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Crisis in the Future of Automobile Energy

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Abstract The situation for automobile fuel is precarious with the world running out of oil. Therefore, a quick and firm exit from gasoline powered automobiles is indicated before it is late. Yet, an analysis reveals that there is no perfect solution because all resources commonly known to power automobiles will likely deplete on earth. For instance, it is estimated that biofuels such as corn-based ethanol will require seven times the arable land in the U.S. if all vehicles in the U.S. were to run on them. The hydrogen economy shows promise, but the platinum which is currently essential in fuel cell operation is in limited supply with only enough for the production of 400 million cars. Compressed natural gas is also not projected to serve the automobile purpose of the United States for any more than 50 years, not to mention that it produces greenhouse gases. The ground lithium for electric cars is also a limited resource. Thus, no common automobile fuel or system has the ability to last more than only a few generations. The extended range electric vehicle (E-REV) shows promise, but much is in research while only some is in production. It is difficult to plan for tomorrow with the technology of today, but virtually impossible to plan on the hope of discovery. This article discusses the various fuels and materials used for renewable automobiles, and brings forth their resource limitations.

Keywords Fuels, Lithium-ion, Biofuels, Hydrogen

1. Introduction and Purpose

There are approximately 250 million registered cars in the United States alone (Bureau of Transportation 2010) that traveled over 3.0 trillion miles in 2007 (U.S. Energy 2009b). They also consumed close to 8 million barrels of oil per day ("Quick Facts," 2011), with 95% of the transportation sector in the U.S. using oil for its energy supply. About 50 million cars are added yearly to the world's automobile population, adding considerably to world oil demand. The issue of automobile fuel security is of grave importance in the world, as oil has a limited time remaining for when it can be used, owing to its impending shortage. This article explores various fuels for automobile energy from a resource availability and limitation perspective with the aim being to replace oil as a possible fuel.

1.1. Research Gap

Therefore, this is the gap that this study explores. A comprehensive analysis is thus undertaken of the viable fuels for viable technologies used for road vehicles. Literature review revealed no such comprehensive study. Thus a wide gap exists between what is available and what is known as available. A number of alternatives are possible that result in decreased oil consumption. Of course, the motivation for this article is to reduce dependence on oil and limit harmful effects to the environment as come from burning fossil fuels. The benefits and hurdles of each alternative are analyzed (Devlin 2010; Devlin and Singh, 2011).

It must be noted that obtaining the fundamental resource data is not a trivial task, as multiple sources must be obtained and evaluated for their credibility and applicability. Consequently, the resource limitations are placed in perspective to bring meaning to energy security for automobile fuels.

1.2. Air Pollution

There is little doubt that burning fossil fuels contributes to air pollution, and possibly to global warming, as well (Singh, 2009). The emissions from automobiles cause lung cancer, respiratory problems, smog, and acid rain. In addition to carbon dioxide, the exhaust of a car contains carbon monoxide, sulfur dioxide, nitrogen dioxide, suspended particles, lead, arsenic, and mercury; carcinogens, toxins, and other toxic gases are also emitted. The yellow clouds over much of Asia are largely a combination of dust, automobile emission, and coal emissions. The increased levels of carbon dioxide have been found to increase ground level ozone, which is a lung irritant and might be responsible for the increase in asthma, and increased susceptibility to respiratory infections (Automobiles: Pollution 1999). Air pollution has been named the #1 health threat to Americans by the American Lung Association (Swenson 2005). The transportation sector produces 76% of carbon monoxide and 41% of nitrous oxide emissions in the U.S. (Swenson 2005).

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So, the contribution of automobile emissions to air pollution is well defined, and a confirmed health hazard, for which it is imperative that the world move away from fossil fuels.

2. Oil Constraints: The Basic Premise

The continually increasing demand for oil needed to produce the gasoline for cars in the world is alarming for four main reasons: cost, supply limits, air pollution, and dependence on oil. In addition, the geopolitics of oil unnerves virtually everybody.

Currently, there are about 1.3 trillion barrels of proven oil reserves left in the world (Taylor 2009; Deffeyes 2005). At current usage rates, about 85 million barrels per day, these oil reserves will only last 41 more years, being consumed at 1000 barrels per second (Gibson 2009). The USA alone consumes approximately 20 million bbls (= 400 million gallons) per day, of which 8 million bbls are used in automobiles (“Quick Facts,” 2011). The prospects of finding more oil than has already been found are dwindling, the world is convincingly past peak oil, and no mineral has been explored more on Earth than oil (Deffeyes 2005). And if more oil is discovered, perhaps oil will last 50 years instead, but that is within a lifetime, and, in terms of industrial development, like tomorrow. Moreover, the incidence of oil blockades and oil wars is all too frequent and troublesome, resulting in price spikes that rock world economies. Thus, remedial steps need to be taken immediately, not kicked down the road to the next generation.

In 2009, President Barack Obama called for raising fuel economies to 35 mpg by the year 2020. Even if this goal had been achieved, which it has not, it would only have reduced the United States’ oil consumption by 2 million barrels a day, roughly 10%. If worldwide, fuel economies were to increase likewise by 10%, it would only give a 10% reprieve on life for world oil. This is far too little to be considered a permanent solution. Hence, it is necessary to find an alternative energy source to power future automobiles.

3. Concept Cars and Feasible Cars

There are scientists all over the world conducting research trying to come up with the best alternative fuel. In addition, there are some ideas that might sound simple and seem to have a lot of potential but are just not feasible with today’s technology. Wind-powered, solar-powered, flying-cars, nuclear-powered, and algae-fueled cars have been proposed, but their feasibility for mass production is still closer to science fiction than reality, and they cannot be considered the answer to a fuel problem that needs to be answered much sooner than later. Hence, rather than wait for the future to unravel in ways unknown, it is much better to plan with the known technologies. And that’s the only way that long-term planning can be done. As an Arabic proverb has it, one would rather “fix the known than wait for the unknown”.

There are only five remaining fuel alternatives that most experts consider to be the most promising. They are natural gas, hydrogen fuel cells, biofuels, hybrid vehicles, and electric vehicles. Each of these will be examined in detail to understand what the best path is for a future of clean air and sustainable ground transportation.

4. Natural Gases

The two most common alternative fuels are both natural gases: propane, or liquefied petroleum gas (LPG), and compressed natural gas (CNG) that burns mainly methane. Both of these types of vehicles use technology very similar to regular gasoline engines to generate power, and they do emit greenhouse gases.

Engines that use propane have been found to last up to twice as long as conventional engines (“Propane Cars” 2009), thereby greatly reducing maintenance costs. Both of the natural gas fuels emit fewer emissions than gasoline engines; propane vehicles produce roughly one third fewer reactive organic gases than gasoline fueled vehicles (U.S. Department of Energy 2003). The performance, power, acceleration and cruising speeds, is similar to a gasoline-powered car and a natural gas-powered car. However, the range of natural gas cars are generally about 25% less than that of gasoline powered cars because of the lower energy content of the fuel.

While the technology is feasible, and natural gases such as LPG and CNG seem to have some characteristics that would make them attractive alternative fuels, there is one simple and dominant reason that natural gases are not really viable alternative fuels for the future – and that is they are derived from a non-renewable fossil fuel. If all the cars in the U.S. were converted to natural gas vehicles, the 146 billion gallons of gasoline consumed each year would have to be replaced by 18.4 trillion cubic feet (tcf) of CNG, given the relative GGE. The U.S. already currently uses 23 tcf for other purposes, so the new total usage would be 41.4 tcf per year. But there are 2074 tcf of total known reserves of natural gas in the U.S. (Rapier 2009). So, at the current usage rate and current number of automobiles being powered by CNG, the natural gas reserves in the U.S. would last 50 years. The world’s reserves are at about 5210 tcf (“Natural Gas,”, 2011), and for its estimated 806 million cars and trucks, the world’s reserves would be depleted in 72 years if all the natural gas was used for automobiles, leaving nothing for cooking fuel. In order to be considered as a long term or permanent source of fuel for automobiles, the energy needs to be derived from an unlimited renewable source.

5. Hydrogen

5.1. Hydrogen Technology

There are two types of hydrogen powered vehicles, the first is a combustion engine that runs on hydrogen, and the second is a fuel cell vehicle that uses hydrogen as its fuel source to power an electric motor.

The cost of the hydrogen internal combustion engine vehicle (HICEV) and other necessary improvements to withstand the additional stresses of combusting hydrogen results in an engine that costs about 50% more than a traditional gasoline engine ("Hydrogen Powertrains" 2010). While gasoline engines produce emissions that are causing the environmental problems we have today, hydrogen powered cars offer the only alternative fuel that has the potential for zero carbon emissions. Theoretically the combustion of hydrogen and oxygen produces only water vapor; however, in the real world application, the combustion of hydrogen with air produces water and nitrous oxides, which is a pollutant; however this is still fewer pollutants than gasoline combustion.

The hydrogen fuel cell vehicle (HFCV) is the type of hydrogen vehicle that gets the most attention as a possible solution to the transportation problem the world faces. A fuel cell is an electrochemical cell that produces electricity from hydrogen. The reactant, hydrogen fuel, flows into the cell, and the products, water and electricity, flow out of the cell. The reactant needs to be replenished when exhausted.

Fuel cells are not a new idea; the first fuel cell was conceived in 1839 by Sir William Robert Grove (Nice 2000). In 1959 the first vehicle powered by a fuel cell was created, a 20 hp tractor; 7 years later the first road worthy vehicle, the GM Electrovan was produced. Since that time the idea of a fuel cell vehicle has been explored by many automakers as a possible alternative fuel vehicle.

5.2. Water Vapor Byproduct

The final product is water, which to most people would seem to be harmless. The vehicle emissions that most people are concerned with are greenhouse gasses such as carbon dioxide and nitrous oxide. However, greenhouse gasses are 95% water vapor, while carbon dioxide represents only 3.6% of greenhouse gases. So, while it is important to reduce carbon emissions in order to possibly stop global warming, it is not a safe assumption that water vapor emissions are not harmful. If hydrogen fuel cell vehicles are the answer to the world's problems, research on how much water vapor the atmosphere can handle needs to be conducted. Currently, it is estimated that hydrogen fuel cells emit one-third to half the amount of water vapor as gasoline engines (Krock, 2010).[1]

5.3. Platinum Constraints

The production of hydrogen requires electricity, and the first concern is whether that electricity is produced from renewable sources or fossil fuels, which influences air pollution. Another environmental concern is that fuel cells are constructed with platinum, an extremely rare metal that makes up only 0.003 ppb in the Earth's crust (Wikipedia 2010m). The three top platinum producing countries in the world -- South Africa, Russia and Canada -- produce over 96% of the world's platinum; South Africa alone is responsible for 80% of the worlds share ("Fuel Cells Gearing Up" 2007). Each fuel cell uses about 0.025 ounces of platinum catalyst per kilowatt; a typical vehicle would require a 100-kW fuel cell. This would translate to 2.5 ounces of platinum per vehicle. The platinum reserves in the world are estimated at roughly 1 billion ounces ("Platinum and Hydrogen" 2008). At the current usage of 2.5 ounces per vehicle, current platinum reserves would be enough to build 400 million hydrogen fuel cell (HFC) vehicles. In the U.S., 7.5 million cars are sold per year (Wikipedia 2010), but this estimate goes up and down over the years. So, if they were all HFC vehicles, platinum reserves would run out in 53 years. For the world, where 50 million cars are produced per year, the platinum would run out in 8 years. If we consider growth in automobile demand owing to increasing population and improved economies, the reserves would run out faster. A small and limited extent of recycling is feasible. Some experts believe that the amount of platinum required per fuel cell can be reduced to as little as 0.2 ounces, a reduction by a factor of 10 ("Platinum and Hydrogen" 2008), but this is still in research. This reduced usage per car would mean that 5 billion cars could be produced, and current platinum reserves would last 100 years.

Some of the experimental hydrogen vehicles cost almost $300,000 to produce; this is partly because they are not being mass produced. The expensive components of fuel cells are proton exchange membranes, gas diffusion layers, bipolar plates, and the precious metal catalysts (Nice and Strickland 2000).

5.4. Hydrogen Infrastructure

A major issue associated with hydrogen fuel cell vehicles is possibly the most important: the cost of building a hydrogen infrastructure. In order for the public to use hydrogen vehicles there needs to be hydrogen refueling stations all over the country, as of today there are only 65 hydrogen refueling stations in the United States (Wikipedia 2010j). Estimates of the cost of building such an infrastructure vary wildly but are on the order of $500 billion to create a nationwide refueling and supply network (Wikipedia 2010j), which by 2022 is estimated at $700 billion since PPI and CPI have both reportedly increased by approximately 40% since then. Even though this may sound like a lot of money, it may be manageable if the cost is spread over 20 years.

5.5. Hydrogen Storage

But another crucial issue with hydrogen propelled cars is the storage of hydrogen. In its normal state, hydrogen takes up a lot of volume. To keep the size of the hydrogen tank to reasonable sizes for a car, the hydrogen must be compressed to up to 5,000 psi. To do so requires making the storage tank small, but very thick and heavy. This dramatically increases

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1 Hence, in addition to causing air pollution and increasing the carbon emissions, gasoline engines also emit significant amounts of water vapor, of 50 to 75% of emissions, thereby likely contributing to global warming.

the weight of the car, making it possibly unreasonable for general asphalt pavements which are designed for less than 3,000 psi strength, and requiring more horse power to travel at any specific speed. To compound matters, hydrogen is substantively combustible, thus endangering a substantial explosion for hydrogen cars by vandalism or terrorism.

5.6. Benefits and Future

Besides being close to a zero-emission vehicle, the fuel cells of hydrogen vehicles are extremely efficient, with between 90%-95% of the fuel cell energy generated actually being transformed into electrical energy (Deshmukh 2009). In contrast, the process that is used to create the hydrogen that is used is still very inefficient.

What is the future of hydrogen fuel cells? The U.S. Energy Secretary, Steven Chu, once stated that in order for hydrogen fuel cells to be the fuel alternative of the future, there needed to be *four miracle*s; the joke was that it only takes fewer miracles to become a saint (Bullis 2009). The four areas of HFCV that need to be addressed in the future are cost, on-board storage in a car, the fuel cell, and infrastructure. The cost needs to be lowered; this can be accomplished by reducing the cost of the hydrogen production or the construction of the fuel cell. The storage of hydrogen on board the car is also problematic. Although hydrogen contains 3 times more energy per pound when compared to gasoline it occupies 4 times as much space; therefore, the equivalent to a 15-gallon gas tank would be a 60 gallon hydrogen tank. In order to combat the issue of space required hydrogen is sometimes stored in high pressure tanks, up to 5,000 psi. These are potential safety and storage issues that are still of concern (Bauer 2005).

Platinum cells are also susceptible to freezing and malfunctions if exposed to temperatures below 32 F (Wikipedia 2010k). Currently it is not feasible to expect hydrogen to be the fuel that replaces gasoline, but it is certainly viable that it could be a fuel for the future if constraints over platinum are eliminated or mitigated.

6. Biofuels

The most commonly used alternative fuel in the United States today is biofuel. The term biofuel refers to both ethanol fuels and biodiesel. As of 2006, the U.S. consumed 44 million gasoline equivalent gallons of E85 ethanol and 260 million gasoline equivalent gallons of biodiesel (U.S. Energy Information Administration 2007). What this means is that already on the road today, cars and trucks powered by biofuels are saving the equivalent of 304 million gallons of gasoline each year, however this is only 0.21% of the yearly U.S. consumption.

6.1. Corn Ethanol

Low blends of ethanol power standard gasoline engines with no modifications. For any higher blends of ethanol, such as E85 or E100, meaning 85% to 100% use of ethanol compared to gasoline, modifications need to be made so that the engine functions properly. Ethanol has a higher-octane rating, and in order to obtain all of the benefits the engines are tuned to have high compression ratios. Even with this modification, ethanol powered vehicles are less efficient than similar gasoline powered vehicles. The gasoline gallon equivalent (GGE) is about 1.5 gallons of ethanol for the same output (Gable 2010). Given that gasoline engines are already inefficient (only 15% of the gasoline's energy is transferred to the wheels), ethanol fares worse still.

However, the use of ethanol has some obvious benefits. It reduces vehicle emissions by an estimated 10%-30% (Wikipedia 2010e).

6.1.1. Land Issues for Corn Ethanol

The next issue is the land required to grow the corn necessary for ethanol production. The U.S. consumes approximately 146 billion gallons of gasoline each year; it produces 9 billion gallons of ethanol each year requiring about 24.7 million acres or 6.2% of the arable land in the U.S. (Wikipedia 2010f). Because ethanol is less efficient by 50% it would require 219 billion gallons of ethanol to replace the US consumption of gasoline. It is estimated that one acre of corn produces between 320-420 gallons of ethanol (Wikipedia 2010e). Therefore 590 million acres of land would be needed to grow enough corn to produce ethanol to replace gasoline. This represents 26% of the land area of the entire United States (2.27 billion acres), and 149% of the arable land area, which is only 396 million acres (Central Intelligence Agency 2010). This shows that as a fuel alternative, ethanol from corn would no longer be able to be domestically produced in the U.S. In all likelihood, it is infeasible to produce that much ethanol with the current production technology.

6.2. Sugarcane

One possibility for improving efficiency is to produce ethanol from other sources than corn, such as they do in Brazil with sugar cane. The energy gain from the production of a gallon of ethanol from sugar cane is nearly 7 times that of corn-based ethanol. Since growing sugar cane requires a warm climate, it is not largely a solution that would lead to national self-sufficiency in the USA; but it is something that is working very well for Brazil. If all the sugar cane needed by USA could somehow be produced in the USA, it would still take up 20% of the arable land, but that is not possible owing to the temperatures in all parts of the USA except the tropical areas. Other plants are being explored for their potential in producing ethanol more efficiently than currently available, such as poplar, switchgrass, and miscanthus (Wikipedia 2010e), but these are far from economic viability.

Again, it must be realized very importantly that a technology that is "possible" does not mean it is feasible or viable. Much of the lay people, and even educated people, not to forget engineers, mistake "possibility" for "feasibility."

Feasibility is primarily a function of economic viability, energy viability, production viability, and, of course, the underlying technological viability.

Besides the edible sugar that is produced in the world, additional sugar production will tax the water resources of nations because sugar needs enormous amounts of water (Kwong *et al.* 2014). To overcome the water shortage, desalination plants may be required. But desalination plants are electricity-intensive, meaning that large dedicated power plants will need to be constructed just for them. All this becomes a major challenge and strain for nations and world economies.

Many energy production systems sometimes consume more energy than they consume, and this too must be kept in perspective while determining the overall feasibility of a fuel.

6.3. Biodiesel: Soy and Palm Oil

Biodiesel can be made from new or used vegetable oils and animal fats, which are nontoxic, biodegradable, and renewable. The animal fats are food manufacturing byproducts, rather than oils from animals raised specifically for fuel. As is the case with petroleum diesel, biodiesel is about 4% more efficient than gasoline in terms of fuel economy ("Biodiesel vs. Ethanol" 2006). The gasoline gallon equivalent, GGE, for biodiesel (B100) is about 0.96 gallons (Gable 2010).

Biodiesel burns much cleaner than petroleum products, and even cleaner than ethanol. Through its lifecycle, production and then consumption, biodiesel emits 41% fewer greenhouse gasses, and lowers the carcinogenic properties of diesel fuel by 94% (Hess 2003). The energy balance numbers are even more encouraging than corn ethanol. A prominent USDA/DOE study shows that there is a 320% gain in energy from producing biodiesel for transportation (U.S. Department of Energy and U.S. Department of Agriculture 1998). This is the highest energy balance of any fuel and is very impressive compared to ethanol's meager 25% gain.

6.3.1. Land Issues for Biodiesel

However, the production of biodiesel requires much more land to produce the same amount of fuel. The soy oils that are most commonly used in the United States only produce 70 gallons per acre ("Biodiesel vs. Ethanol" 2006), which is about 5~6 times lesser than corn-based ethanol. But palm oil, another biodiesel, produces 500 gallons per acre. If all vehicles in the U.S. were to be powered by biodiesel, 140 billion gallons of biodiesel (B100) would be required to replace the 146 billion gallons of gasoline consumed each year. Even if the biodiesel was produced from very efficient palm oil, it would still require 280 million acres of land to power all vehicles in the U.S., approximately 71% of the arable land in the U.S. Ongoing research being conducted suggests that algae may be able to produce even more biodiesel per acre, providing enough fuel while only using 0.2% of the United States' land area, or 1.1% of the arable land area (Siegel 2010); but this is still in the research and speculation stages and must not be considered in a long-term plan being today.

7. Electric Hybrid Vehicles

The hybrids that are on the road today, such as the Toyota Prius or Honda Insight, are known as traditional hybrids. They have a traditional internal combustion engine that runs on regular gasoline. In addition, they have an electric motor, generator, and batteries that provide power and electric support to the gasoline engine. A full hybrid, or sometimes referred to as a strong hybrid, is a vehicle that is able to run on just the engine, just the batteries, or any combination of both.

7.1. Cost and Fuel Efficiency

Hybrid vehicles still rely on gasoline as the source of fuel, and only use battery power and an electric motor to supplement the gasoline engine. The fuel efficiency of a Toyota Prius, the most popular and fuel-efficient hybrid car in the world, is at 51 miles per gallon (mpg) in the city and 48 mpg on the highway (U.S. Department of Energy 2010). These figures, if accurate, are about 1.6 to 2 times as efficient as the average fuel economy for similarly sized cars.

The initial cost of a hybrid car is anywhere from $3,000 to $5,000 more than the same traditionally powered car. Based on the assumption of driving 15,000 miles a year and taking into consideration current fuel costs, some hybrids, such as the Toyota Camry, are able to recoup the extra initial cost of the car in fuel savings in as little of 1.7 years. The Toyota Prius takes 6.8 years to break even, which is still within the expected lifetime of the car. However, the Lexus LS 600h L takes a staggering 114.6 years of driving 15,000 miles a year in order to payback the original cost difference (Visnic 2009). Thus, some hybrids make economical sense, while others certainly do not.

The increased fuel efficiency of hybrids would reduce the amount of oil the U.S. consumes on a daily basis. However, the reduction is only a way to slow the problem that the U.S. is facing. In fact hybrid vehicles are a transitional strategy; even if every vehicle in the U.S. was a hybrid by 2025, because of growth in vehicle use, Rose (2004) reports that the U.S. would still need to import the same amount of oil that it does today. The use of hybrid vehicles is certainly not a permanent solution.

7.2. Rare Earth Constraints

Another concern for the future of hybrid cars is the looming shortage of rare earth elements (REE). There are 16 elements on the periodic table that are classified as REE; two of the sixteen, lanthanum and neodymium, are major components of the batteries and electric motors in some hybrid vehicles. The reason that a shortage is possible is more for political reasons than a lack of reserves. In 2009, China was responsible for 95% of the REE production, however there were reports that China planned to stop all exports of REE by 2012 (“Global Supply” 2010). That would have been very bad news for Toyota Motors had it materialized. That did not happen, but it could happen in the future, given the friction between China and USA. Moreover a case settled at the World Trade Organization (WTO) adjudged that China could not stop or unreasonably reduce rare earth exports to other countries (”United States Wins,” 2014).

For example, each Prius uses 2.2 lbs of neodymium for the electric motor and 22-32 lbs of lanthanum for the NiMH batteries (Korzeniewski 2009). Currently in the U.S. there are 1.2 million Prius cars, which use a total of 36 million lbs of lanthanum. In comparison, a typical 3 MW wind turbine uses 700 lbs of lanthanum (Canine 2009); in order to supply the 35 GW of installed wind capacity currently in the U.S., it requires 8.1 million lbs of lanthanum. At the current rate of 7.5 million new cars sold per year, 225 million pounds of lanthanum would be needed each year to supply the U.S. with hybrid cars.

There are a number of things that are being done in order to avoid demand out pacing supply. The first is for companies to search for a supply of REE outside of China. A mine in Mountain Pass, California began operations in the last few years, but closed down owing to price competition from chins, started again, but then closed down a second time. It has the potential to restart again, and there are potential sites in Canada and Vietnam (Korzeniewski 2009). The second is for changes to be made in the batteries and electric motors in the hybrid and electric cars. This is something that other companies besides Toyota have already done. The use of lithium-ion batteries eliminates the use of lanthanum required in NiMH batteries, and relies primarily on lithium, but lithium is also resource limited as will be evident in the next section. Moreover, Neodymium is the key component of an alloy used to make the high-power, lightweight magnets for brushless DC electric motors of some hybrid cars, such as the Prius, Honda Insight, and Ford Focus (Markoff 2009). The alternative is to use an AC electric motor which does not require such magnets, but the production of such AC motors is yet to take off. In the meantime, the price of Lithium has gone up from $10,000 per metric ton in 2020 to $70,000 per metric ton in 2022 (Spector and Olano, 2022).

8. Electric Cars

An electric vehicle uses an electric motor and a series of batteries. The electric motor can either be in AC or DC. DC motors are generally simpler and less expensive, while AC motors are able to provide better range and more efficient use of the batteries. Once the battery power is drained, the car needs to be hooked up to an external power source. The charging of most electric cars takes about eight hours at which point the batteries are fully charged and the car is ready to drive again.

8.1. Cost and Emissions

The external electric source that provides the power to the batteries of the car is able to do so at the fraction of the cost of the equivalent gasoline energy. If a typical daily commute for someone is 40 miles, driving a car that gets 25 mpg and gasoline that costs $5.00 per gallon, the daily commute costs $8.00. If that commute was done in an all-electric car which uses 0.280 kWh/mile, assuming a cost of electricity of $0.10 per kWh (U.S. Energy Information Administration 2009a), the commute would instead cost $1.12. The cost of servicing an electric car is also much less than that of a similar ICE vehicle, limited perhaps to rotating the tires and refilling the windshield washer fluid.

While driving, the electric vehicle is theoretically a zero emissions vehicle. However, possible emissions are affected by the charging of the batteries in whether they use a renewable source of electricity. If all of the electricity was obtained by renewable means, it would result in the elimination of 19.4 lbs of CO_2 per gallon of fuel, or 3.5 million metric tons of CO_2 per day (1,460 metric tons per year), amounting to a reduction of 25% of the total U.S. current emission levels of 5.75 billion metric tons per year (“Carbon Dioxide Emissions” 2010). In 2022, the average concentration of CO_2 in the atmosphere was 421 parts per million volume. There is an annual addition of 3 to 9 ppmv of CO_2, which could be reduced to 2.25 to 6.75 ppmv if the combustion of gasoline is eliminated (Wikipedia 2010a). Again, assuming the use of clean electricity generation, electric cars would also eliminate the emissions of nitrous oxides and other air pollutants generated by today’s automobile.

8.2. Electric Concerns

There are currently three types of batteries that are used in electric cars: lead-acid, nickel-metal hydride (NiMH), and lithium ion. Lead-acid batteries are the cheapest and most available batteries; they were used in the first EVs such as the GM EV1. They are also the heaviest of the three types; a typical battery pack can weigh 1,000 pounds. They have a limited capacity, generally about 12-15 kWh which results in a range of about 50 miles. They also have a short life cycle, needing to be replaced after 2-3 years, which is well short of the lifecycle of the car. For these reasons, lead-acid batteries are generally not used in new EV production. The use of NiMH batteries can double the range of the vehicle; these batteries were used in second generation EVs like the Toyota RAV4 EV, some of which have well over 100,000 miles on their batteries and are still going strong.

The newest and most promising battery technology is lithium ion, which are also used in laptops, cell phones, and many other electronic devices. The lithium-ion batteries are able to provide twice the capacity of NiMH in half of the weight; a typical battery pack in a Li car weighs 400 pounds, which is comparable to the weight of a gasoline engine. The Chevy Volt and Tesla Roadstar use lithium based batteries.

8.3. Lithium Shortage

But each kWh capacity of a lithium battery requires 1.4 kg of lithium carbonate, which costs about $50 per kg; this still only makes up about 15% of the cost of the lithium-ion battery, up from 3% ten years ago. Current estimates suggest that there are 28.4 million tonnes of recoverable lithium in the ground in the world, which is equivalent to 150 million tonnes of lithium carbonate required for lithium-ion batteries ("Where on Earth" 2008). At the rate of 70 kg of lithium carbonate per car (Tesla Roadster), the current lithium reserves could produce 2.14 billion cars. At the current world production rate of 50 million vehicles per year, the lithium would last for 43 years. Another point to consider is that currently 35% of the world's lithium reserves are found in Bolivia, the poorest country in South America (Richard 2009). There are geopolitical concerns that Bolivia and other South-American lithium producing countries could create a cartel like OPEC, and artificially inflate prices or limit supply of lithium available to other countries (Richard 2009). In January 2023, India discovered 5.9 million tons of Lithium in their northern state of Kashmir.

While mining lithium from the earth's crust may have a limit and geopolitical concerns, first generation technology of obtaining lithium carbonate from the ocean by an evaporation and ion exchange process only costs about $30 per kg. In addition, the ocean contains enough lithium to make approximately 18 trillion vehicles that have lithium-ion batteries similar to the Tesla Roadster (Pease 2008). At today's production rate of 50 million cars per year, the ocean could provide enough lithium to last 360,000 years. In fact, if lithium removal was limited to 0.5% of the total lithium in the ocean to reduce the environmental impact, which could be likely, lithium batteries could still be supplied at current vehicle production rates for 1,900 years. So it would seem that lithium shortages will not handcuff the production of batteries needed for electric cars. However, the effect of removal of 0.5% of the ocean's Lithium must not be under-estimated. A mistake could be made by mining seawater, just as the mistake was made to allow fossil fuel emissions into the atmosphere, where many thought the atmosphere was far too big for anything to go wrong.

If price and material concerns are addressed, this leaves one major battery related hurdle for electric vehicles to overcome -- the limited range provided by on board battery power. But this problem may be more of a psychological problem than a technological one; experts have described this phenomena known as "range anxiety" (Lendino 2009). A study shows that the average daily commute for 75% of the population in the U.S. is 40 miles, a distance below the range of most electric vehicles ("Introducing the Chevy Volt" 2010). Hence, range is not a show-stopper for Lithium cars.

8.4. Electric Usage and Capacity

The other concern that U.S. (and world) would need to address in order to facilitate the switch to electric cars would be the increased use of electricity. The energy need for the 250 million cars in the country would no longer be supplied from gasoline but would instead need to be generated by the electric grid. The current installed electrical capacity in the United States is 1,031 gigawatts (U.S. Energy Information Administration 2008a). So, how much additional load would be placed on the system? For this calculation it is assumed that each of the 250 million cars in the U.S. uses the full capacity of their batteries each day and needs to be recharged each night. The energy stored in an average battery is 8 kWh, which is charged over a period of 8 hrs, and this means that 1 kW of installed capacity is required per car. Therefore, for every car in the U.S. to be charged it would require 250 GW of installed capacity. This is about 25% of the current installed capacity. However, since charging occurs mostly at night, when power plants are not operating at full capacity, it does not mean that 250 GW of additional electric capacity needs to be installed. A calculation using GGE yielded that 457 GW installed capacity would be required, which is still within the ballpark estimate above. So, no new electric generation will be needed.

9. Plug-In Hybrid and Extended Range Electric Vehicles

The newest type of vehicles to make a splash in the search for alternative fuel vehicles are plug-in hybrid electric vehicles (PHEVs) and extended range electric vehicles (E-REV). These two terms for vehicles are often freely interchanged, and even though they have one main difference, they both share one defining similarity. That similarity is that they have the ability to travel in an all-electric mode, while consuming no gasoline, and then they can be plugged into the electric grid and have the batteries recharged. The range-anxiety problem could be addressed by extended range electric vehicles (E-REV) or plug-in hybrid electric vehicles (PHEV), both of which are advancements on the standard EVs or HEVs. The all-electric range currently extends from 10 miles for the Toyota Prius to 40 miles for the Chevy Volt.

9.1. Operational Characteristics

The difference between a PHEV and an E-REV is how the vehicle is driven once the batteries are drained. Once the batteries of a PHEV are drained to a certain level, the ICE powers the vehicle directly while the charge of the battery is maintained. An E-REV uses the same concept of driving in an all-electric mode for a distance; however once the batteries are drained it uses an electric generator to charge the batteries.

9.2. Costs of an E-REV

The ability to get electricity from the electric grid and use it to power a car is more efficient than using the combustion of gasoline. The overall efficiency of an electric car that charges itself from an electricity source using natural gas, for instance, is 44.1% compared to 13.8% for a gasoline car (Gribben 2010).

The Chevy Volt, was first released in late 2010, and in Europe in 2011. It was the most anticipated of the E-REVs. It has have an all-electric range of 40 miles, and after that power is provided by a 1.4-liter, 4 cylinder engine, capable of running on gasoline or E85 ethanol (Wikipedia 2010b). The vehicle is designed so that the 16-kWh battery is operating between 80% and 30% charge. Once the charge reaches 30% the gasoline, E85 ethanol generation starts and powers the electric motor and charge the battery. In order to get the 40 miles of electric range it requires 8 kWh) of charging at a relative cost of $0.80 ("Chevy Volt: Reasons" 2010. Chevrolet suggests that 75% of the population can commute to and work on a daily basis in the all-electric range.

The range-extending engine frees people from "range anxiety" and enables the vehicles to take trips as far as 300 miles, before more gasoline or ethanol is needed (Wikipedia 2010b); this is comparable to today's ICE vehicles. The EPA's testing method for plug-in hybrids has determined that the "City Fuel Rating" will be 230 miles per gallon plus 25 kWh/100 miles (Chevy Volt 2010). This is the type of fuel economy that everyone concerned with the environment and economy was searching for.

9.3. Future of the E-REV

The current state of the art lithium-ion batteries are able to store up to 585 W-hrs of electricity per kg, while new battery types such as lithium-sulfur or lithium-air have potential for much greater energy outputs, 2600 W-hrs and 5200 W-hrs respectively (Markoff 2009), thereby increasing the range of an electric vehicle by up to 10 times. But, lithium-sulfur and lithium-air batteries are still in their research phases and far from realization.

The Volt currently contains a range extending engine that is capable of using E85 ethanol, which, as explored in this study, is better than gasoline. But the use of ethanol as a fuel is not the answer. What if instead the range extender was a small diesel engine capable of running on biodiesel produced from palm oil? Currently the U.S. consumes 146 billion gallons of gasoline to drive 3 trillion miles each year. The Volt fuel economy is rated at 230 mpg plus 25 kWh of electricity per 100 miles (Wikipedia 2010b). Even if the fuel economy was only half of that, 115 mpg, the U.S. could travel the same number of miles on 20% of the fuel. This means that the land area calculations performed could be divided by 5. That would mean that all of the biodiesel needed to power a nation of Chevy Volts could be grown on 12.7% of the arable land.

If the hydrogen fuel cell is advanced, it could be used as the on-board generator creating electricity to power the motor. These advancements could result in a car that runs most of the time in all-electric mode, but when needed, uses a fuel that is clean and renewable. The potential of the E-REV is the most promising of all the technologies available thus far and needs to be the focus of all of the research and funding possible.

10. Resource Limitations

Taken one at a time, gasoline engines in the USA, and perhaps the world, can last 41 years, natural gas engines 50 years, hydrogen fuel cells 53 years, and lithium-operated electric cars 43 years, for a total of less than 200 years. Production of ethanol from corn is likely to require more arable land than exists, while ethanol from sugar will consume 20% of all arable land, but which can be grown only in warm climates. The hydrogen infrastructure has significant cost, technology, and infrastructure hurdles, while hybrid car production is restrained by 95% of the current rare earths being located in China. Taken together, the world can muddle through one technology to another, till all is exhausted. There is no proven technology on Earth today that can take us beyond 200 years.

What this also means is that all future technologies must be developed quickly and mature within the next 20 years to prevent a transportation catastrophe from petroleum oil that is quickly diminishing on Earth.

11. Mix of Technologies

But then, if all of the cars in the U.S. were split evenly between biofuels, hydrogen, and electric vehicles, the crisis the earth faces might be lesser than it is today with predominately gasoline powered cars. The land area required to grow palm oil for biodiesel would be only 1/3 of the area need to power an entire nation of biodiesel vehicles, the need for hydrogen production and platinum-based fuel cell construction would be reduced by 67%, and similarly the electric capacity required and electric usage could be reduced. Such a scheme would produce fewer transition and industrial shocks and allow these resources to be used for 200 years. But the mix of technologies would raise the issue of providing a viable infrastructure for all of these fuels. Also, as the population of the world continues to grow and the demand increases, will finding land to produce biofuels become more difficult? Some questions go outside the scope of this study. However, a mix of technologies might be more successful as a transitional strategy in order to eventually reach the situation where a future EREV is the automobile of choice.

12. New Developments

This article is based on a presentation made in May 2012 in Maribor. The research for this article was undertaken over the years 2010-2011. So, information related to recent developments and new information may not be fully reflected in this article.

One of the major new developments is new finds of natural gas, but whose recovery factor is not fully clear. Fracking is another new development that is currently being undertaken in massive quantities in the United States to release the fuels trapped inside geological reservoirs. However, it is extensively understood among technical circles and geologists that the energy that will be consumed in fracking operations will soon reach higher and higher proportions as the depth of exploration increases, thereby resulting in this temporary boom to be short-lived. It has also been observed that the contribution of product shale to the daily world consumption is substantively miniscule (Wile, 2013). In addition, there are concerns whether there will be enough water available for fracking, not to mention the environmental side effects of using mercury, lead, uranium, formaldehyde, and methanol as chemicals in the fracking process that pollute drinking water tables; methane levels in water wells near fracking sites are reported to be seventeen times higher than normal wells. It is further estimated that fracking operations will consume 72 trillion gallons of water out of the total US water resources of 953 trillion ("What is Hydraulic Fracking," 2013). In fact, concerns in Ohio have risen regarding the adequate availability of water for fracking ("Is there Enough Water," 2012). Moreover, the amount of fracking reserves is reported to be grossly exaggerated by up to 100% and possibly more (McDermott, 2011). Hence, it can safely be concluded that fracking is not the breakthrough technology for automobile fuels that the world is waiting for.

13. Future Directions

It seems absolutely difficult and impossible to identify which automobile fuel will be able to power future automobiles permanently. Nothing with current technology offers anything more than a transitional measure. The horse and buggy were sustainable for thousands of years, but if a pair of horses was to replace each motor vehicle, there is no enough land in the world to grow grass to feed the horses, given that a pair of horses typically needs 3 acres of land to sustain them.[2]

However, the E-REV carries potential if batteries can continue to be improved and the range extender could run on biodiesel, ethanol from sugar, or hydrogen fuel cells of the future that use little to no platinum. Maybe nanotechnology will come to the rescue where new materials can be made in the laboratory. The EREV can be plugged into the electric grid in order to charge the batteries after daily use. For this reason, the use of E-REV's needs to be combined with an increase in the use of clean renewable sources of electricity in order to achieve the maximum benefit. Together the clean electricity and extended range electric vehicle could provide the automobile industry a fuel that is never in danger of running out and creates no problems for the environment.

14. Summary and Conclusions

The world is currently on a path, which if unchanged, will lead to air pollution and global warming problems never before seen. The use of gasoline powered automobiles is also creating a scenario in which the world will run out of oil in 30~40 years and have no means of transportation. But, the economic effects of oil depletion will be felt long before. It has been clearly shown that the world needs to find another fuel source for its automobiles for the future.

There are many alternative fuels that may one day be possible solutions to powering automobiles. However, at this time these ideas are very distant. In as little as 50 years the use of natural gas or propane will lead to a similar situation that the world currently finds itself in with oil, not to mention that the burning of natural gas produces greenhouse emissions. With the technology currently available, the use of biodiesel or ethanol for fuel is not feasible because of the vast areas, estimated at 71%-149% of the arable land in the U.S., respectively, required to grow the necessary crops to produce the fuel. The mostly highly debated alternative fuel is hydrogen. Some believe that hydrogen is ready to be a viable fuel today while others believe that it may be 50 years before that is the case. But as far as this study has concluded, hydrogen has current constraints on platinum that can only supply world automobile demand for an aggregated 53 years. There is no current vehicle with a fuel that can sustainably provide the power to permanently replace the gasoline engine automobile.

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List of Abbreviations

B100 = 100% of bio-deisel
bbls = billion barrels
E-REV = extended range electric vehicle
EV = electric vehicle
HFCV = hydrogen fuel cell vehicle
HICEV = hydrogen internal combustion engine vehicle
NiMH = nickel-metal hydride
PHEVs = plug-in hybrid electric vehicles
REE = rare earth element
tcf = trillion cubic feet

2 This is not to mention that we would return to the medieval and ancient ages, and that the horses would not supply the power that motor vehicles can.

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