having a more rounded exterior resulting in better air flow and decreased resistance. This design change has evolved overtime to meet or exceed overall expectations as well as standards. The shell of a vehicle must work efficiently with the overall blueprint of a vehicle if it is to be successful in meeting road standards.

If consumers were asked to identify differences between a racecar and an everyday passenger vehicle they would probably be drawn to the aerodynamics of the racecar. A racecar serves a clear purpose of getting from point A to point B as fast as possible, which is why the racecar's exterior aerodynamic characteristics would be a distinguishing factor.

Another observation that presents itself when comparing the two vehicles is that of the scale of the controlled environment. The environment plays a significant role in the overall production of a vehicle. Standards and regulations set for a racetrack determine the overall production limitations of vehicles just as standards and regulations set for passenger vehicles define those vehicles. Therefore, the overall blueprint of a vehicle, not limited to the aerodynamics, is dependent on regulations and standards pending the scale of the controlled environment.

If one were to compare vehicles on the road today it would be quite easy to distinguish brands from each other just by looking at the emblems. The emblems on vehicles throughout history have not seen much significant change since they merely represent the manufacturer. If the emblems or badges were removed, most vehicles in today's market would look just like a certain class of vehicle. Without emblems and certain aesthetic characteristics that hold true to the authenticity of a certain manufacturer most consumers would be able to classify vehicles based on model types whether it is a Sports Utility Vehicle, truck, sedan, van or even a hatchback. All vehicles fall into certain categories as they all serve varying degrees of purposes depending on consumer needs. The underlying premise to this observation is that today's vehicles, regardless of model type or brand, are designed in such a way to maximize aerodynamic efficiency. This may explain why without proper identifying characteristics it may be hard to distinguish between brands and this may explain why competition within the automotive industry has been so lively. It also seems apparent that the shape of a vehicle is not the underlying reason consumers choose one vehicle over the other since the shapes of vehicles have all evolved in similar direction.

Chapter 5.2: Dynamic Materials

The style, look and feel of an automobile are some of the most important elements automotive manufacturers consider before entering the production phase. Many consumers are drawn to certain types of vehicles based on exterior and interior aesthetics. Aesthetics tend to be what captures the initial attention of a potential buyer and in some cases heavily

influences a consumer's buying decision. The importance of design does not only affect the consumer's decision to purchase a vehicle but design also affects the vehicle's level of safety, performance, and overall reliability to work efficiently with its main components. The design must also comply with all current automotive standards.

The types of materials used to produce vehicles have evolved over time leading to safer, more efficient and economical options. Increased overall performance as such has also resulted. The overall style of a vehicle depends on its shell construction configuration. Trucks, SUVs, and sedans all serve as passenger vehicles, but the vehicle classes vary due to their capabilities. The feel of a vehicle depends heavily on the components and features a certain class of vehicle has to offer. A consumer seeking luxury components may be drawn to certain comforts such as leather seats and other interior designs enjoyed during every day driving whereas an eco-conscience individual may veer towards a vehicle with better fuel economy. In general, all classes of vehicles offer certain variations of particular models designed to display a wide range of preferences to best create a certain feel for a vehicle.

Advances in technology have made automotive designs innovative in ways that were once considered unimaginable. Steel is currently used to build the skeleton of a vehicle, or what is known as the chassis. A vehicles chassis is a major component for safety, among other things, as it must be able to protect as best as possible the vehicle and its passengers during an impact. Steel is also used for many other components. Most of the weight of a vehicle is derived from this material alone. The steel industry has evolved over time and due to technology development the steel industry is able to make a variety of steels for different purposes. Automotive engineers use various forms of steel when constructing vehicles in order to accommodate certain variables such as safety.

Plastic is another major material used in the design of a vehicle. Plastic is cheap, easy to make, and can be used for a wide array of components on a vehicle. Due to its nature of being lightweight and durable, plastic is widely popular among vehicle manufacturers since it can reduce the weight of a vehicle. Another weight reducing material that has

played a large role in vehicle design is aluminum. Not only is aluminum lighter than steel but it is also extremely durable.

Rubber is a key component in vehicles since all vehicles require tires. The automotive industry was particularly instrumental in propelling the rubber industry into what it is today. Most of the rubber produced globally is consumed by the automotive industry. The tire is what protects the vehicle from the road and its durability is key to increasing efficiency and safety of a vehicle. Rubber components are also found throughout the vehicle and are not limited to tires. The glass and fiberglass industry is another sector heavily reliant on automotive manufacturing. Besides the windows of a vehicle, glass components are becoming more prevalent in vehicles due to technological innovations and features.

Many of the materials used to produce a vehicle have changed over time. It is evident that technology has driven such change and the materials used in vehicles have become lighter, safer, and more durable with good reason. Most of these design shifts have led to the production of more efficient vehicles. With respect to automotive efficiency the materials used to produce a vehicle are just as important as the aerodynamics of the vehicle.

Aerodynamics determines the amount of drag, wind noise, noise emission and undesired lift forces of a vehicle. These variables are important in the design process of a vehicle and must be considered alongside materials due to their significant potential to increase the safety, performance and efficiency of a vehicle. For example, the aerodynamics of an electric vehicle must be designed in such a way that limits the amount of workload the engine must perform due to the limited battery capacity. A poorly designed electric vehicle can suffer significantly in range if its engine has to work harder to propel itself. The overall desirability or demand for electric vehicles relies increasingly on design improvements since today's batteries used to charge electric vehicles have limited range capabilities.

The right materials and aerodynamics are essential to a successful vehicle design. Manufacturers have begun designing vehicles using new materials such as carbon fiber and carbon fiber reinforced plastics. The popularity of these alternative materials has grown due to new emission and safety standards. Carbon fiber and carbon fiber reinforced plastic (CFRP) are proven to be durable, lightweight, and dependable materials. By combining new materials and designing vehicles in such a way reducing aerodynamic drag, the automotive industry has been able to create more efficient vehicles for all types of fuels and alternatives across the board.

Chapter 5.3: Green Materials

The use of recycled materials has become an industry norm in today's market. Increased environmental awareness has imbedded itself in the automotive industry. The use of recycled materials produces less of an overall carbon footprint and appeals to the general public as well as automotive manufacturers due to reduced costs. There is a difference between recycled materials and recyclable materials. Recycled materials refer to the use of materials that have been reprocessed for repurposing while recyclable materials refers to the flexibility of materials to be recycled after use. For example, if a vehicle is marketed as being 95% recyclable this may entail that 95% of the vehicle will be repurposed and the remaining 5% as such in most cases the battery will be waste.

Manufacturers such as BMW have begun producing vehicles that encompass sustainability as a driving factor. The BMW i series, "i" standing for "Innovation", utilizes a wide range of sustainable materials. The BMW i3 for example is manufactured using renewable natural fibers, naturally tanned leather, and open-pore eucalyptus wood sourced from 100% FSC-certified forestry. The interior is produced from 25% renewable raw materials and recycled plastics as well as 100% recycled textiles for its interior. An additional 25% of recycled plastics are used for exterior paneling. The list of materials used to produce vehicles is changing significantly overtime due to new standards and the availability of new technology. BMW has not limited its sustainable practices to materials but has also extended it to the production process of vehicles in the BMW i series. 100% of power used

to produce the BMW i series in the Leipzig, Germany plant is obtained from renewable energy sources. Due to these production changes energy consumption to produce these vehicles has dropped by 50% and water consumption has dropped 70% (BMW 2016). The electrical components of a vehicle are often the most challenging to recycle. The best way to recycle such components is by simply reusing them. As mentioned previously, automotive batteries, especially, those for Hybrid or EVs, are a major recycling concern for environmentalist. The automotive industry will need to figure out the best alternative for these batteries before they reach their life expectancy and before these vehicles populate more market size. One solution to recycling such high voltage batteries would be to reuse them as power storage for solar and/or even wind energy. Given the prematurity of the need for these solutions, the question remains as to how resourceful the automotive industry will become if EVs and Hybrids begin to dominate the market down the line and whether or not a cleaner production process will be able to offset some of the challenges.

Chapter 6: Automotive Production

This chapter considers the environmental impact of producing a vehicle. It identifies hidden costs related to components used in the production process. It reviews the total production costs of Hybrid and EV batteries and the use of government and private funding to improve the US automotive production process and carbon footprint and it suggests that the range to measure the footprint of producing a vehicle should be extended.

Chapter 6.1: Production Cost and Efficiencies

How efficient is the production process of a vehicle? This question immediately raises a serious concern regarding the size of the carbon footprint related to the production of a vehicle. Imagine the results of separating all the components of a vehicle and organizing them in piles based on material composition. Now imagine where all those materials came from and how they were produced. Most likely a complex picture results. Every component in a vehicle has its own production process. Understanding each of those processes and each of the related footprints further complicates the imagined picture of the size of the carbon footprint.

Total energy consumed to produce each of these component products is difficult to calculate. An estimation of the total cost related to production processes such as labor, trade, extraction, refining and transportation is a major project in and of itself. Due to the complexity of calculating the actual carbon footprint of the production of a vehicle, the information presented in this chapter is a general observation of some costs and efficiencies in the automotive production process.

It seems fair to state that electric vehicles produce less emissions post-production compared with Hybrids and combustion driven vehicles. It is more difficult to state unequivocally that electric vehicles produce the smallest carbon footprint during production compared with Hybrids and combustion driven vehicles. In other words, measuring how environmentally friendly a certain type of vehicle is does not begin from

when the tail pipe produces its first round of emissions. It begins at the start of the automotive production line bearing in mind the environmental costs of the components used in the production process.

Awareness of the costs of energy, water and all other processes required during the production phase of a vehicle add value to the understanding of a vehicle's true measure of efficiency. For example, while the batteries used for Hybrids and EVs have become more environmentally friendly overtime, their production cost and subsequent carbon footprint are worth observation. Batteries currently used in Hybrids and EVs required extensive research and development. The environmental costs related to the mining of components used in the production of these batteries have been substantial. Companies such as Toyota, Tesla and BMW have already invested extensively in the research and development of energy storage in an attempt to improve energy storage capacity of these batteries and in turn to improve their Hybrid and EV market exposure. In the long run and on the assumption that energy storage capacity is extended, this type of research and development investment not only benefits manufacturers, but it also benefits the environment and consumers.

In today's market, lithium-ion batteries power most Hybrids and EVs. The amount of energy needed to produce lithium-ion batteries is of major concern to manufacturers, environmentalists and consumers. The high cost of the materials used to assemble these batteries is one of the reasons why Hybrids and EVs are costly in comparison with combustion driven vehicles. The production of lithium-ion batteries requires the mining of rare earth metals. The mining process alone contributes significantly to the size of the footprint of the Hybrid and EV (DOE 2015a). The high cost of producing advanced components like the lithium-ion battery required to assemble these vehicles adds significantly to the total energy costs for production. As a result, there is an environmental controversy surrounding overall value of producing Hybrids and EVs. Consumers and critics speculate whether the low emissions produced post-production actually offset the overall emissions pre-production. The post-production emissions include the recycling of these high voltage batteries once the vehicle is no longer useful. The controversy is

debatable and currently inconclusive mainly since the first generation of Hybrids and EVs have barely hit their life expectancies. Given that the automotive industry evolves quickly to meet challenges with new technologies, it is likely that the controversial issues related to the impact of the production, use and disposal of lithium-ion batteries in Hybrid and EVs will be resolved some time in the future. The likely solution will no doubt alleviate the concerns of manufacturers, consumers and environmentalists. Figure 9 presents a breakdown of vehicle emissions pre- and post-production.

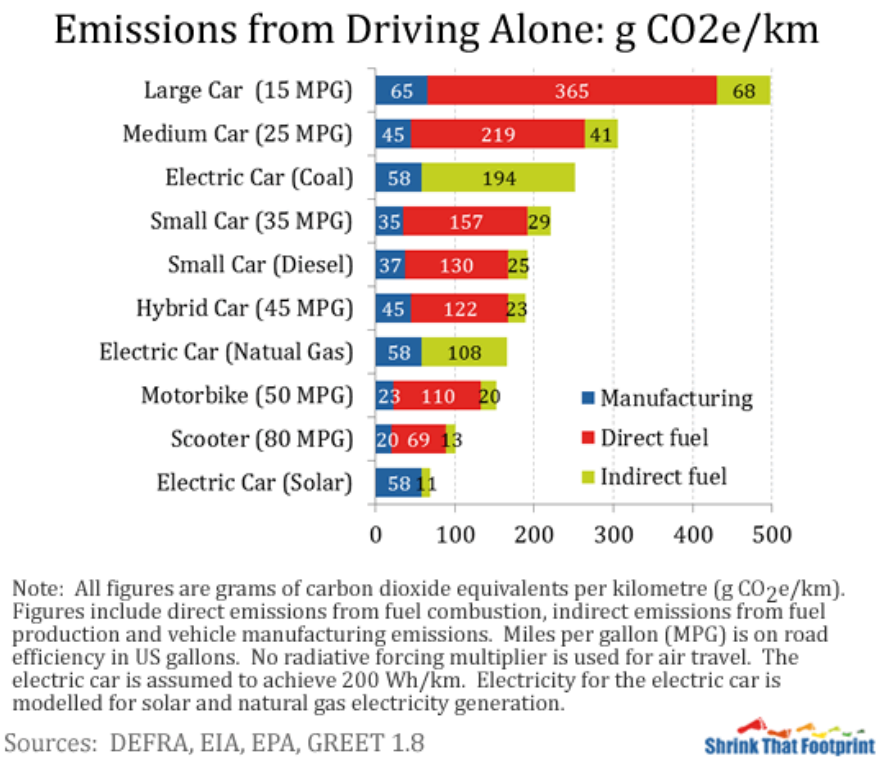

Figure 9: Emissions from Driving Pre- and Post-Production (Shrink 2016)

Chapter 6.2: Factories and Renewable Energy

An immense amount of energy is needed to power automotive factories. Automotive manufacturers are mandated to comply with national and state emission regulations and

standards that sometimes vary depending on the manufacturer's location. In many instances the regulations and standards are written with the intent to encourage factories to incorporate renewable energy sources in order to offset the amount of pollution produced during the production cycle. Many manufacturers are forced to use renewables if their emissions exceed maximum allowances. Since emission standards are often adjusting emission allowances, factories must be properly designed, maintained and updated effectively in order to meet evolving objectives at the lowest possible cost. Wind power, hydropower, solar energy, bio energy, and energy storage are all examples of renewables and technology being introduced to the automotive industry.

In the USA, autoworkers are building vehicles twice as fast as they did a decade ago. This production increase is a direct result of infrastructure development. The US Department of Energy has issued American automotive manufacturers almost 10 billion dollars worth of loans since 2009 in an attempt to revitalize the American automotive industry. These investments go into upgrading and maintaining factories across the USA with a view to produce vehicles more efficiently. The intent is to use advanced technologies such as renewable energies to help offset production costs and energy consumption. The intended outcome is to produce more affordable and competitive fuel-efficient vehicles while lowering the overall production footprint (DOE 2015b).

Government funding together with private funding and other initiatives are intended to reduce the overall carbon footprint of factories producing vehicles but the funding is not limited to infrastructure development alone. Much of the funding is aimed at investments in new technology that support initiatives to produce vehicles in the factory more efficiently and with less energy consumption. Technologies supporting components such as energy storage for batteries used in Hybrids and EVs have benefited from investment funding since producers have access to the resources necessary to improve technologies using the best available research and development (DOE 2015b)

Chapter 6.3: Extending Measures

The marketing profile of the Hybrid has gained serious momentum over the last few years. Not only has the Hybrid proven to be versatile in design but it has also proven to be more fuel-efficient as compared to EVs and combustion driven vehicle counterparts. Although it is apparent that Hybrids allow consumers to reduce their carbon footprint during ownership, it is not clear whether the overall production footprint of the Hybrid outweighs the benefits of fuel savings at the pump. Determining the amount of energy needed to produce a Hybrid vehicle is fundamental when calculating the actual impact on the environment.

Research suggests that policy and decision makers should extend the source range of vehicle emissions and not limit it to the emissions that start at the tail pipe in order to improve the measure of the total vehicle footprint. One example to consider is the emissions of sulfur and diesel fuel. While technology has advanced to clean and reduce the amount of sulfur content produced by diesel engines and traditional gasoline vehicles, much of the sulfur emitted into the atmosphere actually comes from the vehicle production process.

Depending on the actual source of energy needed to power factories during the production of a vehicle, higher levels of emissions may or may not result. For example, vehicles produced using electricity that is generated by coal would increase the amount of sulfur emissions contaminating the atmosphere compared with electricity generated by other sources. The true computation of a vehicle's footprint should therefore include the cost of energy utilized during the whole production process, including energy consumed related to the production process of components used during production, together with the cost of energy used during vehicle usage and disposal.

Chapter 7: Conclusion

Chapter 7.1: Chapter Summaries

Gas, diesel and electricity are the most common types of fuels used in the USA to power passenger vehicles. Diesel-powered engines consume less fuel and produce more energy compared with gasoline-powered engines. Diesel fuels have not enjoyed much popularity in the USA, as drivers tend to prefer gasoline fuels. Recently, however, and very slowly, diesel-powered vehicles are starting to gain in popularity in part because diesel fuels produce less carbon emissions and provide an overall boost in fuel economy.

Even though gasoline engines produce significant amounts of pollution, they continue to dominate the USA market. Federal and state regulators work together with manufacturers and introduce new technological innovations with a view to produce more efficient combustion engines.

Electric-powered vehicles are gaining momentum due in part to manufacturers like Tesla, a company producing more attractive electric-powered vehicles that produce little to no emissions when driven. Electric vehicles have drawbacks including limited range per miles per charge and limited access to charging stations among others. Most brands are investing in new EV line-ups to widen their appeal to consumers and the effort to produce high-energy storage batteries continues to be the main challenge.

Hybrid vehicles use two sources of energy, most commonly combustion fuels and electricity. Hybrids are proving to be more attractive to consumers due to fuel efficiency and due to their smaller carbon footprint. There are three types of electric vehicles, the plug-in Hybrid electric, the Hybrid electric and the all electric. While these vehicles appear more sustainable than traditional combustion engine vehicles, electric energy produces pollution. The production, cost, size and charging of batteries remains a challenge for automotive engineers. The emergence of PHEV technology has become more widespread in common models. Automotive manufactures have begun phasing in plug in options to

their most popular models. These shifts have allowed consumers to purchase their ideal vehicle with Hybrid technologies as an added incentive. The availability of these new options may push the automotive industry in a new direction whereas plug-in technology is becoming more of an added feature rather than an expensive investment.

The USA makes unleaded gasoline fuel readily available and affordable to its consumers. EU countries prefer diesel fuels due to supply and demand. Relative government regulations can drive the automotive manufacturers and can persuade consumer preferences. Standards for CO2 and NOx emissions play a role in driving the direction of the automotive industries in the USA and other countries. The popularity of diesel fuels in the USA is growing and government incentives aimed at persuading consumers to switch to diesel will reduce the amount of CO2 in the atmosphere. Diesel is becoming an ideal substitute good over the tradition fuel combustion engine and may slow down the rate at which alternative Hybrids and EVs enter the market.

A catalytic converter is an example of a vehicle component designed to reduce harmful emissions into the environment. Both diesel and gasoline engines require catalytic converters (although different concepts) and other exhaust gas aftertreatments systems. Electric vehicles don't produce combustion related emissions when in operation. Nevertheless, electric vehicles pollute the atmosphere during the charging of batteries. Catalytic converters are just one example of many pollution control components of a vehicle. Fuel injecting in vehicles today is another example of ingenuity as they have proven to be more efficient around the board. Eco-driving modes have also become a standard feature in vehicles today as they provide an option for everyday driving to reduce energy loads on vehicles and thus increase overall efficiencies. Eco-driving modes provide consumers with on demand driving options that allow consumers to stay in control of their habits. The popularity of these modes may influence consumer behaviors in the future and should be considered a stepping-stone towards the introduction of more fuel efficiency.

Automotive market trends respond to, among other things, oil prices. USA consumers don't necessarily base the decision to purchase a new vehicle on the rise or fall of the price

of oil. Fuel consumption tends to remain steady during oil price fluctuations. The question arises as to whether or not a consumer would consider purchasing a vehicle other than one powered by gas as an alternative taking into account investment factors. The average life cycle of a vehicle also drives consumer preferences. Many factors both technical and personal play a role in the decision making process related to the purchase of a new vehicle. For example, consumers often prefer certain brands or they may focus more attention to the appeal of an eco-friendly vehicle. These changes in behavior have driven the development of a new line of vehicles in most automotive manufacturers' lines.

The abundance of oil in the USA market has an influence on the emergence of the alternative fuel automotive market. The timing and speed of the emergence of alternative vehicles is linked in part to the overall increase in environmental awareness and the need to reduce carbon footprint. Should the abundance of oil decrease it seems only natural that automotive manufacturers would provide vehicles that best fit the resources available.

Vehicles using all types of fuels are already fitted with eco-friendly technologies. New technologies continue to drive the direction of the automotive industry. Innovative is critical if manufacturers wish to meet or exceed state and federal regulations and standards. As a result, traditional combustion engines have become more competitive with alternative fueled vehicles in terms of efficiency.

The abundance and availability of the supply of oil available in the USA market is difficult to measure. Natural resources, including oil supplies, are limited. Changes to the automotive industry infrastructure using renewable sources of energy like wind and solar to power processes pre- and post-production present viable alternative to the depletion of natural resources. The changes in infrastructure and energy supplies would prolong the life of available oil supplies maintaining the demand for liquid fueled vehicles.

Tesla is a company that currently tests the USA market for sustainability of electric vehicles. There are risks involved but Tesla has emerged, in the least, to be a leader in promoting an era of sustainable vehicles. Their mission towards sustainability has driven

the automotive industry in a new direction, but the demand for all electric vehicles has limited the production of EVs among Tesla's competitors. The availability of EVs rely heavily on preorders for all brands and limited supply and demand will eventually drive automotive manufacturers in a progressive or regressive direction depending on success.

New product development aimed to reduce air pollution in the USA automotive industry is influenced in part by the Clean Air Act, which gives the EPA authority to control allowable levels of air pollution. The EPA sets standards for automakers and issues permits for factories setting air pollution limits. At the state and regional level, state agencies generally issue permits governing allowable emissions. Individuals also possess the ability to reduce air pollution through healthy practices. The EPA measures annual emission estimates as an indicator of the effectiveness of emission standards. The production of Hybrid vehicles is on the rise and an increase demand in alternative fuel vehicles has the potential to help reduce the growth of CO2 emissions.

Automotive manufacturers often try to meet or exceed federal and state emission standards. This has helped to pave the production processes of automobiles leading to more sustainable practices and phasing out outdated and poor practices. Incentives and grants for manufacturers have helped to offset the costs of making alternative technologies. Tax cuts and grants for consumers in turn lead consumers to more likely consider the purchase of an alternative vehicle.

The automotive industry faces both new challenges and advantages for development of new vehicles and component parts. The automotive industry and federal and state regulators work together and can influence the direction of the automotive industry through various vectors.

Automotive consumers today are technologically savvy and highly aware of sustainable environmental practices in due part to the presence of social media. Consumer demand for ride sharing options and social connectivity play a role in the direction the automotive industry is headed in that manufacturers need to update their vehicle components in

partnership with other companies in such a way that the life cycle of automotive vehicles and components are in line with the demand for new technological trends. Vehicle production runs must be able to maintain these new trends and keeping up with them may prove to be costly in the future.

Automotive design involves creating the style, look and feel of a vehicle. Aerodynamics is the motion of air around an object. A vehicle's ability to move takes into account variables such as the automobile's weight, acceleration, velocity, mass and force. Vehicle manufacturers strive to achieve aerodynamic efficiency leading to fuel efficiency. In order to meet efficiency standards in the future, these variables will become harder to manipulate in the right direction as time goes on. Innovative designs will be heavily invested in if the internal combustion engine needs to stay competitive in the future market.

Design of a vehicle affects consumer preferences but also safety and overall performance. Steel is used to build the chassis of a vehicle. This is a safety feature able to best protect a driver or passenger in case of impact. Plastic is used for a wide variety of components. It is inexpensive, lightweight and durable. Aluminum, glass and fiberglass are also widely used durables and weight reducers. These shifts in materials have lead to more efficient vehicles.

Air resistance plays a role in a vehicle's overall performance. Designers strive to reduce the amount of work an engine must perform in order to perform effectively.

Emblems can easily identify vehicle brands. Without the emblems, it would become more difficult to distinguish brands within classes of vehicles. Similar body types are a result of vehicles being designed to maximize aerodynamic efficiency. Using recycled materials reduces the overall carbon footprint of a vehicle, reduces costs and increases appeal for eco-minded consumers. Challenges remain regarding the recycling of high voltage batteries. The resourcefulness of the automotive industry is being challenged as alternative vehicles enter the market with unresolved recycling issues.

Production costs of a vehicle consider the environmental impact of producing a vehicle at all stages. Vehicle production leaves a carbon footprint. Materials used to process components of vehicles purchased by an automotive manufacturer also create a carbon footprint not always fully considered in the production process. An estimate of total energy consumed for labor, trade, mining, refining and transportation costs of components is complex at best. Measuring total footprint of a vehicle begins at the start of the automotive production process. Federal and state regulations and standards may benefit from measuring the overall footprint of a vehicle pre- and post-production. The overall efficiency of vehicles is not limited to the tailpipe and transparency should be made more available.

Production costs and carbon footprints for Hybrid and EV batteries have improved overtime. Tesla, Toyota and BMW among many invest extensively in research and development to improve energy storage capacity. There still remains a high cost of materials used to assemble, maintain and discard these batteries. This has led to an environmental controversy surrounding the value of producing Hybrids and EVs. Given that the first generation of Hybrids and EVs have barely hit their life expectancies, the issues are likely to be resolved only at a future date when more data is available.

Given the immense amount of energy needed to power automotive factories and evolving federal and state emission standards, it is essential that factories be designed to be flexible in terms of being able to introduce more efficient processes at lowest possible costs. Renewable sources of energy continue to be introduced to the automotive industry replacing the use of natural resources for energy. The intended outcome is to produce more affordable and competitive fuel-efficient vehicles while lowering the overall production footprint.

Hybrid vehicles are proving to be more fuel-efficient compared with EVs and combustion driven vehicles. The question remains regarding the calculation of the total footprint related to the production of a Hybrid. The source range of measuring vehicle emissions should be extended to cover pre- and post-production costs. Pre-production costs should

include the production process of components used during production and post-production costs should include the disposal costs of batteries and other non-recyclable parts.

Chapter 7.2 Overall Analysis

The supply of oil available to USA markets plays a significant role in the automotive market in that combustion-fueled vehicles remain dominant. Given the ever-increasing awareness of the environmental impact that the depletion of natural resources has on the environment, it is possible that in future, the abundance of oil available to USA markets may not be the driving force with respect to the types of fuel-driven vehicles available in the USA market.

A drawback to the success of electric-powered vehicles is the limited battery range and the high cost of mining component parts. Extending the life cycle of ion-lithium batteries has proven to be a long and slow process for automotive engineers. This factor, together with the environmental cost of disposing of batteries after there useful life, may continue to significantly slow down the introduction of alternative vehicles in USA markets.

Due to increased fuel efficiencies related to improved aerodynamic factors, the shape and design of passenger vehicles, regardless of brand, are tending to resemble one another more and more. USA consumer preferences for the shape of SUVs, however, based on the perception that SUVs are safer than sedans, may lead to the popularity of crossover vehicles regardless of aerodynamic factors.

Chapter 7.3: Hypothesis Conclusions

The research generally supports the hypothesis in the introduction in that it is likely that plug-in Hybrids may emerge in the USA market as the best alternative to combustion driven vehicles. Many challenges remain concerning extending battery range, availability of charging stations, and shifting consumer preferences. These factors complicate the introduction of Hybrids and a prediction of their future market share. Incentives and tax

credits can help to persuade consumers to redirect their preferences towards the Hybrid but government funding is often limited. Marketing the Hybrid as a combustion-fueled engine vehicle with a plug-in electric option may help consumers to shift their preference and ultimately increase the market share of Hybrid vehicles. It may be reasonable to predict that in the short-term combustion driven vehicles may fairly equally share the automotive market with Hybrid vehicles. Diesel fueled combustion engines may also become more popular due in part because they are already more fuel-efficient than gasoline engines.

Chapter 7.4 Strengths and Limitations

The USA automotive market is large with many contributing factors driving its direction. Some factors are measurable like regulations and standards and some are less predicable like consumer preferences. Regulations and standards vary for different processes in the production line. The automotive industry is fast moving with many variables some of which are competing with each other. This situation helps to explain the complexity of the industry and it also makes it more difficult to make a prediction as to how the market will look in the future. Government entities all across the globe that have control over emission standards must consider production runs. Unrealistic targets would hurt the automotive industry and are thus less likely to occur. A slow transition towards alternative fueled vehicles will likely occur in the meantime. The amount of time it takes to phase out internal combustion engines is unknown and the time spent in the meantime would only allow the emergence of innovation towards combustion fuel efficiency to grow.

Chapter 7.5 Potential Applications of the Research Findings

While the USA automotive market has its own unique characteristics, comparisons with other automotive markets can be made. Identifying and understanding factors related to fuel availability and affordability, industrial infrastructure, environmental policies and consumer preferences can help the industry to better identify and respond timely to market trends. The benefits of research and development related to extending battery range for electric engines will have an impact on other automotive markets across the globe. The

speed and timing of the introduction of vehicles driven with alternative fuels in other countries will also be impacted by this research and development. Countries faced with a lack of natural fuel infrastructure may prove to be better markets for alternative fuel vehicles. Automotive brands may therefore set up production to appeal to these niche markets with alternative fuels. The USA is examined more specifically as a market that has been through and withstood many changes overtime. The lessons learned, variables analyzed, changes in market behavior and milestones met by the automotive industry in the will further help in identifying market behaviors in markets across the globe.

Chapter 7.6 Possible Future Research Directions

Understanding and predicting the balance of all factors underlying the direction of the USA automotive industry is a daunting task. Comparisons with other markets in EU countries and Asia may help to gain a better understanding of how markets are driven effectively bearing in mind unique characteristics of countries and consumers. The automotive industry faces new challenges related to the coordination and timing of production runs especially in light of the development of new partnerships between the automotive industry and technological/communication and transportation companies based on changing consumer demands. The overall awareness of environmentally friendly practices is key but not limited to determining the direction of the automotive industry. Factors such as infrastructure, available technology, and supply and demand for energy sources plays just as an important role in the future of automotive innovation. The pull oil companies have on certain economies will contribute to the overall direction of the automotive industry. Economies driven by fossil fuels will face risks in the near future as to whether alternative fuel sources are their best option and whether or not there is an alternative to offset any losses. Analyzing the role the oil industry plays in the global market is necessary for future research and development. What is clear is that the oil industry like the automotive industry both have profit at the forefront of their agendas and interfering with these agendas can prove to be a costly one at best.

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