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LEADING ALTERNATIVES TO FOSSIL FUELS FOR POWERING VEHICLES

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FOR POWERING VEHICLES

by

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To Mom and Dad. Thank you for always believing in me and doing everything you can to help. I love you always.

“Progress is impossible without change, and those who cannot change their minds cannot change anything.”

-George Bernard Shaw

A special thanks to Dad for all the time volunteered as well as the constant support and love. I couldn't have done it without you.

TABLE OF CONTENTS

CHAPTER ONE

Introduction

Introduction

As a native Californian, I was raised in and exposed to a widely diverse range and spectrum of habitats and ecosystems in which to observe and enjoy some of nature's splendor and glory. I could often be found relaxing or body surfing on a local beach, on an intense mid-morning hike through the Santa Monica mountain range or camping and exploring at Yosemite National Park. Indeed, I can trace my deep appreciation, respect and love for nature and the environment back to my first recollection of visiting that unique and personally treasured setting.

I was nine or ten years old. My family of five was embarking on our first trip to that renowned national park. We arrived through the east entrance after a long drive. There laid out before us was my first view of the iconic park. We felt compelled to follow the lead of most vehicles in front of us which veered off the side of the road to the first of many vista points. Eagerly piling out of our car we stood collectively in awe at the vast expanse and grandeur, breathing in the fresh, cool and pine scented air which has remained my enduring feeling, rekindled with every memory or visit. Therein towered the majestic might of the massive El Capitan cliff and the perplexing iconic wonderment of the Half Dome formation, among others chiseled by glacial movements of past millennia. We watched and listened to the rushing power of Yosemite and Bridal Veil Falls and hiked the seemingly endless trails under immense pine tree canopies. It is safe to say that I was captivated by nature's beauty, standing there with my family in those and many other breathtaking moments. Both panoramic and more intimate, closeup views were and have been beyond storybook. Fairytale images were, for me, inspiring beyond any other experience in the natural world.

History

Fast forward roughly ten years, at which time I was in the midst of my undergraduate education at the University of Washington. I was embroiled in my third year at the Seattle campus, and had not as of yet chosen a major. I had taken a variety of science courses, as I knew that general genre was my calling. Moreover, living and traveling there in the northwest United States brought with it much opportunity to enjoy the outdoors, including Pacific Rim volcanoes, and classic forested plant and animal ecologies and ecosystems. On the first day of a geology course centered on America's National Parks, I was transported back to those first memories of my favorite park and instantly decided on a major course of study. After that class session, I headed into an advisor's office in the Earth and Space Sciences (ESS) building on campus and declared for a Bachelor of Arts focus in ESS. I was on my way toward an ESS (Geology) degree and my passion for the natural world was at least in part resolved, if not restored and better focused.

Forward yet another five years, having discontinued my study to become an environmental advocacy attorney at William Mitchell College of Law in St. Paul, Minnesota (not a great “fit” for me), I elected to remain locally and pursue a two-year position serving with AmeriCorps there in St. Paul in a program called the Promise Fellows. I was placed at Battle Creek Middle School to serve in the classrooms, aid the teachers, and monitor a select group of students with an eye on academic achievement and dropout prevention. Concurrent with this position, I started with the Natural Sciences and Environmental Education program at Hamline University.

Environmental preservation through various modes and in global venues has waxed and waned for decades but has increasingly gained prominence in recent times. I have neither diminished nor wavered in my personal love for and interest in that preservation. This writing focuses on but a few current and future options for viable alternative vehicle power/fuel sources in that environmental preservation effort. Specificity for personal and cargo transport includes cars, trucks, passenger mass transit (buses, trains, trollies, among others), police, fire and paramedic vehicles. Individually and collectively, these speak at least in part to my passion, as even my beloved Yosemite National Park has undergone smog based and other environmental impact and decay due to the burning of fossil fuels.

Perspective

Prior to working with the middle school students, I had not considered a career in education, environmental or otherwise, despite signing up for the Master of Arts in *Education* program. Working with the young, impressionable students in conjunction with beginning the Hamline Master’s program made me think often as to how I would, including hypothetically, approach teaching environmental education courses. Given my heightened passion for nature and the environment, I reasoned that most aspiring environmental learners and potential advocates would likely share my same enthusiasm. Tapping into that interest and channeling it into genuine passion would seem to be a spectacular quest. The challenge then would be to find an efficient and effective way to impart a portion of my enthusiasm (positioned as an hypothetical instructor).

I am still not fully certain as to specifically how I would implement this strategy in my theoretical classroom. Yet, borrowing from available medical strategy and current technology with its ability to demonstrate how existing circumstances can progress into later-stage diseases and degradative conditions of physiology and anatomic architecture, does offer promise. Those of us that have witnessed pre and post imaging of many medical concerns can attest to their effectiveness in understanding how intervention, especially early, can play a vital, if not pivotal, role in end-game success. Apart from infectious enthusiasm, teaching students with a similar interactive approach as to the result of human incursions into the natural world and its consequences may offer impactful results. I am a believer in the thought that technology has played a devastating role in our rapidly declining global environmental health but, with education and effort, can help get us out of a looming crisis. Even through the speculation and uncertainty as to how I would approach this task, I cannot help but be excited for the possibilities.

Conclusion

Upbringing, exposure, and history can play a major role in one's philosophy as it relates to his or her career. My enthusiasm for the outdoors growing up combined with my undergraduate and graduate educations and service have painted a picture for me of the philosophy I would bring to a future career. I believe the most effective contributors in any chosen field are those who utilize genuine passion toward and advocacy for the work they do. That is the brand of person I aspire to be in my future career

The Problem

It is no cryptic secret that humans have taken an enormous toll on the environmental health of our planet. As human population has increased and technological and industrial advancements have accelerated, so too has environmental destruction increased at an alarming rate. The Industrial Revolution accelerated the burning of fossil fuels at a highly elevated pace. As technology advanced to match industrial progress, the sheer number of units of machinery emitting harmful substances onto the earth and into the planet's air and water increased at a commensurate rate. This in turn has contributed mightily to an intense greenhouse, global warming, and ozone-depleting effect within our atmosphere, causing rapid climate change and threatening our planet's natural eco-stability.

Indeed, experts have posited that human overpopulation (alongside the aforementioned factors) is the leading contributory cause of environmental problems; and consequently one of our greatest challenges in the hope of maintaining some semblance of natural balance on our planet will be population control. With overpopulation comes overconsumption, and the fact is that Earth's natural resources are finite. Since overpopulation appears to have no simplistically viable solution, it has long been offered that we need to find alternative ways of coping with our limited resources and furthering a responsible and effective stewardship of the global environment.

As noted, there are two main problems with relying on the use of fossil fuels to power much of our planet, vehicles and otherwise: 1) fossil fuels are finite, and, perhaps of greater importance 2) they are environmentally destructive and degradative. So the question becomes: if not fossil fuels, then what?

An alternative fuel is defined as "a fuel for internal combustion engines that is derived partly or wholly from a source other than petroleum and that is less damaging to the environment than traditional fuels." Concurrently, petroleum is "an oily flammable bituminous liquid that may vary from almost colorlesless to black, occurs in many places in the upper strata of the earth, is a complex mixture of hydrocarbons with small amounts of other substances, and is prepared for use as gasoline… or other products by various refining processes. [www.merriam-webster.com]

The purpose of this research and writing is to compile pertinent information relating to alternative fuel gathering methods and usage with the greatest chance of future success. According to the National Resources Defense Council's (NRDC) website, "Renewable energy comes from natural sources that are constantly and sustainably replenished." The technologies which make renewable energy possible can potentially have a hand in "improving our air quality, reducing our reliance on fossil fuels, curbing global warming, adding good jobs to the economy and -- when they're properly sited -- protecting environmental values such as habitat and water quality." This substantive issue is one that increasingly plagues our planet at this point in human history. It follows logically that as many humans as possible should be made aware of and empowered to effectively understand this vital concern.

It is widely believed that the greater the number of individuals who combine forces for a cause, the better chance that cause has to meet its goals and succeed. Every motivated person added to the cause serves to strengthen its chances of succeeding. Thus, this study has significance simply in its potential ability to inspire interest in the subject matter and hopefully illicit action in promoting responsible custodianship of the environment..

Research for this topic focused on the best renewable fuel sources currently available for powering vehicles. Findings were varied, with some of the leading candidates being biodiesel, compressed natural gas, fuel cells, electric, and solar.

The National Resources Defense Council (NRDC) and US Department of Energy websites were major resources for me. Those entities as a whole are some of the most powerful, effective, and respected resources on environmental issues, containing interesting and enlightening information to contribute with respect to alternative and renewable fuel and energy.

This work and the accompanying PowerPoint presentation will potentially and hopefully serve as an educational augment to adults in general and more selectively targeted toward administrators within the fire service. The target audience would be fire service members attending various seminars on how to improve their respective departments. Fire departments have an ongoing interest in ways to advance their technologies, techniques, and protocols while keeping operating costs minimalized. Increasingly, departments have begun to express the same concern for environmental issues as the country at large, especially given the growing wildland fire events of recent years and decades. This presentation intends to educate these personnel as to the future of alternative, renewable fuel, which could be of use when powering fire engines, fire trucks, paramedic and rescue vehicles, generators, and water and retardant distribution, as well as decreasing some of the causes of destructive wildfires.

CHAPTER TWO

Literature Review

Compressed Natural Gas

Definition

Gases exist naturally above and beneath the earth's surface. These gases form in a manner similar to that of petroleum and in fact, oftentimes natural gas and petroleum are formed side-by-side through parallel processes. Natural gas can itself be considered a "fossil fuel" as it is found in and around oil deposits ("Background," 2013).

Over millions (sometimes hundreds of millions) of years, both marine and terrestrial animal and plant remains decay and become compressed under layers of natural sediment deposits (sand, silt, etc.). The decomposed tissues are then subjected to long periods of pressure and heat and, consequently, what began as carbon material becomes converted into natural gas and oil ("Natural Gas Explained," 2019).

While petroleum is primarily composed of compressed carbon material, natural gas exists in a variety of different vaporous elements and compounds. Typically, these gases are composed of methane (70-90%), ethane (0-20%), propane (0-20%), butane (0-20%), carbon dioxide (0-8%), nitrogen (0-5%), and hydrogen sulfide (0-5%) ("Background," 2013).

How It Works As A Fuel

As a fuel source similar to petroleum, compressed natural gas (CNG) works by burning and producing electric power as a byproduct of combustion. Vehicles powered by compressed natural gas utilize an internal combustion component in engines.

Within the internal combustion engine natural gas, composed primarily of methane (CH_4) as noted above, reacts with oxygen (O_2) from the air around it, resulting in emissions composed mainly of water vapor and, unfortunately, some carbon dioxide (CO_2). The internal combustion engine facilitates the incendiary interaction of these molecules with each other. The burned gas is then converted to power production or "work" by the engine. Moving pistons are housed inside stationary cylinders within the engine and the gases, which expand on combustion, push the piston in a pulsating manner which in turn results in the rotation of a crankshaft. The crankshaft subsequently powers or rotates the vehicle's wheels ("Internal Combustion," 2013).

Advantages

Compressed natural gas has been at the forefront of alternative fuel usage for years. There are several advantages to compressed natural gas over traditional fossil fuels to power vehicles (as well as other machinery and equipment) when considering environmental impact.

The primary advantage of CNG is its markedly reduced environmentally harmful emissions. Conventional gasoline powered vehicles produce many emissions that are significantly more damaging to the environment. Chief among them are large quantities of carbon dioxide as well as carbon monoxide, nitrogen oxide, and even mercury. Yet while CNG does emit CO_2, one of the attractive aspects of this type of fuel is that the CO_2 emissions are far less than those of petroleum. Thus CNG, by contrast, produces substantially less harmful greenhouse gases ("How Much Carbon," 2019).

In a study done in Delhi, India (the second-most populous city on Earth), the above concerning emission levels were indeed found to be appreciably lessened after the city transitioned to full-time use of CNG on all public road vehicles. In 2002, the city passed a law mandating that all vehicles switch to CNG engines. Shortly afterward a substantial, measured decline in the atmospheric presence of carbon monoxide (down 10%), various nitrogen oxides (6%), sulfur dioxide (22%), and total suspended particles (14%) was recorded (Khan, Yasmin, & Shakoor, 2015). The statistics show that the environmental health of our planet would greatly improve if we were able to transition from gasoline to compressed natural gas on a large scale. Given the large, city-wide model cited in Delhi as a significant sample size, one may assess the results of their "experiment" as encouraging if not inspiring.

Another advantage to natural gas lies in the reduced potential of a major "spill," or release either on land or ocean waters. When oil and petroleum gathering methods break down, large-scale environmental disasters can and have occurred. As seen in the Persian Gulf War Oil Spill and the Deep Water Horizon Oil Spill caused by British Petroleum (BP), equipment breakdowns in oil gathering can and have led to release of enormous quantities of petroleum that have destroyed both marine and terrestrial ecosystems. Comparatively, in the event of a natural gas leak, even the worst incidents could release gases which would dissipate into the atmosphere, reducing the immediate environmental impact. Although these incidents add to the total emissions of greenhouse gases, that effect is still dramatically less harmful than large-scale oil spills.

Disadvantages

This study hopes to identify alternative fuel options that have the greatest chance of supplanting deleterious fossil fuels as the primary energy source for vehicles on our planet and to do so in a renewable way. As well as compressed natural gas has performed in a globally limited overall sample size, it does present its own set of drawbacks.

The most prominent drawback to compressed natural gas is that, similar to petroleum, its availability is finite. The same problem that exists with fossil fuels persists with natural gases, in that we will eventually deplete the planet's usable store. For this reason, it will be tough to rely on natural gas to renewably supplant fossil fuels as the predominant available fuel source on Earth. Its use does not seem irrational but may best be viewed as a vast improvement to oil powered vehicles.

Further, there exists the problem of actually implementing a large-scale change to CNG vehicles internationally. The CNG tank itself is large, thus occupying significant space in commercial vehicles, limiting its storage capacity, among other issues. Additionally, the transition for vehicles requires a conversion kit which can prove expensive unless incorporated in production. As well, storage at facilities on a commercial basis would involve considerable investment to transition ("The Advantages and," n.d.). Converting a conventional engine to CNG compatibility can cost anywhere from $8,000 to $50,000 depending on the vehicle's make and model ("CNG Conversion," 2020). As with any large-scale change, the consumer population needs to be convinced to commit to this or any alternative. It remains to be seen if the environmental benefits of switching to CNG convince enough people worldwide to participate. Growing public and political pressure may help surmount hesitance by the manufacturing industry.

Another disadvantage of CNG is the method by which natural gases are collected and harvested. A primary collection method is fracking. Fracking is "the process of drilling down into the earth before a high-pressure water mixture is directed at the rock to release the gas inside" (Shukman, 2018). This method, while effective at collecting large quantities of both natural gas and liquid oil, is very environmentally destructive. As is easily understood, large-scale drilling operations are extremely physically disruptive to local ecosystems, creating compromise and adversity for both wildlife populations and habitats as well as topography and natural beauty. Fracking has been a point of contention in the national political discussion in recent years (Biello, 2014). On one hand, it allows us to collect natural gas which is a superior alternative to gasoline environmentally. On the other, its very procurement is harmful to the environment in different and notable ways.

Biofuel/Biodiesel

Definition

Biodiesel is another example of an alternative vehicular fuel. It is most commonly manufactured from natural, biologic substances such as vegetable and soybean oils, animal fats, or (perhaps unexpectedly) sources like restaurant grease. New additions to this list are made frequently, offering biodiesel and other various biofuels as an increasingly diverse alternative and renewable fuel option. The technical definition of biodiesel is "a fuel composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM D 6751" ("Biodiesel Basics," n.d.). The ASTM is the American Society for Testing and Materials, an entity which sets quality standards for used materials. ASTM D 6751 refers to the Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels (ASTM D6751-20, 2020).

Biodiesel fuel is created via a chemical process known as transesterification. "The transesterification of vegetable oils, animal fats or waste cooking oils is the process behind conventional biodiesel. In the transesterification process a glyceride reacts with an alcohol (typically methanol or ethanol) in the presence of a catalyst forming fatty acid alkyl esters and an alcohol" ("Transesterification," n.d.). The fatty acids referred to here can originate from either vegetable or animal origin, with common feedstock being that made from sunflower, soy, or rapeseed oils. In 2018, the United States measured the total makeup of all produced biodiesel fuels to be 54% soybean oil, 15% corn oil, 13% recycled feedstocks such as used cooking oils, 9% canola oil, and 9% animal fats ("Biodiesel," 2019).

In the transesterification process, fatty acids, alcohol, and catalysts are combined in specific proportions. A chemical reaction ensues which produces raw biodiesel as well as raw glycerol. The raw biodiesel product shares the same high viscosity as that of traditional fossil fuels. Specific properties are dependent on the different raw materials that can be used to produce it, but results in a biodegradable and far less environmentally toxic product than petroleum-based distillates (“Transesterification,” n.d.).

How It Works As A Fuel

Biodiesel can run a standard diesel engine in much the same way as traditional existing diesel can. Within most diesel engines is an internal combustion (or compression-ignition) mechanism. In the internal combustion engine, “fuel is injected into the combustion chamber and ignited by the high temperature achieved when a gas is greatly compressed,” as noted previously with compressed natural gas. Subsequently, within the transmission component of the engine, “The transmission transfers mechanical power from the engine and/or electronic traction motor to drive the wheels” (“How Do Diesel,” n.d.). The resultant power generated is roughly equivalent to that of fossil fuels.

Advantages

Extensive studies have shown that biofuels, and biodiesel fuels in particular, produce markedly smaller amounts of environmentally harmful carbon-based emissions than petroleum, regular diesel, and other traditional fossil fuels. In fact, an oft-cited study reflects a large decrease in total emissions of carbon monoxide (CO) and hydrocarbons (HC) (Curto, Giambrone, MacGrogan, & Williamson, 2015). A chart from this study titled “Average Emissions Impact of Biodiesel for Heavy-duty Highway Engines” considers the percentage change in emissions when certain percentages of biodiesel are mixed with regular diesel. Emissions are shown to decrease drastically as more and more biodiesel is added to traditional diesel. When 100% biodiesel is measured for emissions, however, hydrocarbon emissions decreased by roughly 67% and carbon monoxide emissions were lowered by about 49% (Curto, et. al., 2015). Measured improvements of these emission levels, while not ideal, are certainly encouraging.

The United States Department of Energy set out to debunk a common myth that "in terms of emissions, biofuels emit the same amount as gasoline or more." Instead, they posited that "Biofuels burn cleaner than gasoline, resulting in fewer greenhouse gas emissions, and are fully biodegradable, unlike some fuel additives." The department went on to note that the fuel additive cellulosic ethanol (a type of biodiesel fuel produced by grass, algae, and other plant matter) has the potential to reduce greenhouse gas emissions by up to 86% ("Biofuels and Greenhouse," 2008). Beyond encouraging, statistical results of this level are dramatically impressive in the reduction of atmospheric toxins.

Another advantage of biofuels relating to emissions is the fact that it is carbon neutral. According to the US Energy Information Administration: "The U.S. government considers biodiesel to be carbon-neutral because the plants that are the sources of the feedstocks for making biodiesel, such as soybeans and palm oil trees, absorb carbon dioxide (CO_2) as they grow. The absorption of CO_2 by these plants offsets the CO_2 that forms while making and burning biodiesel" ("Biodiesel and the Environment," 2019). Biofuels even being carbon-neutral (as opposed to a net carbon-negative) are thus clearly preferable to traditional petroleum oils which emit large quantities of the most harmful carbon-based greenhouse gases.

Finally, because biodiesel is biological in origin (i.e. made of plant and animal products that can be regenerated or "re-grown"), it is considered to be reliably renewable. This is an enormous advantage over fossil fuels both environmentally and due to petroleum’s finite nature. Crops used to produce biofuels can be planted continuously and in some cases year-round. This remains one of the most crucial benefits of this or any other type of alternative fuel since renewability and ultimate sustainability is an additional drawback of our current reliance on fossil fuels.

Disadvantages

As is to be expected, biofuels are not without their own set of disadvantages. Since they are a relatively recent development, biofuels are currently more expensive than their fossil fuel counterparts (Viesturs & Melee, 2014). According to the US Department of Energy, between October 1 and October 31, 2019, B20 biodiesel cost $2.87 per gallon, biodiesel B99-B100 cost $3.73 per gallon, regular gasoline cost $2.68 per gallon, while regular diesel cost $3.08 per gallon (“Fuel Prices,” 2020).

In this same vein, with respect to energy availability, though biofuels can be produced from a wide-ranging and diverse field of ingredients, indicating its renewable availability as plentiful (whereas fossil fuels will eventually fully deplete), a large portion of biofuels are created from edible materials and oils. Mass production of biofuels from these ingredients could potentially cause food supply shortages as well as price increases (Viesturs & Melee, 2014).

Finally, a major disadvantage of biofuels is the potential to contribute greatly to deforestation. Farmland is required to grow the agricultural portion of products that compose biofuels, and this has in part resulted in the clearing of large forested areas, primarily tropical. For the purposes of this study, this is obviously counterproductive to the goal of responsible stewardship of the environment. Additionally, trees do much to scrub the atmosphere of CO_2, one of the main gases that contributes to the greenhouse effect problem. Consequently, some of the positives associated with biofuel's lowered emissions are negatively mitigated by the deforestation required to cultivate its feedstock (Anastasopoulou & Karagiozidis, 2012).

Fuel Cells

Definition

Fuel cells are relatively small, self-contained, battery-like devices. Their primary function is to convert chemical potential energy (meaning the energy stored within molecular bonds) into electrical energy. All types of vehicular fuel cells combine atmospherically abundant oxygen (O_2) with hydrogen (H_2) to produce mechanical power from electrical energy ("Fuel Cells," 2020).

How They Work As A Fuel/Power Source

There are several different variations and types of fuel cells, but they generally work by creating electricity through an electrochemical reaction wherein a hydrogen-based gas is combined with oxygen to release energy and water (as a byproduct). This differs from combustion engines in that the energy being released is formed electrocatalytically (electron-transfer reactions) rather than via a fuel being physically combusted ("Fuel Cell Today," n.d.). Heat is an additional byproduct of the electrochemical reaction in a fuel cell, which plays into how efficient this energy source can be.

According to the Office of Energy Efficiency and Renewable Energy, fuel cells operate similarly to batteries, although they do not exhaust stored energy as batteries do and hence, they do not require recharging. But like batteries, they generate (or release) energy and heat for as long as hydrogen is supplied. “A fuel cell consists of two electrodes - a negative electrode (or anode) and a positive electrode (or cathode) - sandwiched around an electrolyte. A fuel, hydrogen, is fed to the anode, and air is fed to the cathode. In a polymer electrolyte membrane fuel cell, a catalyst separates hydrogen atoms into protons and electrons, which take different paths to the cathode” (“Fuel Cell Basics,” 2020). The flow of energy is caused by the movement of electrons as with routine power wiring (e.g. lighting, motors, televisions, etc.). “The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons produce water and heat” (“Fuel Cell Basics,” 2020). This process of electron transfer takes “simplistic” advantage of the naturally stored (and thus potential) energy within molecular bonds.

Advantages

Fuel cells boast numerous advantages over traditional gasoline and diesel vehicle engines. Perhaps most intriguing of these is the drastically fewer emissions they produce when compared to fossil fuel engines. As discussed prior, fuel cells create no tailpipe emissions and, aside from heat, the sole byproduct of the electrochemical reaction in a hydrogen fuel cell is water vapor. In 2013, the US Department of Energy measured that traditional gasoline vehicles emitted roughly 430 grams of CO_2-equivalent per mile whereas various hydrogen fuel cell-powered vehicles gave off 100-110 grams of CO_2-equivalent per mile (“Benefits and Challenges,” n.d.). One notes the importance of the term “equivalent” as highly significant because there is no actual carbon emission footprint resultant from the use of fuel cells.

In a 2014 study performed on Hyundai vehicles, emissions were measured from the Tucson model which was available with a traditional gasoline engine and as a fuel cell electric vehicle (FCEV). The gasoline engine produced 436 grams of CO_2 equivalent per mile, whereas the FCEV models produced between 173 and 286 grams of CO_2-equivalent per mile. The fuel cell Tucson vehicles were classified into three categories: hydrogen from natural gas, 33% renewable California hydrogen, and 46% renewable California hydrogen. These three variations on the Tucson engine represented a (respectively) 34%, 54%, and 60% reduction in emissions relative to the gasoline-powered model (“How Clean are,” 2014). Further, the emission of water vapor actually performs positive work toward scrubbing the atmosphere of carbon dioxide, the most environmentally harmful greenhouse gas.

Another benefit of fuel cells is the diversity in how they (and the hydrogen used to power them) are able to be produced. According to the Connecticut Hydrogen-Fuel Cell Coalition, “Hydrogen can be produced using a wide variety of sources here in the U.S. Hydrogen can be renewable and produced by waste, biomass, wind, solar, tidal, wave, and geothermal” (“Hydrogen and Fuel,” 2016). Collectively, these sources essentially offer a reliably and renewably unlimited supply of hydrogen gas. “Production technology includes electrolysis of water, steam reforming of natural gas, coal gasification, thermochemical production, and biological gasification. With so many sources for hydrogen generation, the U.S. has the ability to create sustainable energy in an efficient and cost-effective manner" ("Hydrogen and Fuel," 2016). This is a significant aspect for the United States, as it has the potential to drastically decrease its dependence on foreign or domestic petroleum, as well as traditional fossil fuels in general.

Disadvantages

One of the most prominent challenges fuel cells face in their quest for fuel prominence is hydrogen production. All fuel cells rely on a steady infusion of hydrogen to power their mechanism. According to the Environmental and Energy Study Institute, "Hydrogen is by far the most abundant element in the universe, accounting for almost 75 percent of normal matter. Unfortunately, hydrogen does not exist in its natural, pure state [H_2] on Earth. It must be derived from compounds such as water (H_2O) or hydrocarbons" (Amaury, Shook, & Werner, 2015). While this process is energy-intensive, it can be powered by renewable and emission-free energy sources. The extraction of hydrogen from hydrocarbons, currently the cheapest method accomplished from methane reformation, the process does emit harmful pollution and greenhouse gases, yet reduced in amount from those emitted by hydrocarbon combustion (Amaury, Shook, & Werner, 2015).

Another drawback of fuel cells is the general difficulty of gaining public acceptance. Fuel cell technology is relatively new and fuel cell vehicles are thus more expensive than conventional petroleum-based vehicles and hybrids ("Benefits and Challenges," n.d.). On a positive note, however, fuel cell vehicles are decreasing in price as the technology develops and ages. Between 2006 and 2014, fuel cell system production costs decreased from \$124 per kW to \$55 per kW and the amount of platinum (as of now an essential and very costly ingredient) used to build the systems has decreased by about 5 times ("Benefits and Challenges," n.d.).

Durability has also thus far been an issue with fuel cells. Conventional vehicle engines have an enormous advantage over fuel cells in this respect. In 2014, fuel cell durability had increased over the previous several years from around 29,000 miles to about 75,000 miles, obviously constituting a vast improvement, though experts have offered that fuel cells would likely need to exhibit a durability of roughly 150,000 miles in order to compete with traditional fossil fuel vehicles ("Benefits and Challenges," n.d.). As with other compressed gas options, storage at refueling stations, as well as within the vehicles themselves, represents a challenge.

The public would also need influential and effective education on the option of fuel cell vehicles. Any new technological advancement, perhaps particularly within the auto industry, brings public concerns about its dependability, safety, and viability. Though it may represent a significant, timely, and costly effort, a widespread public education campaign would likely do much to sway public opinion in favor of fuel cells ("Benefits and Challenges," n.d.).

Electric Vehicles

Definition/How It Works As A Fuel

In contrast to fossil fuels, liquid/gaseous fuels, or an internal combustion engine, electric vehicles rely solely on an internal battery pack to power their motor. There are multiple variations of electric vehicles such as all-electric, hybrid, and hybrid electric.

Since the aim of this study is to analyze potential fuel sources other than petroleum and traditional fossil fuels, it will focus strictly on all-electric vehicles.

Electric vehicles are charged through an external source connected to the power grid. A charge port on the exterior of the vehicle receives the cord connected to the power source. This connection is received by the onboard charger unit which converts AC power from that port to DC power which is used to charge the traction battery. The connection from the external power source also charges the vehicle's traction battery pack which stores excess energy in reserve for use by its electric traction motor. The electric transmission unit transfers mechanical energy from its electric traction motor which in turn mechanically/physically turns and drives the car's wheels for propulsion. Electric vehicles also sport a DC/DC converter unit which helps convert high-voltage DC power from the traction battery pack to low-voltage DC power which is used to power an electric vehicle's accessories and keep the auxiliary battery pack charged ("How Do All-Electric," n.d.).

Advantages

Just as compressed natural gas, biofuels, and hydrogen fuel cells do their part to reduce environmentally harmful emissions in vehicles, electric cars make enormous strides in moving away from greenhouse gas production. In fact, all-electric vehicles produce zero direct emissions, defined as those that are "emitted through the tailpipe, through evaporation from the fuel system, and during the fueling process. Direct emissions include smog-forming pollutants (such as nitrogen oxides), other pollutants harmful to human health, and greenhouse gases, primarily carbon dioxide" ("Reducing

Pollution," n.d.). Because of this, electric vehicles aid in drastically improving air quality in urban areas where vehicle populations are dense as well as decreasing the carbon footprint and depleting the ozone protective layer.

Another area where electric vehicles maintain an advantage is in the category of life cycle emissions. Life cycle emissions are "all emissions related to fuel and vehicle production, processing, distribution, use, and recycling/disposal. For example, in a conventional gasoline vehicle, emissions are produced when petroleum is extracted from the ground, refined to gasoline, distributed to stations, and burned in vehicles. Like direct emissions, life cycle emissions include a variety of harmful pollutants and [greenhouse gases]" ("Reducing Pollution," n.d.). Electric vehicles have a profoundly decreased environmental impact here because absent are all the steps through which gasoline needs to traverse to be refined and burned. Life cycle emissions can still persist, however, because electric vehicles are a beneficiary of the power grid, as power plants may still emit their fair share of pollutants unless wind, solar, hydroelectric and other safer sources are better harnessed.

Another significant benefit with electric vehicles is cost per year to run and maintain. A 2018 study by the University of Michigan found that electric vehicles cost about half what it takes to run a conventional vehicle per year. "The average cost to operate an [electric vehicle] in the United States is $485 per year, while the average for a gasoline-powered vehicle is $1,117, according to the study by Michael Sivak and Brandon Schoettle of Michigan's Transportation Research Institute... This study only examined fuel costs, but the maintenance cost for electric vehicles has also been found to be lower because they have fewer moving parts, no exhaust system, less need for cooling, less abrasive braking options, and no need to change 'oil, fan belts, air filters, timing belts, head gaskets, cylinder heads and spark plugs'" (McMahon, 2018). This, of course, represents a general average, and statistics vary depending on geographic location and fuel price points regionally as well as the model of electric or conventional vehicle in question.

A positive factor that is only increasing in scope is the availability of electric vehicle charging stations in public. At the time of the electric vehicle's advent, it proved difficult to locate a charge port outside of those found at consumers' homes. Gradually, frequency of charging stations has significantly increased, with many workplaces and offices installing ports in their parking lots. The availability of these mitigating advances figures to double the potential for all-electric capabilities and ranges in electric vehicles, as an owner will not need to wait until returning home to recharge. All told, around 10,000 charging stations can currently be found nationwide. GPS-driven mobile applications (apps) and websites make it easy to find a charging station near driver locations. "Most public charging uses Level 2 or DC fast-charge electric vehicle supply equipment (EVSE). Level 2 can provide 10 to 60 miles of range per hour [of charging], while DC fast charge can deliver 60 to 100 miles of range in 20 minutes or less. Public vehicle charging stations are now located in spots where vehicles are highly concentrated, such as shopping centers, city parking lots and garages, airports, hotels, government offices, and other businesses" ("Charging on the Road," n.d.). Leaving aside the dramatic environmental protection benefits, as convenience increases, consumer concerns decrease. It becomes a compelling win-win scenario.

Disadvantages

Even though charging station frequency and availability has been increasing in recent years, the main challenge facing the prominence of electric vehicles is their actual drivable range per charge. Generally speaking, electric vehicles average far fewer miles per "fill-up" before fuel depletion than any other type of fuel, alternative or otherwise. Estimates vary, but it is generally accepted that electric vehicles have a range of about 80-100 miles in all-electric mode ("Electric Vehicle Basics," n.d.). This also varies based on price point, as more costly models will boast longer ranges. The most luxury optioned electric cars on the market today place in the upper 300-mile range (Hyatt & Ewing, 2020). This is a limitation of electric vehicles that is only improving, however, as ranges extend further on average each year. As of 2016, the median range of all-electric vehicles was 83.5 miles, conventional gasoline vehicles had a median range of 412 miles. When adding plug-in hybrid electric vehicles into the conversation, the median range improves to 440 miles ("Fact #939," 2016). Moreover, a 2019 Hyundai model plug-in hybrid has a documented range in excess of 700 miles which incidentally calculates out as over 120 miles per gallon of gas.

Utilizing the charging infrastructure with respect to charge time is another major issue facing the rise of electric cars. On average, a Level 1 charge (obtained from home outlets with a 120-volt AC current) takes around 17 hours. A Level 2 charge (240 volts of power from either a sophisticated home port or a public charging station) is completed in

3.5-7 hours (Lapedus, 2019). And a Level 3 charge (a 480-volt charge from a standalone public charging station akin to a traditional gas station for fossil fuel vehicles) is even faster, potentially as low as 30 minutes for an 80% charge (“Levels of Charging,” 2016). Most private homes are Level-1-charge-capable, with Level 2 capability being rarer in frequency and Level 3 charges are not geared for home installation currently. This means that many current electric vehicle owners may be looking at the better part of a day plugged into power to achieve a full charge for their car.

In 2019, electric vehicles comprised only between 1% and 3% of all vehicles on the road worldwide (Lapedus, 2019). As discussed prior, swaying public perception and enthusiasm for a fresh concept has typically proven to be a significant challenge. This seems to be of particular concern with purely electric vehicles due to the radical shift in lifestyle they represent. Most consumers have lived their driving experience dependent on their gasoline-fueled cars and have been hesitant to transition on a large scale to seeking out electric charging stations rather than the familiar petrol “watering hole.” Public awareness campaigns and social trendsetting are effective tools, but they do represent massive time and financial efforts. Political and environmental group pressure, as well as continued industry advancements will likely be necessary to shift public perceptions and choices.

Solar-Powered Vehicles

Definition/How It Works As A Fuel

The concept of solar power is that of harnessing energy from the Sun’s rays and converting it into electrical power. The technology has existed on the periphery for more than 175 years, although it has only gained major momentum in recent decades. Humankind has long utilized solar energy in many different ways, the most prominent of which has been to supplement electrical power in homes. To this point in human history, however, we have not yet utilized it to power moving vehicles on a mass scale, more as a speculative option thus far.

Solar panels work via the utilization of photovoltaic cells. A photovoltaic cell is "an energy harvesting technology that converts solar energy into useful electricity through a process called photovoltaic effect… A photovoltaic cell is comprised of many layers of materials, each with a specific purpose. The most important layer of a photovoltaic cell is the specially treated semiconductor layer" (Bethel, Doney, Hanania, Stenhouse, & Yvelland, 2018). This layer is itself divided into two crucial sublayers (p-type and n-type) which are responsible for the actual conversion of sunlight energy into working usable electrical current.

Sunlight is composed of small clusters of electromagnetic radiation. When these bundles of energy (called photons) strike the surface of the n-type sublayer (a semiconductor which makes up the outer surface of the solar panel) energy is transferred through the p-n junction to the p-type sublayer (an alternate type of semiconductor). The p-n junction is, in fact, an electric field formed by joining the p-type and n-type semiconductors (Bethel, et. al., 2018). "This field causes negatively charged particles to move in one direction and positively charged particles in the other direction... When light of a suitable wavelength is incident on these [solar panel] cells, energy from the photon is transferred to an electron of the semiconducting material, causing it to jump to a higher energy state… In their excited state these electrons are free to move through the material, and it is this motion of the electrons that creates an electric current in the cell" (Bethel, et. al., 2018).

The converted energy harvested from the sun's rays is then used to power the solar vehicle's engine directly or stored in batteries. The system is set up similarly to a standard electric vehicle's engine, utilizing the battery's stored energy to turn the crankshaft and the wheels, thus propelling the vehicle. The key difference between electric and solar power is that plug-in electric vehicles require electric power from the general power grid and solar electric vehicles do not. Combinations of both can be employed and may be the best option for both power production and driving distance advantages.

Advantages

The attraction of vehicles propelled by solar technology is evident: a limitless, free energy source that will surely prove to be self-sustaining for as long as our solar system's star burns. This factor of limitlessness is immeasurably valuable. As well, preservation of natural resources is surely significant as our planet's finite natural resources approach depletion. Since global society appears to be "insistent", in large part, on maintaining a reliance on fossil fuels, popularized solar vehicles could conceivably help maintain those stores of petroleum as long as possible before they are inevitably exhausted ("10 Benefits and Disadvantages," 2019).

Solar vehicles appear to be completely environmentally friendly, as no harmful greenhouse gases are emitted through their use and they require no power plants or nuclear reactions to produce their electrical energy. A completely solar-powered vehicle would also be the first able to claim the ability to charge or "refuel" while in use. Such claims are contingent upon day hours and sun exposure for use and continual recharging. This concept has thus far proven to be impossible with any other known type of fuel (Ortega & Moynihan, 2019).

It is exciting to imagine the large-scale potential of solar power as an alternative power source for vehicles. Consider the utilization of all or most of the surface area on vehicle exteriors. Large box trucks or 18-wheel hauling trucks, for example, have many square feet of flat, exposed surface area on the top and sides of their storage boxes. This is all surface area that could potentially be used for solar panels, which could provide significant energy supplementation and augmentation in a hypothetical combination solar-powered electric-motor truck or other vehicle. This would eliminate (or at the very least heavily mitigate) the massive amounts of liquid or gas fuel required to power a large truck over long distances. It has the potential to be utilized across all manners of road vehicles, from small commuter cars and vans, to fire service apparatus, paramedic ambulances, and even trains pulling box cars "coated" with solar panels (all of which have vast amounts of unutilized surface area).

Disadvantages

The central challenge of solar-powered vehicles is that the technology has not advanced satisfactorily as of yet. It is still a relatively new venture with respect to vehicles and may take considerable time to reach the forefront of the alternative energy movement. Solar units must be made flatter and become lightweight to be utilized in a practical sense, as well as at lower costs of production and integration into or onto vehicles' outer "shells." Developers encounter issues achieving an extended range for exclusively solar-powered vehicles given the current level of technology. Additionally, there currently is limited methodology to harvest sufficient solar energy in non-sunny weather. For these reasons, all-solar cars remain rare and exceedingly expensive for the moment. Alternatively, hybrid solar/plug-in equipped vehicles may offer considerably more driving range, though, as with all-electric would be partly dependent on evolved battery energy storage capacities.

As with other cutting-edge innovations, however, the solar vehicle stands a significant chance of developing into relevancy. As discussed previously, public opinion will consistently prove to be a hurdle to clear in rising to prominence of any new and ambitious technological advancement.

CHAPTER THREE

Project Description

This study is aimed at profiling several potential alternative forms of energy with the greatest chance of supplanting fossil fuels as the predominant commercial and specialized vehicle fuel/power source for contemporary and future consideration. This necessitated research and structured analysis on five prominent and up-and-coming alternative forms of commercial vehicle fuel: compressed natural gas, biodiesel/biofuel, hydrogen fuel cells, electricity, and solar power. These were chosen based on their position of prominence toward the forefront of the renewable energy field of study and ability to lessen (ideally eliminate) the carbon footprint, greenhouse effect and ozone layer depletion from obtaining and combustion of fossil fuels. Research focused on detailing the fuels as to how they operate to power vehicles as well as their respective benefits and challenges compared to traditional fossil fuels. The framework of this study is thus based on individual and collective data with respect to function, practical success, emissions, cost and ultimately public acceptance of alternative fuels and power sources.

Research was performed primarily using the Hamline University online Bush Library as well as academic and government websites such as those for the United States Department of Energy, the Alternative Fuels Data Center (a subdivision of the United States Department of Energy), and the United States Energy Information Administration. Research was compiled to support descriptions, discourse, and analysis of various alternative fuel forms discussed and provided a comprehensive overview of each subject. Internet search engine queries were performed to gather pointed facts and data to support various claims the study set out to make, which were pulled exclusively from official or reputable science or departmental websites.

An additional ambition of the project was to view the research from the perspective of fire service administrators and personnel attending a hypothetical professional development conference or seminar. Conferences such as FDIC International provide administrators with presentations on what is new, up-and-coming, and the potential future of fire service concerns including practicality and budget. FDIC International is a global conference "open to all qualified [fire service] industry professionals looking for the most comprehensive selection of Fire and Rescue products and services." Attendees include Administrative Chiefs, apparatus and equipment specialists, Company Officers, EMTs and Paramedics, Fire Chiefs, Fire Inspectors, and Fire Marshals among others ("About FDIC International," n.d.).

This Capstone Project is imagined as a presentation to be given at a conference such as FDIC International. Attendees of the presentation would be those interested in learning about the future of alternative energy sources as they may relate to fire service objectives and options. Fire department administrators are ever motivated to improve their agencies and make them more efficient, cost-effective, and technologically forward. In this light, information on renewable and reliable fuels to power their fire engines, fire trucks, paramedic ambulances, portable generators, saws, and other equipment would prove intriguing and potentially valuable to them.

The factor of renewability would likely be of paramount interest to attendees. Fire departments, their administrators, and the respective cities and counties they protect, are traditionally budget conscious. If a renewable (or semi-renewable) form of powering vehicles and equipment were to rise to prominence, it could substantially alter the way departments allocate their limited budgets. Hence, this could potentially lead to upgrades in non-apparatus emergency response equipment.

Leaving aside the deleterious environmental impact of fossil fuels, reliability of any mode of fuel powered transport is of clear significance. This is most especially true with respect to vital public services which are in turn critically dependent on apparatus and equipment. Consequently, a new primary power/fuel source would need to offer the lowest chance of failure necessitated in an emergency scenario. This is a factor which must remain uncompromised and that would be of paramount interest to attendees.

As environmental stewards of our planet we have, in the eyes of many experts and students of conservation, behaved irresponsibly both historically and contemporarily. This, arguably, may have put us on an irreversibly destructive path, yet also arguably may yet be correctable, given what many believe must be very quick action. As technology has contributed mightily to our “chosen” pathway, so too may it help salvage our (essentially) critical global status. Determined public and political mindsets are and will continue to be the key to environmental (our) survival.

CHAPTER FOUR

Conclusion

A common theme throughout this writing and its accompanying research was the subject of vehicle emissions. An overarching general take away from all points considered is that each alternative power source and fuel profiled boasts a dramatic decrease in its emissions of environmentally harmful greenhouse gases as compared to traditional fossil fuels. More specifically, each fuel/power source was found to have its own distinct set of characteristics, advantages and disadvantages compared to fossil fuels.

Compressed natural gases tout a significant reduction in harmful emissions, as proven on an appreciable scale in a major study performed in Delhi, India, the second-most densely populated city on Earth. Moreover, they are demonstrably advantageous over fossil fuels with respect to their mode of collection. Oil spill accidents are environmentally devastating in the extreme, whereas a breakdown in natural gas harvesting equipment releases substantially less-harmful gases into the atmosphere and are more easily compensated for with restoration of equilibrium. However, natural gas, much like fossil fuels, is finite in nature and thus does not represent an endlessly renewable option as a successor to fossil fuels. And while accidental release during collection is far less toxic, its primary method of collection, fracking, is also destructive to ecosystems and thus partially defeats the purpose of environmental preservation, and hence not ideal.

Biodiesel and biofuels also produce a far smaller amount of greenhouse gases than petroleum products. They are also carbon-neutral and biological in origin, meaning the byproducts they do emit are far less environmentally harmful and they are renewable in nature. Biofuels, however, are currently far more costly than conventional gasoline due to their newness on the alternative fuels scene. They are also largely produced from edible materials and oils (potentially leading to food shortages and price increases) and their production contributes heavily to deforestation (again somewhat defeating the purpose of environmental preservation). As with compressed natural gas, they are not ideal.

Hydrogen fuel cells are a diverse and versatile alternative method of fueling/powering vehicles which produce substantially fewer and far more environmentally friendly emissions than conventional fuel (emissions essentially being water vapor). Additionally, hydrogen for fuel cells is abundant and able to be produced through many different processes. Contrarily, hydrogen is energy-intensive and costly to produce and fuel cells face durability issues at this moment in their relatively young development. Public support and interest have also thus far proven to be challenging to achieve.

Electric vehicles go well beyond a fundamental claim of reduction of environmentally degradative emissions as they produce zero emissions overall. They are also far less expensive to own, operate, and maintain than conventional gasoline vehicles and, as the technology they rely upon improves, are advancing in quality, affordability, and driving range at a highly advantageous rate. Availability of public charging stations and the advent of useful mobile apps are making all-electric vehicles an increasingly reliable option. Yet challenges remain, as related to their heightened recharging time, and public perception. Plug-in hybrids were noted as superior with respect to the negative factors.

Finally, solar vehicles, while still in their developmental infancy, present significant promise. Their fuel source (solar photonic energy) is limitless in supply and completely renewable, so the development of a suitable solar car, bus, truck or train presents great promise toward complete global independence from fossil fuels. Their zero-emission nature and vast potential for integration/implementation (using vehicle exterior surface area) give solar vehicles enormous potential to rise to prominence. The rudimentary technology has existed for decades and continues to evolve, prompting much opportunity to expand and integrate into a vehicular power source either solo or as an augment to other modes. Challenges to overcome include solar limitations (weather) and amount of usable power harnessed and converted to engine work.

Based on the collected research and analysis herein, one rational conclusion for alternative vehicular fuel/power sources to ultimately supplant fossil fuels may not prove to be any singular option. Rather, it is this student's belief that a combination of one or more above noted options (among others not detailed herein) will serve to better power the world's vehicles. Independently, each offers its own advantages and relative application, yet in concert appear to be most productive, efficient and advocate best for global environmental preservation. Responsible custodians for our planet, shared with millions of other animal and plant species, we must rapidly move to these and other alternatives.

It is also this author's belief that electric and solar power (perhaps in concert) stand the greatest chance for environmental salvation with respect to eliminating the carbon footprint from vehicles powered by fossil fuels. Given the relatively short time frame that technology has advanced transportation options, it may be only decades before limitations of these two alternative power sources/fuels will be rendered inconsequential. Electric vehicles will likely charge quicker and easier, recharging locations will become far more plentiful, and storage batteries will sport vastly improved mileage ranges. Likewise, technology utilized in harvesting freely available photonic energy will (also) likely progress sufficiently to provide humanity with vehicles powered renewably and limitlessly by the sun, fully emancipated from reliance on our finite natural resources. One need only look to the progression of technologies such as cellular phones, portable computers, and many other recent technological marvels to be convinced of humanity's ability to advance at a rapid and effective pace. It rationally follows that the same will likely happen with alternative, renewable methods of fueling/powering vehicles.

This project aspires to selectively address one component of the far grander human-caused "pathology" to Earth's global health. Our planet has been the unwitting recipient of technological and industrial advancements using fossil fuel-based powering. As such, the potential implications of the alternatives herein may be enormous. The collective decision to move beyond petroleum-based fuels for vehicles could play a major part in correcting or slowing the environmental destruction wrought by the accumulation of greenhouse gases in our atmosphere. Future related projects seem easily conceived. Apart from new innovations for power/fuel sources, more in-depth research on the inner workings of battery storage capacities, efficiency of photon conversion to work energy, and conversion of existing vehicle emissions to a non-environmentally toxic status. Moreover, a deeper understanding of the science behind each leading alternative with a critical analysis therein, current and future total resource availability, consumer and market analyses, and public perception and enthusiasm would be insightful.

This author believes appreciable strides have been made over the course of these works with respect to research and writing acumen. The scope of this research process was both enlightening and stimulating. Many more resources were consumed than were actually incorporated and cited, such that the process itself may have been of as much value as the utilized specific information and details. Limitations of available information to novel innovation on the chosen cited subjects are of course due to the cryptic nature of private research in the industrial world. Leaving aside licensing/patenting regulations, I anticipate many refinements and great advancements to each of these alternative power/fuel options.

The process of organizing and articulating information into a usable and understandable (at least for this author) schematic flow was challenging yet highly rewarding and satisfying. In the future, I look forward to more pinpointed, in-depth research while still targeted at the enhancement and promotion of environmental protection and sustainability. Appropriate stewardship of our shared planet continues to be a clear personal goal, but with an accompanying narrowed focus toward the powering of vehicles and equipment within future fire departments.

Undoubtedly, future visits to my beloved Yosemite National Park will include quiet reflection upon my research insights.

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