University of Washington Engineering Undergraduates

June 5, 2015

Sarah Baumgartner, Engineering Board Director
Innovative Engineering Incorporated
86 Engineering Street
Seattle, WA 98139

Dear Ms. Baumgartner:

As you may know, the environment is at risk due to high amounts of emissions from fossil fuel vehicles. In our report “The Ethics of Eco-Friendly Vehicles”, we address this concern by considering and comparing possible alternative energy sources and their benefits and issues. We then recommend what we believe to be the best course of action. We hope that this provides you with valuable insight on how to approach and solve this problem.

Specifically, we address how hydrogen fuel cells are not a viable option for the future given current technology and how electric cars and hybrid electric cars are a viable option because of their realistically achievable solutions. Thus, we recommend the development of electric and hybrid-electric technologies while implementing specific safety and design standards for all vehicles, thus reducing emissions while maintaining driver safety.

Should you have any questions, comments, or concerns, please feel free to contact us.
Sincerely,

_____
Brian Tsang

_____
Madeleine Stewart

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Josh Quichocho

The Ethics of Eco-Friendly Vehicles

HCDE 231 Team 7 A

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June 5, 2015

Summary

Most cars today derive power from fossil fuels. Cars play a huge role in modern societies. The effect of fossil fuels from cars, then, becomes readily apparent. By being efficient and conveniently accessible, fossil fuels have propelled the progress of cars forward. Fossil fuels have been so effective that entire societies have built infrastructures that rely on their use.

Fossil fuels, however, contain flaws. Emissions from fossil fuel-powered cars contribute to rising temperatures. The dominance of the fossil fuel car has exacerbated the problems caused by global warming. In addition, fossil fuels are not a renewable resource. Such a reliance on fossil fuels cannot last forever. Thus, engineers must explore alternative fuel sources to alleviate the pressure fossil fuels have on both the environment and their own supply if an imminent energy crisis is to be avoided.

Alternatives have been explored. Hydrogen fuel cells are one such alternative. Hydrogen fuel cells are environmentally friendly and rely on hydrogen, an abundant resource. However, hydrogen fuel cells come with serious issues. Hydrogen fuel cells are volume inefficient, flammable, difficult to detect, costly to manufacture, and require a significant restructuring of society.

Electric cars are another alternative. Electric cars produce no emissions, cost little to refuel, and are quieter to operate than fossil fuel-powered cars. However, electric cars contain their own safety concerns. Electric cars also require a costly and time-consuming process to be effectively implemented into society.

The solution, then, would be electric cars, with hybrid electric cars as an intermediary stage. Electric and hybrid electric cars are the most realistically achievable to implement. These technologies have the most potential to match safety standards and set new environmental standards. Thus, moving towards electric and hybrid cars is a necessary step in securing our future.

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Introduction

Much of today's cars run by burning fossils fuels. Though an effective choice, burning fossil fuels is environmentally harmful and unsustainable. This report examines the effects of fossil fuels as a power source and explores possible alternatives. In particular, the report will examine the potential of hydrogen fuel cells and electric cars. While both options produce far fewer emissions, they also have downsides regarding safety, design, and implementation. Taking both sides into consideration, we recommend the continued development of electric and hybrid electric cars over hydrogen fuel cell technology, as its concerns with safety and implementation are far easier to address than those with hydrogen fuel cells. Thus, we cover the impact fossil fuels have on our society as well exploring hydrogen fuel cells and electric/hybrid-electric alternatives. Through this exploration, we compare the potential benefits and problems, and thus recommend a course of action. While both options produce far fewer emissions, they also have some particular downsides regarding safety, design, and implementation.

The Impact of Fossil Fuels

Cars have long relied on fossil fuels as the primary source of power. At the turn of the 20th century, the development of the internal combustion engine gave fossil fuels the opportunity to take center stage of transportation on a global scale [1]. A heavy reliance on fossil fuels to power cars is still visible today among developed nations. Fossil fuels did not rise to such a great demand by chance, but rather, fossil fuels brought with them a host of advantages beneficial for commerce and essential for advancing nations. Fossil fuels have proven to be a reliable and efficient means of energy, especially when compared to other alternative sources of energy such as solar and wind power [2]. The reliability and efficiency of fossil fuels promotes commerce essential for progress. Fossil fuels even provide the cheapest and most convenient method of energy [2]. Alternatives to fossil fuels often cannot be quickly harnessed to meet the growing need of the world and often cannot be gathered at reasonable costs. With such major advantages, fossil fuels continue to be the primary source of power for cars.

Although fossil fuels have heavily contributed to the progress of developed nations, fossil fuels have also heavily contributed to global warming as a side effect. As the average global temperatures continue to rise, global warming continues to gain greater concern worldwide. The growing use of cars has played a large role in global warming. As seen in Figure 1, total consumption of fossil fuels in the United States has increased significantly since 1950 [3]. Over the past 30 years carbon emissions have steadily increased by 1.5 percent per year [4]. Among developed nations, between 20 and 25 percent of total energy consumption arises from the transportation sector, and 85 percent of this energy comes from road transportation [1]. With such an enormous portion of the total energy, fossil fuel consumption from cars has especially been a factor in global warming. Emissions from these types of cars release greenhouse gases into the atmosphere, which allows temperatures to continue to soar [2]. With such

numbers, cars especially contribute to the effects of global warming. By heavily contributing to increasing temperatures, the emission from current cars has dealt and will continue to deal considerable environmental damage if the enormous fossil fuel consumption of cars continues.

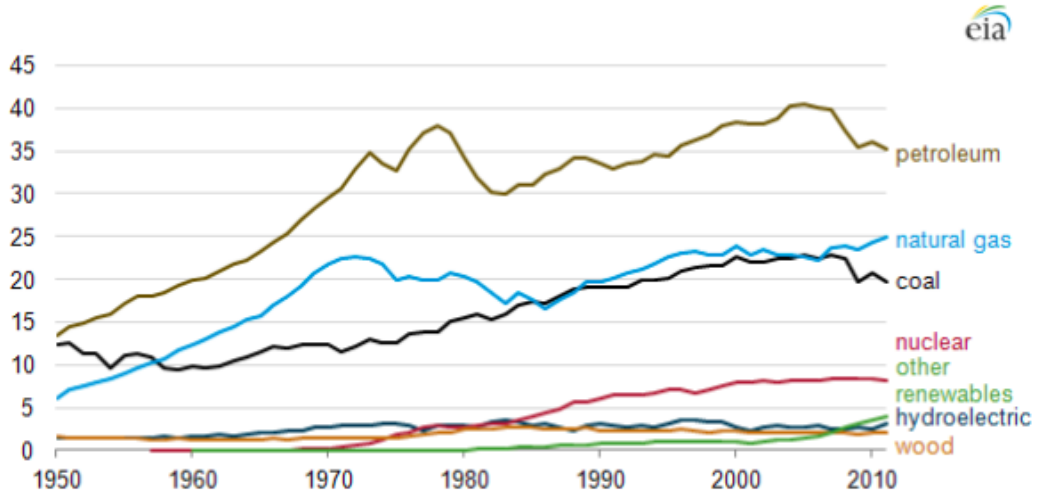

Figure 1: "U.S. primary energy consumption estimates by source, 1950-2011" (taken from [3]). Consumption of fossil fuels in the U.S. has increased significantly in the past century.

Beyond global warming, the burning of fossil fuels holds with it a serious issue by being a nonrenewable resource. As the world's population and industry rises, the demand for cars rise, leading to larger and faster consumption of the earth's fossil fuels. In only 20 years, the demand for fossil fuels has doubled [2]. The existing reservoirs cannot produce the enormous volumes that the world requires on a daily basis [1]. Fossil fuels are nonrenewable since, in reality, they are "the remains of animals and plants that lived during the prehistoric era, which lessened the simple hydrocarbon chains [2]." The result then is a dwindling reservoir of this resource. If the trend continues, this dwindling resource may lead to increasing prices as the resource becomes scarcer and as methods of extraction become more complex [1]. If no possible alternative for power can be found and effectively implemented, an energy crisis will occur.

Alternatives to fossil fuels do exist and are currently being explored, but they have yet to be effectively implemented. Alternatives often are unable to match the reliability and efficiency offered by fossil fuel-powered cars. While a number of alternatives do exist, two especially viable candidates to compete against fossil fuel-powered cars are hydrogen fuel cells and electric vehicles. Currently, these alternatives offer their own unique advantages and disadvantages when set against the standards set by fossil fuel-powered cars.

The Potential of Hydrogen Fuel Cells

With emissions of water vapor and heat, hydrogen fuel cells seem like a perfect choice to alleviate environmental concerns about global warming. In terms of efficiency, hydrogen fuel cells contain three times the amount of energy when compared to an equivalent weight of gasoline [5]. Hydrogen is also abundant on earth, being present in water, the air, and many other easily accessed sources. In the United States, most of the hydrogen produced is used for treating food and metals, creating fertilizer, and refining petroleum [6]. The hydrogen used in these processes could be a source of clean hydrogen fuel instead. In fact, several cities have already successfully implemented hydrogen fuel vehicles. In a program titled HyFLEET: CUTE, or Clean Urban Transport for Europe, Australia successfully employed buses powered by hydrogen fuel cells, as seen in Figure 2. Over the course of the program, 33 buses served 8.5 million passengers and traveled over two million kilometers [7]. The cells themselves are also beneficial in design. Engineers can stack cells upon one another to form larger systems, thus allowing for a wide variety of usages [8]. Yet, despite all of these benefits, there are a few key flaws that make this technology far from ideal.

Figure 2: The HyFLEET:CUTE buses run on hydrogen fuel cells (image from [9]).

Ethical Issues with Hydrogen and Production

Even in the HyFLEET program, there were efficiency problems when considering public use. One of the main issues is with hydrogen itself. Although hydrogen is weight efficient, it is not volume efficient. In order to achieve a driving range of 300 miles, which is widely considered to be the minimum for public use, a hydrogen-powered vehicle would need between four and ten kilograms of fuel [5]. Using today's technology, this volume of fuel means a fuel tank larger than the trunk of a car. This in turn also increases the car's weight, which further reduces efficiency, especially when coupled with factors such as traffic and terrain [7]. So why is it so difficult to reduce the weight of the engine? Because so much hydrogen gas is being stored, it must be compressed at high pressures. By making the engine lighter, the structural integrity becomes compromised, putting the driver at a greater risk of injury. In fact, generating enough hydrogen to fill every cell would be a difficult task by itself. Currently, the most common

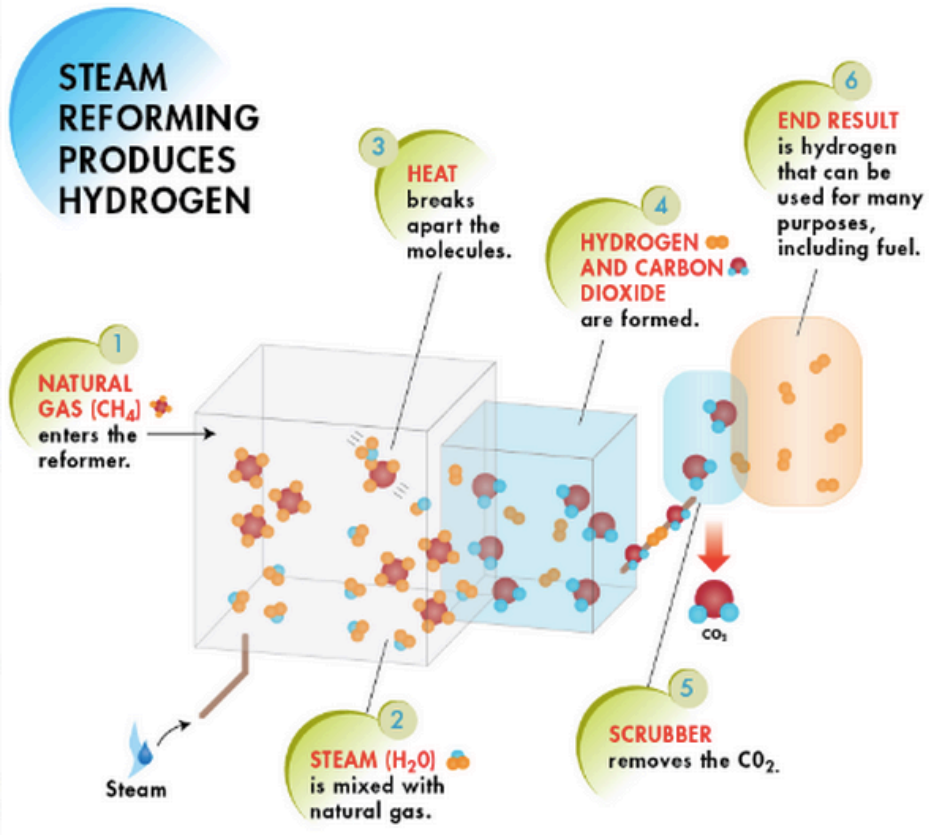

Figure 3: Steam reforming is used for filling hydrogen cells [6] (Image from [11]).

technique is a process called steam reforming (see Figure 3), where steam combined with natural gas becomes hydrogen [6]. Yet this process, in contrast to the hydrogen fuel cell itself, produces emissions. It is indeed possible to produce hydrogen using renewable energy sources, such as wind or solar energy, but it is quite impractical. In order to generate enough hydrogen using clean energy, it was estimated that by 2054, four million one-megawatt windmills, or 400 million photovoltaic arrays would have to be built [10]. In terms of the windmills, that is 100 times over today's capacity. Thus, not only is the implementation unwieldy, but also the methods used to make the fuel itself.

Problems with Cost and Design

Another large issue is that of safety and the impact such a large change will have on society. Hydrogen is flammable, as evidenced by early hot air balloons and the Hindenburg. While it is true that hydrogen fires are more survivable and less deadly than gasoline-powered fires, they would be difficult to prevent. While a gasoline leak can easily be detected, hydrogen is a much more elusive compound. This creates situations where leaks could potentially go unnoticed, and simple acts such as lighting a cigarette could cause a disaster. The leaked hydrogen poses concerns as well. An estimated 10-20 percent of hydrogen will escape into the atmosphere, where it will oxidize and potentially damage and deplete the ozone layer [10]. Current fuel cell

models also lack reliability and longevity, making them less attractive. Perhaps the most compelling reason against this technology, however, is cost. Storing and generating hydrogen is complex and costly, resulting in prices predicted to be 88 percent higher than that of gasoline [10]. Such vehicles would thus be impractical to those with lower incomes. It would also require significant investment and work to reconfigure the current power networks. The current network was not designed with hydrogen power in mind, so implementing hydrogen-powered vehicles would also require the implementation of storage and generation facilities, refilling stations, and everything in between to allow for transportation of the hydrogen gas. With a natural gas pipeline being around half the cost and the estimated cost of the windmills being around 4.7 trillion dollars, finding an economically viable solution is difficult [10]. In order to decrease costs to make it even potentially fathomable, it would require technologies that simply do not exist yet. Thus, while it may be classified as an alternate energy source, in its current state that is all it can be: an alternative to something else.

Electric Cars as an Ethical Alternative

The other alternative is electric cars; while offering many solutions to the problems posed by global warming, adoption of electric cars brings about several ethical barriers. However, these barriers may be overcome with more attention given to car material, noise cues, infrastructure, and hybrid vehicles.

Benefits of Electric Cars

Electric cars have several clear benefits. Most prominently, electric cars boast “zero tailpipe emissions” and low cost of refueling [12:2610]. Additionally, electric cars are much quieter than cars with internal combustion engines, and therefore have the potential to reduce traffic noise [13], although for this to take effect, a significant percentage of cars on the street would need to be electric [13]. However, the barriers discussed in the next section may prevent purely electric cars from being widely successful.

Barriers to Electric Car Adoption

There are several barriers to widespread electric car adoption involving materials used, interactions with other drivers, and lack of infrastructure. Regarding materials used, as electric cars are designed to be power-efficient, they are generally lightweight. While this characteristic improves efficiency, it can leave passengers of electric cars more vulnerable to collisions. Therefore, use of purely electric cars may pose a difficult tradeoff between power consumption, safety, and material cost such that materials that are both lightweight and rigid enough to survive collisions may be too expensive for the average consumer. The lightweight materials used can also be difficult to recycle, which would produce a “throw-away” car [14]. Another tradeoff appears here, between a car that requires less power but is made of wasteful material and a sturdier car that uses more power [14].

While the lack of traffic noise can be positive, lack of noise can also be dangerous in situations guided by auditory cues, including low-visibility driving maneuvers, interactions with visually-impaired pedestrians [13], and low-speed driving [13]. In “situations where cars drive slowly (stopping, backing up and parking maneuvers)”, quieter hybrid electric cars were more likely to be involved in a collision than combustion-engine cars in certain studies [13:14]. Therefore, quieter electric cars can pose safety risks for those both inside and outside the car.

A final consideration in the adoption of electric vehicles is the infrastructure required to power a fleet of electric vehicles, which poses problems both in electricity production and car use. In terms of electricity production, Joseph Romm makes an important observation when he notes that in reducing greenhouse gas emissions by adopting electric cars, the greenhouse gases emitted while producing electricity to fuel electric cars must also be considered [12:2610]. Therefore, adoption of electric vehicles must be partnered with adoption of efficient methods of producing electricity. Issues with infrastructure may also pose a problem for the users of electric vehicles. Electric cars require a completely different infrastructure for refueling than what is currently available, namely charging stations instead of gasoline pumps, as seen in Figure 4. This poses a “chicken and egg problem,” such that adoption of electric cars will be low until the proper infrastructure exists, yet investment in the infrastructure will be insufficient until adoption of electric cars increases [12:2610].

Figure 4: “ECOtality Blink charging stations for electric & plug-in cars” (image from [15]). Adoption of purely electric vehicles would require an infrastructure of charging station.

Solutions to Barriers

A range of solutions to the challenges discussed above exist. These include manipulating car design, increasing rigidity, and equipping electric cars with a supplementary gasoline engine. In the trade-off between material cost, safety, and power consumption, the designers of the Delft electric car model chose to bypass the

trade-off by creating a car intending to make the driver “feel a bit vulnerable” to prevent risky driving behaviors. The designers also made sure to equip the car with a highly functional control system [14]. While this approach can only partially lessen the risk of collision, further research into design manipulation to prevent collisions should be pursued.

When it comes to collisions, Robert Kaeser et al. determined that increasing rigidity of an electric vehicle’s shell could greatly reduce the potential trauma to the passengers in the vehicle [16]. In the case of a frontal collision, hard shells combined with proper interior design fulfill safety requirements [16]. Design of the side doors (such as the addition of interlocking joints) and proper padding can protect passengers in the case of a side collision [16].

The lack of traffic noise may also pose a collision risk. The most plausible current solution is to project artificial traffic noise from the vehicle; however this invalidates the benefit of decreased traffic noise. Designers and researchers should therefore pursue creative solutions to the lack of auditory cues.

Finally, hybrid cars pose a viable solution to many of the issues presented by adoption of purely electric vehicles. Hybrid cars are cheaper, have a greater range, and still greatly reduce emissions [12]. These hybrids use both an electric battery and gasoline engine (see Figure 5) such that the car only consumes gasoline when the electric fuel source runs low [12]. As most trips are “relatively short”, this solution solves the issue of range limited by battery capacity while greatly reducing emissions, as the gasoline engine would only rarely be in use [12:2612]. Additionally, if charging stations are not available, the car can use gasoline, reducing the dependency on a currently nonexistent infrastructure [12]. Some of the best uses for hybrid vehicles are in an urban setting, for example “buses, maintenance vehicles, and delivery trucks” [12:2612].

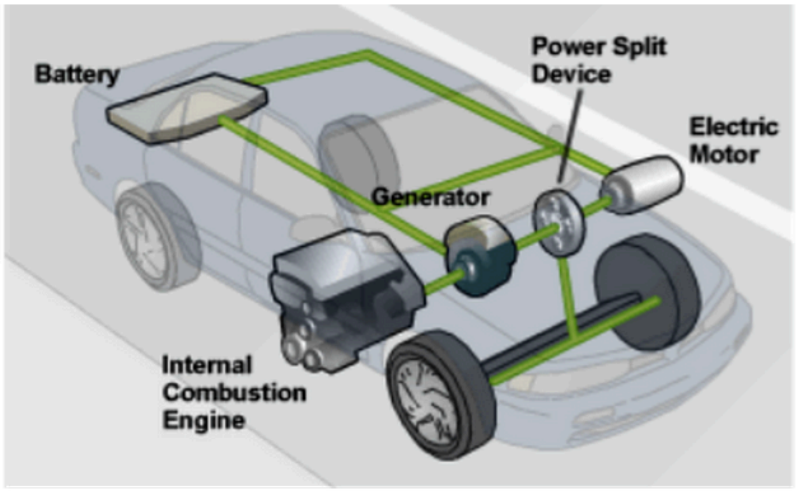

Figure 5: “How Hybrids Work” (taken from [17]). Electric hybrids are equipped with both an electric battery and an internal combustion engine.

Recommended Course of Action

It is evident that both hydrogen fuel cells and electric cars have their own unique benefits and concerns. However, when taking into consideration the challenges of these alternatives, it becomes clear that electric cars are significantly more viable given today's technology. Hydrogen fuel cells simply are not there yet; today's technology is insufficient to take fuel cells anywhere near marketable. While electric cars have many solutions to their safety concerns, such as padding and rigid frames, hydrogen fuel cell cars are restricted by the way their fuel storage works. With hydrogen being so much more expensive to access than electricity, it becomes clear that investing the large amount of money needed to construct a new infrastructure would also restrict those with lower income, who would not be able to afford hydrogen fuel. Until more efficient methods to generate and store hydrogen are found, hydrogen fuel cells must remain as an alternate source. In comparison, the problems with electric cars are far more benign, with realistically achievable solutions. Thus, we recommend that development of purely electric cars and hybrid electric cars be conducted in parallel while setting industry-wide safety standards regarding the sturdiness of the car design. This allows for both long-term and short-term solutions. Hybrid technology is certainly nothing new, and thus can be improved while the emission-free electric car can also be developed to a point of viability. Hybrid-electric cars, though not completely emission free, are still efficient in terms of emissions and can function effectively in both short and long distance travel. Given the current fossil fuel infrastructure, hybrids would also allow for a smooth transition between the two systems. Putting safety guidelines in place would ensure that safety hazards be kept to a minimum while maximizing potential efficiency. Thus, both drivers and the environment can benefit from these changes.

Conclusion

Because emissions have such a large impact on the environment, it is important to find a clean, alternative fuel source for one of the biggest producers: cars. Thus, we considered two potential sources: hydrogen fuel cells and electricity. Both solutions reduced the amount of emissions while also sharing other benefits, such as reducing sound pollution and the accessibility and abundance of the energy source. However, with closer inspection, it becomes clear that hydrogen fuel cells simply have too many problems involving design, safety, implementation, and cost. Electric and hybrid electric cars are also not without problems, with conflicts between safety and efficiency as well as infrastructure. However, the main difference is that the problems for electric and hybrid electric models have viable, achievable solutions. Given the level of today's technology and the current fuel infrastructure, electric and hybrid electric models are simply much more realistically implemented. Thus, we recommended pursuing the electric/hybrid electric line of thinking while also considering the problems associated with it. This would be recognized by implementing industry-wide safety standards and other design guidelines. Though hydrogen fuel cells may eventually become viable as technology progresses, the development of electric and hybrid electric technologies promises the most realistically achievable safety and environmental goals.

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